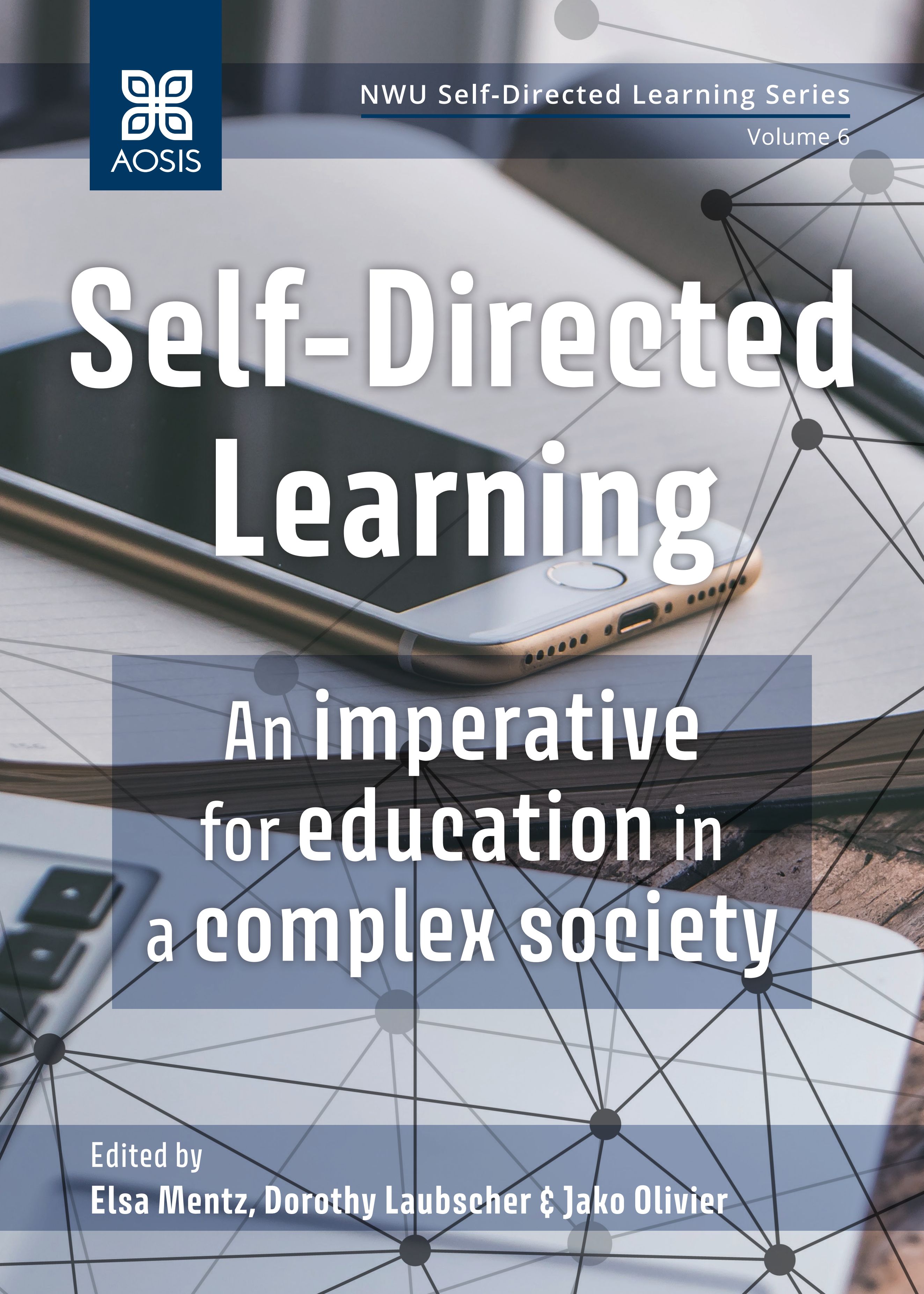
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NWU Self-Directed Learning Series
Volume 6
Self-Directed Learning
An imperative for education in a complex society
Edited by
Elsa Mentz, Dorothy Laubscher & Jako Olivier

NWU Self-Directed Learning Series
Volume 6

Self-Directed Learning

An imperative for education in a complex society

AOSIS

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EDITORS
Elsa Mentz
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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 manuscript was subjected to rigorous two-step peer review before publication, with the identities of the reviewers not revealed to the author(s). The reviewers were independent of the publisher and/or authors in question. The reviewers commented positively on the scholarly merits of the manuscript and recommended that the manuscript be published. Where the reviewers recommended revision and/or improvements to the manuscript, the authors responded adequately to such recommendations.

Research Justification

This book on self-directed learning (SDL) is devoted to original academic scholarship within the field of education. This is the eighth volume in the North-West University (NWU) SDL book series. In this book, the authors explored how SDL can be considered an imperative for education in a complex modern society. With this book, the authors aim to extend the scholarship of SDL and build upon previous volumes in the NWU SDL series, now specifically focusing on SDL within diverse contexts. In this book, academics motivate and provide evidence as to why SDL can prepare students with 21st-century skills that are essential in shaping the landscape of modern society in terms of the learning environment and praxis of SDL. The target audience of the book would be scholars and researchers in the field of SDL and higher education.

Although each chapter represents independent research in the field of SDL, the chapters form a coherent contribution concerning the scholarship of SDL and specifically the effect of environmental and praxis contexts on the enhancement of SDL in a complex society. The publication as a whole provides diverse perspectives on the importance of SDL in varied contexts. Scholars working in a wide range of fields are drawn together in this scholarly work to present a comprehensive dialogue regarding SDL and how this concept functions in a complex and dynamic higher education context. In the preface, a comprehensive explanation regarding how each chapter fits into the overarching themes of the book is provided, and a detailed exposition of how each chapter contributes to the relevance of SDL within a complex educational milieu is explained.

This book presents a combination of theory and practice, which reflects selected conceptual dimensions of SDL in society as well as research-based findings pertaining to current topical issues relating to implementing SDL in the modern world. The methodologies used in the various chapters include exploratory evaluation, content analysis, conceptual analysis, quantified self-assessed competence ratings, mixed-methods and qualitative approaches. The varied methodologies provide the reader with different and balanced perspectives as well as varied innovative ideas on how to conduct research in the field of SDL.

A rigorous double-blind peer review process was followed in preparing this publication. In accordance with the requirements of the Department of Higher Education and Training, this book contains more than 50% original content not published elsewhere. Furthermore, care was taken to ensure that no part of the book has been plagiarised. We are confident that the 10 chapters in this book will serve as a valuable contribution to the body of scholarship in the field.

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Contents

Abbreviations, Boxes, Figures and Tables Appearing in the Text and Notes

List of Abbreviations

AGPL	Affero General Public License
CAPS	Curriculum and Assessment Policy Statement
CDE	Centre for Development and Enterprise
CHAT	Cultural-Historical Activity Theory
CK	Content Knowledge
DLA	Diffusion Limited Aggregation
DoBE	Department of Basic Education
HE	Higher Education
HEI	Higher Education Institutions
ICT	Information and Communications Technologies
IK	Indigenous Knowledge
KSSLCI	Knowledge Survey of the Science Literacy Concept Inventory
MST	Multiple-solution Tasks
MSTQ	Multiple-solutions Task Questions
NOS	Nature of Science
OAS	Online Advice Source
OER	Open Educational Resource
PBL	Problem-based Learning
PCK	Pedagogical Content Knowledge
PCR	Polymerase Chain Reaction
PNM	Particulate Nature of Matter
PPC	Person-Process-Context
PST	Pre-service Student Teachers
RTOP	Reformed Teaching Observation Protocol
SACMEQ	Southern and East African Consortium for Monitoring Educational Quality
SDL	Self-directed Learning
SDLI	Self-Directed Learning Instrument
SDLRS	Self-Directed Learning Readiness Scale
SDML	Self-directed Multimodal Learning
SIT	Social Interdependence Theory

SLCI	Science Literacy Concept Inventory
SLP	Short Learning Programme
SRL	Self-regulated Learning
SRSSDL	Self-rating Scale for Self-directed Learning
STEM	Science, Technology, Engineering and Mathematics
TPDP	Teacher Professional Development Programmes
VNOS	View of the Nature of Science

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Foreword

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While learning on one's own – from toddlers exploring the world around them to older adults adapting to changes characteristic of that life stage has always been with us, serious study of this mode of learning is relatively recent in comparison to other aspects of learning such as memory and cognition. What has become known as self-directed learning is now a prominent arena for research and theorising. There is, in fact, a voluminous literature base to draw from, an annual international conference on the topic and a website which houses, along with other resources, an online journal devoted to self-directed learning.

One of the major sources for our growing understanding of the nature of self-directed learning as well as strategies for promoting and developing this mode of learning has been the research conducted by the Faculty of Education at North-West University in Potchefstroom, South Africa. Having adopted self-directed learning as a major objective in their curriculum and instruction, their research and publications have advanced the world's understanding of how curriculum design and instruction can facilitate the development of self-directed learning. This book, *Self-Directed Learning: An imperative for education in a complex society,* is the sixth in a series reporting on the ground-breaking research and writing on self-directed learning being conducted by this faculty. Their work is even more poignant in today's world of a pandemic wherein learners of all ages have had to move to being more self-directed in their learning. Further, technology as a vehicle for learning, as well as the rapidly changing nature of technology requiring continued learning and adaptation, has itself fostered the need for being more self-directed in our learning. As academic institutions struggle to adapt to changing platforms for teaching and learning, the chapters in this book offer both theoretical and practical guidance for developing self-directed learners able to thrive in an ever-more complex world.

Chapter 1 establishes the importance of considering the cultural context of promoting self-directed learning and, in particular, the African context in terms of the philosophy of Ubuntu. What does it mean to be self-directed in a multicultural society where some cultural groups may value interdependence, familial relationships, and learning through story-telling and song and dance

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rather than being independently self-directed? Chapter 2 is an exploration of factors of the learning environment that are likely to facilitate self-directed learning, one that fosters a sense of accomplishment and ownership in learning. Chapter 3 explores the place of self-directed learning in the dramatic shift to online multimodal learning as a result of the COVID-19 pandemic followed by an overview of microworlds as supporting environments for multimodal self-directed learning (ch. 4). Furthermore, Chapter 5 identifies how technology facilitates metacognitive regulation behaviour, such as planning, monitoring and evaluation. Chapter 6 centres on the importance of self-assessment throughout the learning process and the role that 'knowledge surveys' can play in promoting self-assessment, an important component of self-directed learning. Chapters 7, 8 and 9 report on research studies exploring the viability of SDL for in-service teacher education (ch. 7), the use of problem-cased learning in a chemistry classroom (ch. 8) and developing self-directed learning skills of pre-service mathematics teachers' proficiency in geometry problem-solving (ch. 9). In the final chapter (ch. 10), the focus is on how semi-illiterate street vendors acquire facility in mathematics through oral, self-directed, situation-specific contexts.

The chapters in this book advance both the theory and practice of self-directed learning. Scholars and practitioners alike will find something to engage their thinking about self-directed learning and, importantly, strategies to employ in fostering self-direction in learners of all ages. The ability of learners to identify their learning needs and the strategies and resources to address those needs is imperative in our rapidly changing, technology-driven, 21st-century world of today.

Preface

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This publication on self-directed learning (SDL) critically interrogates how this phenomenon is an imperative for education in a complex society. Part of the complexity of education in the modern society is concerned with the diverse contexts in which learning takes place. A central theme on how SDL is approached in this publication is the effect of context and practical steps in the learning process. Consequently, the chapters can be grouped thematically along two lines: the environmental context and praxis of SDL.

Approaching SDL in terms of context is not a new concept, and this use is fairly ubiquitous in the wider SDL discourse. For Knowles (1975), it was an affectual aspect embodied as a 'climate' that determined relationships for learning. In addition, Knowles (1975) even described learning situations as resources in themselves. While Grow (1991) emphasised the situational nature of learning, Garrison (1997) included self-management as a process related to shaping the context, as part of his model of SDL. Moreover, Brockett and Hiemstra (2019) emphasised the social context. Self-directed learning is inevitably contextualised and localised, and this book aims to provide glimpses from 10 unique conceptual and empirical contexts. The learning environment as supporting element to SDL is evident in the first chapters presented in this book. Firstly, the need to localise SDL is evident through embracing the African philosophy of Ubuntu as an essential element of the praxis of SDL (ch. 1). Chapter 2 specifically unpacks the affordances of environments for SDL. In addition, the relevance of online contexts for SDL was also evident in Chapters 3, 4 and 5 as technology is increasingly becoming an important aspect of the learning setting.

An additional focus of this book is praxis which, in this publication, pertains to SDL in practice. The term *praxis,* as derived from the Ancient Greek πρᾶξις,

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specifically links up with Aristotle's idea of praxis as *doing* (Balaban 1986). To this end, in the presented chapters, praxis relates to specific interventions and realisation of SDL versus mere *theoria* (thinking) or *poiesis* (making); however, elements of the latter could be considered within the wider constructivist views underpinning the research presented here.

Within the context of a wider education system where change is needed to address the epistemological and digital challenges students experience, we also consider Paulo Freire's view of praxis. In this regard, Freire (2005:51) described praxis as 'reflection and action upon the world in order to transform it'. Hence, through some of the chapters presented here, the way in which a strive towards SDL impacts and even transforms learning is evident. Chapter 6 relates to knowledge surveys that can be transformative for students through pathways to SDL and, in this case, specifically by means of self-assessment. The next chapter (ch. 7) looks at authentic activities for an in-service professional development program for teachers. Chapter 8 also focuses on SDL praxis through a problem-based learning (PBL) intervention. In the following chapter (ch. 9), SDL praxis is considered in terms of problem-solving within the context of mathematics. The book ends with Chapter 10 unpacking the transformative power of SDL in terms of the ethnosemantic structure of folk arithmetic. For further elucidation, we present a short overview of the chapters included in this book.

The first chapter of this book presents a critical conceptual discussion on how SDL fits in within an African educational paradigm, especially within the context where a lot of the scholarship on SDL is situated within the Global North and West. In this chapter, a broad overview of what SDL entails is presented in order to set the scene for the rest of the book. Furthermore, this chapter explores how SDL can be culturally responsive within the higher education environment through considering intersections between SDL and the African philosophy of Ubuntu.

In Chapter 2, a theoretical basis for a learning environment as a variable in the SDL process is unpacked. From the scholarship, it is clear that learning environments have an impact on learning and by implication SDL as well. Importantly, a move towards online environments has also had a significant impact on what a learning environment could entail. Importantly, this chapter provides some criteria for environments that could be supportive for SDL in higher education.

The third chapter continues with the theme of an online environment where SDL is considered within a multimodal learning context. Specifically, this chapter relates to online advice regarding the shift from face-to-face to multimodal learning. This research involves an empirical investigation of a corpus of online advice texts which were evaluated against the literature and set criteria related to self-directed multimodal learning. This analysis shows that the selected online advice corresponded with existing scholarship and showed some evidence of reification and support of many principles associated with self-directed multimodal learning

Chapter 4 also relates to learning in an online environment as it investigated microworlds as supporting environments for self-directed multimodal learning. In this chapter, with a strong constructionist theoretical foundation, the microworlds under analysis relate to Internet-based educational resources from different fields. Apart from an inductive qualitative descriptive analysis, features of multimodality are also described. Finally, the chapter also considers requirements of SDL, problem-solving and opportunities for collaboration in terms of the microworlds.

In Chapter 5, the focus is on adaptive prompts to facilitate metacognitive regulation within an online environment. This chapter explores how technology facilitates metacognitive regulation with adaptive prompts by means of an in-depth literature review. Furthermore, a conceptual framework to support research within this field is proposed based on the deduced evidence for the conditions of prompting. Importantly, this chapter identifies various categories of metacognitive prompts for the domains of metacognitive regulation, as well as prompts to aid in the planning, monitoring and evaluation on novice, transition or expert levels.

From Chapter 6 onwards, the focus turns to SDL praxis in subject-specific contexts. Chapter 6 reports on the way knowledge surveys can be supportive to students along pathways to SDL by means of self-assessment. From the data generated from validated and aligned instruments, this chapter confirms that developing students' capacity for self-assessment accuracy is essential to their becoming truly educated. In this regard, knowledge surveys are highly relevant instruments for developing such a capacity. This chapter emphasises the need for teachers to foster self-assessment skills, and it highlights the vital role of self-assessment in decisions that students are confronted with in terms of learning, educational plans and career paths.

Chapter 7 focuses on SDL for in-service teacher education. These authors report on empirical research findings of an in-service professional development program focused on 10 natural sciences teachers. This research determines that SDL should underpin teacher professional development interventions. Furthermore, the need to engage in-service teachers in authentic laboratory work in order to enhance their understanding of the tenets of science is also highlighted. The intervention does not lead to transformed teaching and learning, and consequently, it is recommended that wider and earlier participation in the process and context could potentially counter a contradiction of control between the intended and realised objects. A revised profile of implementation is proposed as a heuristic for teacher professional development.

Chapter 8 explores collaboration as a 21st-century skill in a Grade 10 Chemistry classroom in terms of implementing PBL. This research focuses on a purposively selected teacher and found that with the implementation of PBL, learners rely on each other within groups rather than on the teacher. Furthermore, it was found that PBL implementation promotes SDL because of its collaborative nature. They concluded that there is room to improve the way in which beginner teachers enhance SDL through their teaching. The study also recommends intervention programmes to enable teachers to improve their skills in implementing PBL in physical sciences classrooms to enhance SDL.

Pre-service mathematics teachers' proficiency in geometry problem-solving through the use of multiple-solution tasks in terms of SDL is explored in Chapter 9. In this study, research was done with university students in a module on Euclidean geometry. The findings of this chapter show that the set intervention was successful in increasing the SDL of students with an initially moderate SDL score compared to those with an initially high SDL score. In addition, students with an initially high SDL score were more competent in solving geometry problems compared to students with an initially moderate SDL score. It was concluded that there is a close connection between self-directed capabilities and problem-solving capabilities.

The final chapter (ch. 10) investigates the role of SDL in the context of the ethnosemantic structure of folk arithmetic of street vendors in Beirut. In this chapter, the aim was to determine whether the acquisition of numeracy using self-directed approaches and engagement in specific numeracy practices in workplace settings differentially modifies the type of representation for identified groups of street vendors and illiterate adults living in non-symbolic cultural contexts. It is evident that the ethnosemantic analysis of the researched vending practices explains the structure of logical relationships and the underlying complex computations which are inherent to a folk system of arithmetic which has been developed and consequently appropriated by semi-illiterate street vendors in a self-directed manner.

In conclusion, this book explores how SDL can be considered as a key imperative for education specifically in a very complex dynamic society. To this end, the learning environments and praxis of SDL emerged as central overarching themes. As such, the first chapter situated SDL within an African context, while the second unpacked the relevance of the learning environment for the SDL process. The next three chapters explored SDL in technology-enhanced multimodal contexts specifically in terms of online advice, microworlds and adaptive prompts. The last five chapters involved SDL praxis in terms of knowledge surveys as a form of self-assessment, fostering of SDL for in-service teacher education, collaboration and PBL for school chemistry, problem-solving for pre-service mathematics teachers' proficiency in geometry as an imperative for SDL and the ethnosemantic structure of folk arithmetic of street vendors. From both the conceptual and empirical works presented in this book, the complex educational milieu is evident. However, within this complexity, it seems to be possible to foster SDL, enable SDL praxis and through this process regard its universality while appreciating its localisable transformative relevance.

Chapter 1

The promotion of self-directed learning through the African philosophy of Ubuntu

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Abstract

Research on self-directed learning (SDL) is crucial in 21st-century educational institutions. This necessity is a general feeling in educational institutions. Self-directed learning is not all about an exact educational technique; it is

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more focused on the conviction that students should discover their learning needs, control learning progression and increase learning goals. The concept of SDL has been studied comprehensively. However, the increasing research exploring the cultural aspect of SDL is biased in favour of Western culture and overlooks the African context. As South African educational institutions aim to create culturally responsive learning environments, the sociocultural setting should be considered. The chapter aims to show how the African philosophy of Ubuntu is beneficial for the promotion of SDL.

Introduction

Self-directed learning is where the conceptualisation of the learning process is directed by the learner (Brookfield 1984, 1985a, 1995). One of the main focus points in SDL is the increase in independent learning (OECD 2016), which has been used in the United Kingdom and other Western countries to refer to the learning process purposefully positioned in informal educational structures (Brookfield 1985b, 1986). This focus point has attachments to UNESCO's philosophies of 'informal' and 'non-formal adult education' (OECD). The concept of SDL has been studied comprehensively. However, the increasing research exploring SDL is biased in favour of Western culture (Rensink 2016). Although past research has foregrounded culture as an essential yet influential SDL dimension, it remains less well researched, particularly between ethnic communities (Rensink 2016). The need for in-depth studies on SDL in 21st-century educational institutions in Africa is crucial. To function efficiently in the 21st century, society necessitates one to own SDL skills as SDL is deemed essential in higher education (Bellanca, Paul & Paul 2014; Cheng et al. 2010). It is imperative in South African educational institutions which aim to create culturally responsive learning environments. This chapter aims to show how the African philosophy of Ubuntu is beneficial for the promotion of SDL.

Problem statement

Current changes in education highlight SDL as a crucial prerequisite; it is essential to scholars' learning attainment and their future in the world of work as adults (Lopes & Cunha 2017). Internationally, students struggle to keep up with the upsurge in knowledge and the rapid development of technology (Duckworth et al. 2019; Du Toit-Brits 2019; Du Toit-Brits & Blignaut 2019). Difficulty in forecasting the potential vicissitudes caused by the increase in knowledge leaves students unprepared to meet future demands (Brockett 1985a, 1985b; Guglielmino 2013). Consequently, education no longer efficiently supports students in dealing with their future education needs (Brockett 1983a, 1983b; Hiemstra 2013; Hiemstra & Brockett 2012). Therefore, SDL needs to be seen to help students face future learning needs, prepare them for change (Collins 1991) and help them increase their knowledge (Hammond & Collins 1991). Self-directed learning can help students develop agency and be more self-directed (Hiemstra & Brockett 2011; Pane et al. 2018). South Africa and Africa are rich in diversity, comprising many cultures. If the persons' cognitive development varies across cultures (Santrock 2017; Vygotsky 1962, 1987), the meaning of SDL in different cultures can also differ because of the unique ways applied to understand different phenomena. This further implies that what is regarded as knowledge and truth for an individual is not automatically the case for another individual. To comprehend SDL in the African setting, it is therefore needed to engage with others to grasp what it means to be self-directed in learning, hence our aim towards showing how the African philosophy of Ubuntu is beneficial for promoting SDL.

■ Self-directed learning as context and background

Considering the above introduction and problem statement, an overview of the historical foundations of different perspectives and SDL models is provided in this section. The aim of this chapter is not to deliver in-depth collected work on all the perspectives of SDL. The perspectives presented in this chapter only give readers an introduction to and general background of SDL, with the drive to show how the African philosophy of Ubuntu is beneficial for promoting SDL.

The concept of self-study was a binding fragment and part of the lives of Socrates, Plato, Aristotle, Alexander the Great, Caesar and Descartes, to name but a few (McKenzie 1991). Because of societal circumstances and the lack of official learning institutes and bodies, numerous individuals have to learn independently (Hiemstra 1981, 1982, 1985, 1994, 2013). In 1975, Knowles pioneered and established SDL as a student-centred process. He explained SDL as 'a process' of development by which students establish their learning aims, discover essential learning resources, select appropriate techniques and assess growth through reflection (Brookfield 1995; Caffarella & O'Donnel 1987). It is evident in the body of scholarship of SDL that the most used explanation of SDL is that of Knowles (1975), who defined SDL as:

> [*A*] process 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 for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. (p. 18)

Knowles' theory of SDL is an expansion of the notion of adult learning that developed from his supposition that, as individuals develop physically and intellectually, they would proceed from the necessity for other individuals to control them, not wanting to depend on others. He also suggested that adults need to habituate independence – grow the necessity to manage and control themselves – as they have a sense of independence based on their contextual understandings and experiences. He further explained adult students' characteristics and their learning needs, referring to adult students' self-directedness. Knowles conceptualised SDL from his research on the learning needs and processes of adult students. In his research, he is against a 'mechanistic or transmission-type' of learning; as an alternative, he saw SDL as an enthusiastic and self-motivated approach in which the student takes control of the learning process, with the educator in a supportive role (Knowles 1975). He believed that students should be lifelong learners who are self-directed individuals, with the educator who engages with them instead of merely transmitting knowledge. To be more self-directed, students should be more goal-oriented and have a sense of ownership of their learning goals, taking accountability in assessing their learning results (Knowles 1975). Knowles also explained that SDL could be seen as a teaching–learning approach (Fisher, King & Tague 2001; Long 2000).

According to Guglielmino (1977:57–69), self-directed students are 'open to learning opportunities' and have a positive 'self-concept like an effective learner'. While learning, they are allowed to take the initiative, act responsibly and function independently. They also have a 'love of learning', show 'creativity' in their learning and are 'future oriented' with the 'ability to use basic study skills and problem-solving skills'. Long (1989:3) (who concurs with Guglielmino) emphasised the 'role of learner characteristics' in SDL. Guglielmino and Long believed that the students' above-mentioned features can promote students' commitment to SDL. Tough (1979) explained that SDL is a process where students plan and take responsibility for their learning. Self-directed learning is also an intentional learning process where students aim to achieve specific information, knowledge and skills (Cross 1981). To achieve specific information, knowledge and skills, students should recognise and accept responsibility for their success and progress in learning (Brockett 1985c; Brockett & Hiemstra 1991). Students' ability to develop learning aims, assess learning outcomes, and select suitable learning strategies and essential resources is critical in becoming self-directed in their learning. In such a learning process, interaction among students and the learning situation is a prerequisite element for the establishment of self-direction (Candy 1991) where students operate independently (Wilcox 1996), and SDL is seen as a model of learning (Blumberg 2000) as well as a form or type of learning (Merriam 2001). That said, it is pivotal that students recognise the applicability of what they learn (Knowles, Holton & Swanson 2005). Learning is based on the internal motivation of a students' desire to know more, and in this process of acquiring information, they solve problems and accept responsibility for learning and performing SDL activities (Manning 2007).

In the literature, SDL is viewed as a process in learning that embraces the recognition of gaps in students' learning, the preparation of how to improve on such learning gaps, and being able to use plans to improve and willing to assess the outcomes of learning (Knowles 1975). The process of SDL is also employed in steps that would enable students to develop into self-directed students. These steps include the following: Identification of their learning needs and goals; selection of their learning resources and the most appropriate strategies to learn, and evaluation of if their identified goals were reached (Knowles 1975:18).

Also, interpreting the thoughts of self-directedness proposed by Caffarella (1993) and Merriam (2001), SDL can be classified as 'linear', 'interactive learning style' and 'critical interactive' (Merriam 2001). These classifications have been established to indicate how SDL arises from a holistic viewpoint. Linear views on SDL captured the particular approaches needed to support students, and these approaches move in a progressive direction (Merriam 2001). The linear classifications were made in the 1960s and 1970s, and research done by Houle, Tough and Knowles on SDL falls inside the linear classification. Research on SDL during the 1970s and 1980s was interactive, as students then tried to provide a better understanding of the learning process. Interactive SDL classifications emphasise the student, as well as the environment of learning, and most SDL models and perspectives fall within the interactive classification (cf. Candy 1991; Cavaliere 1992; Garrison & Baynton 1987; Grow 1991; Long 1989; Spear & Mocker 1984; Straka & Schaefer 1997).

Lastly, the viewpoints of SDL in the critical interaction classification are situated in 'critical theory' of Mezirow (1985) – exploring SDL through political self-consciousness and the capability of students to make alterations. The SDL research of Brookfield, Collins, Hammond and Mezirow is based on the interactive classification grounded in critical beliefs. Next, we give a brief overview of the Person-Process-Context (PPC) model embedded in the 'Personal Responsibility Orientation' model of Brockett and Hiemstra.

The importance of context in self-directed learning

The PPC model is highlighted because it focuses on the 'psychological', 'pedagogical' and 'cultural' dimensions of context and their importance in cultivating SDL. This model suggests that SDL can be accomplished when (1) individuals (students) are self-directed, (2) the learning process inspires students to be accountable, and (3) the cultural and learning situation provides a favourable setting for SDL (Hiemstra & Brockett 2012).

The PPC model integrates three critical dimensions of SDL: person, process and context (Brockett & Hiemstra 1991; Hiemstra & Brockett 2011). This model illustrates that the person and process can be in place and accommodated but that the context of learners should also be acknowledged and integrated into teaching and learning for education to translate into meaningful learning experiences. The *person* is, for example, represented by life satisfaction, how they think about themselves, their experiences in life and creativity. The *process* entails learning styles implemented in education, planning and organisation of teaching and learning moments, and facilitation of teaching and learning (Hiemstra & Brockett 2012). *Context* represents, among others, the environmental climate comprising the culture of different stakeholders in the teaching and learning situation, the environment created for learning to occur and the climate of the classroom in which teaching and learning take place (Hiemstra & Brockett 2012). In this chapter, we focus on *context*, described as the 'sum total of all factors that can influence what and how a variety of content areas are taught and learned' (Metzler 2005:54). That said, 'education is more effective when [educators] adapt instructional formats to the context within which they teach' (Siedentop 1991:226). After all, students construct meaning in particular contexts indigenous to them, such as their cultural and social contexts (Duchesne & McMaugh 2016). Hence, context is essential in any learning environment, for example, to promote SDL as knowledge and what is seen as knowledge and how such knowledge is understood differently from one learner to the next and from one context to the next (Duchesne & McMaugh 2016).

These essential elements involve students in their learning practice, influenced by their social circumstances (Hiemstra & Brockett 2012). The PPC model further suggests that educators are essential in inspiring and promoting SDL and self-directedness in students. Here, SDL should be considered a 'process' facilitated by collaboration between students and their learning environment. In this 'process', students' cultural background is imperative in their journey towards self-directedness. Many other aspects, that is, social and demographic aspects, can affect students' self-directedness (Du Toit-Brits 2015; Knowles 1975).

Considering the different contexts students come from can give educators insight into the best possible teaching and learning practices. In light of the above information, we argue that educators who consider context may be able to:

1. identify the needs of their students to understand them better
2. design, develop and facilitate lesson content so that it reflects the students in the class
3. deconstruct and reconstruct what it means to be successful, for example, allowing students to set appropriate goals reflecting their unique contexts
4. improve on their teaching methodology, as they can use reflective practices in adapting the way they teach to be more responsive to different contexts.

The underpinning methodology of teaching and learning and, most importantly, the context in which teaching and learning occur are imperative in this chapter, as they shape the learning experiences of students, which can contribute to the promotion of SDL (De Klerk & Fourie 2017; Hiemstra & Brockett 2012). Thus, SDL should be regarded as a 'process' facilitated by collaboration between students and their learning environment. Therefore, we argue that context is vital in SDL as it can support a 'frame of learning' and a 'melting pot of learning' where context can encourage student engagement and application of new understandings in their learning. Therefore, SDL cannot be separated from the context's students come from, and SDL development does not happen in a specific contextual 'vacuum'.

The African context

Africa, the second-largest and most-populous continent globally, is endowed with rich and diverse cultures with an estimate of over 1000 spoken languages (Ouane & Glanz 2010).

Most Africans can be identified through their culture, inherited knowledge, history, customs and language as their landmark (Dei 2012; Kanu 2020). *Culture* is defined as the totality of people's lifestyle and tradition, including their way of dressing, talking, eating and learning (Cole & Packer 2019). It is the central structure of learned behavioural patterns characteristic of society members (Cole & Packer 2019; Kanu 2020). In addition, culture is considered an ancient landmark, although landmarks are related to the identity of place (Kanu 2020). There is a relationship between culture and the recognition of people (Cole & Packer 2019) because culture can speak of landmarks and vice versa. Overall, Africans have their way of doing things differently from Europeans or any other continent (Nwigwe 2019).

The African context consists of several norms and values which bond African people (Essien 2018; Sesanti 2016). Furthermore, Africa has different modes of philosophy, which have been forever marked by the colonial experience and can be divided into precolonial and postcolonial expressions (Horsthemke 2017; Kanwar 2019). Precolonial African philosophy mainly involved oral tradition; the written custom came with and flourished in colonialism, for example, missionary education (Horsthemke 2017). Indigenous philosophy and learnt philosophy portray the former, while political philosophy and academic philosophy represent the latter. Traditional philosophy comprises folkloric customs, myths, stories and legends, continuing in the postcolonial period in both verbal and written forms (Horsthemke 2017).

The African view of the communal self

All over the continent of Africa, the notion of the self is an 'embodied subjectivity'. It indicates the African self as individuality influenced by the body and community. An indispensable feature of the self is that it is seen as the 'body I am'. The self is exposed to communities' influence, and it can be said that the African self is relatively prejudiced by social construction (Nwoye 2006). The African notion of the self has been described as consisting of eight dimensions: 'embodied self', 'generative self', 'communal self', 'narratological self', 'melioristic self', 'structural self', 'liminal self' and 'transcendental self' (Nwoye 2006:121). However, for this chapter, we only elaborate on the communal self. The *communal self* relates to the African self's dialogical identity, emphasising communal reliance and interdependence. This description, as mentioned, entails that the communal self is in collaboration with community members (Nwoye 2006). With this collaboration, attention is drawn to the association and interdependence present among communal selves in the African context, where community support strengthens the individual (Markus & Kitayama 1991; Yasmin, Naseem & Masso 2019).

In the African worldview, the world consists of collaborations, interdependence and interconnections (Knoetze 2020; Markus & Kitayama 1991). It is the community that builds and supports the individual self, and the individual is seen as a being in the community. Mbiti (1970) supported this statement, saying that the individual cannot exist without the community in the African context, strengthening the expression 'I am because we are; and since we are, therefore I am' (Mbiti 1970:141).

Therefore, the self in African beliefs is fundamentally communal and collective; the self, or 'I', as part of a larger group of people relying on each other, is seen as 'we-ness' (Du Toit 2011), 'therefore I am' (Letseka 2013; Makhudu 1993). In other words, I am and I exist through other human beings, which is the essence of Ubuntu, as discussed below.

The notion of the African philosophy of Ubuntu

Ubuntu is an African notion focusing on communal and collective philosophy based on a 'non-individualistic character'. It can also be seen as the foundation of African philosophy (Hlela 2018; Letseka 2000, 2013). In the 1800s, Ubuntu was recorded in South Africa. The term Ubuntu originally comes from Nguni languages such as Zulu and Xhosa. However, similar terms are also used in other African languages like Kiswahili, spoken in Tanzania ('*ujamaa*'); focus on freedom, fairness and harmony; and signify the underpinnings of 'indigenous black populations of sub-Saharan Africa' (Waghid 2018).

Reviewing the body of scholarship on Ubuntu, we realised that to give meaning to Ubuntu in English is challenging as numerous researchers (Assié-Lumumba 2017; Broodryk 2006; Dzobo 1992; Hlela 2018; Knoetze 2020; Lefa 2015; Letseka 2013; Letseka & Iyamu 2011; Makhudu 1993; Masondo 2017; Mbiti 1970; Ngozwana 2020; Piper 2016; Tran & Wall 2019; Yasmin et al. 2019; Xulu 2010) have written about Ubuntu as an African philosophy. These researchers have diverse understandings of and explanations for 'humanness' or 'I am because we are' and focus on its communal and collective nature.

'[B]e-ing' an African and the African 'knowledge branch' are embedded in Ubuntu (Hlela 2018; Masondo 2017), and therefore, Ubuntu can be recognised as '...the wellspring flowing with African ontology and epistemology' (Ramose 2002:30). Ubuntu is recognised as the heart of African philosophy. We argue that Ubuntu, therefore, represents, as Ramose (1999:35) say, 'a persuasive philosophical argument...[the idea]...that there is a "family atmosphere" – a kind of philosophical affinity and kinship among and between the indigenous people of Africa', which can be seen as a philosophical relatedness and consanguinity among the indigenous people of Africa.

When we give Ubuntu a closer look, 'ubu-' is focused on numerous forms of being and is oriented towards '-ntu' (Hlela 2018; Letseka 2013; Masondo 2017). On an ontological level, there is no separation between 'ubu-' and '-ntu' and they are commonly grounded in 'be-ing' a 'one-ness' (Dzobo 1992; Gyekye 1997; Oruka 1990). 'Ubu-' as the 'be-ing' is conspicuously ontological, and '-ntu' as the 'be-ing' who takes responsibility may be said to be epistemological.

As a human being [*umuntu*], one needs to have attentiveness to endorse collectivity, relatedness and togetherness in the community, which continues to direct the being in acquiring experiences and knowledge (Okyere-Manu & Konyana 2018). This notion resembles a significant action rather than an act because 'be-ing' human is not sufficient in Ubuntu. A person is instructed to come to be a human being, and one needs to demonstrate that one is the image of Ubuntu (Botho).[1] This notion is based on the ontological understanding of the principle of 'be-ing' and more specifically 'be-ing' as 'one-ness'. Botho is thus seen as the relatedness between individuals to promote agreement, interconnectedness and togetherness between individuals living together in a community. Human beings should have profound compassion, understanding and awareness of another human's feelings and goodness to model being human to other human beings (Mangena 2016), hence 'I am, because we are...' (Mbiti 1970:141) or- 'Umuntu ngumuntu ngabantu' ('a person is a person through other people') (Nyaumwe & Mkabela 2007; Shutte 2001; Xulu 2010). Thus, it is essential to note that 'the individual is not independent of the

1. Ubuntu and Botho are the same words but they are from different languages. Ubuntu is used in all the Nguni languages and Botho in the Sotho languages.

collective; rather, the relationship between a person and her/his community is reciprocal, interdependent and mutually beneficial' (Oviawe 2016:3). Hence, the starting point of African epistemology is based on 'we are, therefore I am' because African philosophy is a collective awareness that is not just based on what we perceive and reason but also on what we feel and learn. That said, this communal collective also reflects a rich knowledge base that exists in African communities.

The rich knowledge base existing in African communities

Concerning Ubuntu, as stated above, the community is the top priority (Venter 2004). In African communities, individuals are firstborn from their community and into the community, making the individual always part of a larger collective of Africans (Venter 2004). African life is grounded in the various communities to which individuals belong, and individuals become human through other human beings (Venter 2004). From infancy, we are raised in particular settings where we are exposed to knowledge in particular contexts that ultimately shape our thoughts and language (Vygotsky 1978). Therefore, Africans can be seen as a collection of individuals with a rich knowledge base shared from individual to individual and community to community. How we think about knowledge and what we see as knowledge is indigenous to the communities in which we are raised. Thus, communal education starting early in a child's life resembles the 'we-ness' (Du Toit 2011) of education, as we all learn from and through each other, strengthening the role of Ubuntu and its promotion of SDL.

The notion above relates well to social constructivism as a learning theory based on Vygotsky's belief that learning is underpinned by social processes vital for learning to occur (Duchesne & McMaugh 2016). In addition, social constructivism advocates that human growth is dependent on the knowledge that is constructed through interaction with others (McKinley 2015). In other words, people work together to add meaning to something they learn collectively or deconstruct and reconstruct knowledge to arrive at new meanings. As much as constructivism's focus may be on the collective, it is also interested in the learning process happening in a person as they learn and construct knowledge through others. In social constructivism, learning and learning effectiveness are dependent on social interaction (Duchesne & McMaugh 2016).

The rich knowledge base that we refer to in this sense is established through collaboration among African people. Viewed from Ubuntu, the rich knowledge base that African people have is the basis of their existence that they use to manoeuvre through life and fulfil their communal duty of 'each one teach one'. Living according to this African American proverb means that every literate African person has to help other Africans to a point where they are literate – in other words, each person is a source of information that needs to be transferred to the next person (Each One Teach One 2020). Students from African communities reflect unique experiences because of the way(s) in which they conceptualise what was taught to them. Such experiences reflect an understanding of phenomena that belong to different communities in Africa and further confirm that a rich knowledge base exists but can also be taken advantage of in a student's journey towards SDL.

Social constructivism, Ubuntu and SDL are related in that all of these concepts are based on social engagements between people – be it to identify new learning needs; to develop group and individual learning goals; to share knowledge, experiences or resources; to construct new knowledge; to form a collective; or to develop into a self-directed individual. These concepts epitomise the 'we-ness' (Du Toit 2011) that resembles how Ubuntu contributes to SDL. To conclude, Ubuntu's notion signifies compassion, fellow feeling, kindness, consideration, understanding, sympathy, goodness and sharing, to mention but a few distinctive qualities. Ubuntu gives individuals the motivation to develop into a 'be-ing' with the qualities mentioned above underpinned by respect for other individuals. It also allows individuals to accept responsibility and to be genuinely human. It is our understanding that Ubuntu is significant to all nations and all domains of life. In this chapter, we use Ubuntu as a 'conceptual lens' to show how this African philosophy is beneficial for promoting SDL.

Young African students in the 21st century require skills (including the skill to be self-directed in their learning) that will prepare them and others for global teamwork, suggesting the need to incorporate SDL in the African context. Louws et al. (2017) corroborated the need for self-directedness and SDL in the changing world associated with the digital revolution (Guglielmino 2013; Verster, Mentz & Du Toit-Brits 2018). In the African context, like on other continents, SDL impacts organisational innovation significantly and, in turn, organisational innovation has direct and significant influences on organisational performance (Li-An 2011). Self-directed learning is a suitable and favourable process of fostering lifelong learning and keeping students up to date (Kidane, Roebertsen & Van der Vleuten 2020; Mohammadi et al. 2020) (Guglielmino 2013, cited in Du Toit-Brits 2019):

> Modern-day changes at economic, social, cultural and political levels and the education system characterised by transformation and scarce resources, demand SDL, which is vital to students' success in education and the world of work. (p. 1)

It is essential to highlight some of the studies on SDL conducted in Africa.

Self-directed learning research in Africa

Self-directed learning literature is widely available in Western countries; specific research and publications in SDL related to the African context and culture have increased significantly in Africa. However, most published research appears to have been carried out in South Africa. Du Toit-Brits (2019) studied the development of students' self-directedness and how educators' expectations influence it. One of the critical conclusions in her study was that direct teaching methods are still prevalent in South African schools and their Higher Education Institutions; hence, students are not adequately prepared for lifelong learning in the 21st century. Du-Toit-Brits (2019) also concluded that educators are fundamental in hindering and fostering SDL for students to become self-directed in their learning. She further asserted that interaction mediates SDL among students and the environment in which learning takes place, emphasising the educator's centrality and their expectations, which influence the guidance they give students in becoming self-directed significantly. Acquisition of SDL skills by students to meet the changing demands in a dynamic framework of rapid globalisation and massive 21st-century transition were recommended. Studies revealed that most African youth nowadays prefer to engage with, that is, computers and smartphones, which require them to develop their SDL skills so that they can use these technological devices to their advantage in teaching and learning (Amugongo 2018; Schlebusch 2018).

The North-West University's SDL Research Unit outlines a great diversity of SDL expertise, including online resources such as videos produced by the Unit over the years (eds. Mentz & Oosthuizen 2016). This compendium points to the fact that SDL has become increasingly important, not just for South African education but also for education sciences globally, which is evident in the book of Mentz and Oosthuizen (2016) titled 'Self-directed learning research: An imperative for transforming the educational landscape'. The book focused on SDL theory, exploring strategies like cooperative learning, teaching using case studies, teaching large classes and using blended learning to promote SDL. Most of these mentioned strategies apply to the African context – for example, in African culture, people believe in supporting each other; therefore, using cooperative learning where 'Ubuntu /Umuntu' culture is encouraged to develop SDL skills might be suited to the African student.

Another study that showed a relationship between culture and SDL was conducted at the Central University of Technology in South Africa (Swart 2018). The study involved African engineering students who enrolled in a module for project-based learning to determine the applicability of SDL to first-year African engineering students. Results showed that African engineering students understood the importance of adopting SDL and proposing indigenous learning methods. In the African context, people believe in sharing ideas, and these shared ideas are later applicable in one way or the other when one wants to solve a problem – this is where indigenous learning methods might be of importance. Self-directed learning applies to all regions/continents and cultures worldwide, including Africa (cf. Joshi & Dixit 2020; Mzuza & Van der Westhuizen 2019). However, a few students indicated that it was taxing to pursue SDL in different contexts that comprised diverse cultures – suggesting that the different contexts people come from indeed impact SDL.

One more study on SDL was conducted at Malawi College (Molande, Mtemang'ombe & Chikasanda 2017). In this study, the researchers explored the effectiveness of PBL and the traditional teaching method on students' performance in Woodwork. The researchers found that PBL was a more practical approach than traditional teaching methods (Molande et al. 2017). Results showed a substantial difference in student success among the two groups of participants (Molande et al. 2017).

A study in Tanzania (Charles 2017) explored undergraduate students' information literacy skills and SDL capability at the Open University of Tanzania. The findings showed no substantial variations in abilities in terms of gender, age and marital status in information literacy practices among students (Charles 2017). The findings also revealed that different factors in information literacy skills could influence students' development of SDL. In light of the findings, Charles (2017) suggested that literacy education should start from the primary education level to provide students with a better information literacy skills foundation before they embark on higher education studies.

In their study in Kenya, Opiyo and Oboko (2019) explored the potential of SDL to 'give a second chance and provide learning opportunities to youths and young adults'. Results showed teaching methods promoting lifelong learning might help people who want to further their education when they are older, especially those who have left school in their younger years because of various reasons. The researchers, in this case, believed that SDL skills offer learners the flexibility to learn in a way suited to them despite busy plans.

A study conducted in Nigeria sought to determine the SDL readiness of nursing students' and how their readiness influences learning outcome (Ojekou & Okanlawon 2019). The results showed a significant relationship between learning outcome and the type of method used (Ojekou & Okanlawon 2019). The results also revealed that nursing students' SDL readiness level had a significant effect on learning outcome. The researchers recommended that nursing training institutions provide essential resources to embrace SDL as a central-line teaching technique to certify competent lifelong experts (Ojekou & Okanlawon 2019).

Numerous studies conducted in Africa on SDL have proven that it is also relevant to the African context. One cannot talk about research conducted on SDL without elaborating on the 'communal self' in the African context.

The connection between the principles of Ubuntu and self-directed learning characteristics

This section deals with the relationship between Ubuntu and SDL. We highlight this connection through a discussion of the principles that underpin Ubuntu and the characteristics of SDL. As mentioned in the previous section, Ubuntu is signified through certain principles. These principles include, among others, care, community, harmony, hospitality, respect and responsiveness (Bolden 2014; Nzimakwe 2014).

Care, or caring, is a norm and a principle of Ubuntu (Metz 2007). Waghid and Smeyers (2012:13–15) mentioned that the link between ethics of care and Ubuntu relates to an awareness of morality leading African people on to a journey where their dealings with people are underpinned by care, compassion, hospitality and the forgiveness of others for all to function together where they are connected and interdependent. According to Gregory (2000):

> [*C*]aring is, first of all, to be aware of the network of human relationships in which one is involved and secondly, to consider the effects of one's actions on the people to whom one is socially related. (p. 252)

That said, three elements of Ubuntu underpin care. These elements include the following: how African people deal with each other should resemble taking each other into account, remember that we are all humans and remember that we should be generous (Mugumbate & Nyanguru 2013; Sekudu 2019).

The role of community in Ubuntu resembles a sense of togetherness among African people. On the one hand, community or functioning as a community resembles harmony and is deemed a blend of identity and solidarity (Metz & Gaie 2010) among African people. Communal harmony in this sense is characterised by the idea that '[e]very member [of the community] is expected to consider him/herself an integral part of the whole and to play an appropriate role towards achieving the good for all' (Gbadegesin 1991:65). On the other hand, in Ubuntu, harmony is established through close social relations in a group that reflect sympathy (Mokgoro 1998). 'The fundamental meaning of community is the sharing of an overall way of life, inspired by the notion of the common good' (Gyekye 2004:16), which can eventually contribute to harmonious living conditions.

Hospitality in Ubuntu should be seen as African hospitality (cf. Gathogo 2008). African hospitality is described as 'an extension of generosity, giving freely without strings attached' (Gathogo 2008:42). As Ubuntu resembles a collective or one-ness with a group, it can also be said that within such a group, African hospitality is resembled through 'an unconditional readiness to share' (Echema 1995:35). Archbishop Tutu (1989) expressed African hospitality and its interdependent inclination best by saying:

> Africans believe in something that is difficult to render in English. We call it Ubuntu, Botho. It means the essence of being human. You know when it is there and when it is absent. It speaks about humaneness, gentleness, and hospitality, putting yourself on behalf of others, being vulnerable. It embraces compassion and toughness. It recognizes that my humanity is bound up in yours, for we can only be human together. (p. 69)

Acting towards others with warmth and kindness, for example, is part of being African and expresses the ideal African persons (Gathogo 2008).

Ubuntu and respect go hand in hand. Respect in this regard is twofold because one should first respect oneself before knowing how to respect others (cf. Poovan, Du Toit & Engelbrecht 2006). In addition, treating others with respect also entails acknowledging that each person is a valuable asset to the African community, resembling their dignity (cf. Bekker 2006). Mbigi and Maree (1995) argued that respect and dignity is part and parcel of Ubuntu, and the trust of fellow Africans is obtained by treating them with respect and granting them dignity. Working optimally and functioning as a larger team where relationships are built necessitate unconditional respect (Poovan et al. 2016). Treating each other with respect and dignity from Ubuntu's perspective is vital to reach goals identified and set by individuals and groups (Poovan et al. 2016). Thus, learning communities should be based on high levels of respect and dignity to increase trust levels to occur among individuals forming part of a larger group (Poovan et al. 2016).

Responsiveness in Ubuntu is characterised by openness to other perspective or other views that people from various backgrounds hold in the African context (cf. Pitsoe & Letseka 2016). In the education context, responsiveness thus means that educators are receptive, open and sensitive to individual students' needs in a larger group. Educators and students being responsive listeners and responsive speakers in this regard are also valuable (cf. Shotter & Cunliffe 2003). We believe that being responsive speakers' means that we speak based on what we heard or that our reaction is based on what we heard. Also, being responsive entails mindfulness – to be mindful of what is said and how it is said, ensuring that it contributes to the collective and collective meaning-making. Moreover, responsiveness epitomises the centrality of communication in Ubuntu and African communities, as communal sharing of knowledge occurs through communication (through every individual's voice in the larger group) (cf. Deetz 2003).

It is crucial to also elaborate on the characteristics of SDL to illustrate the connection between Ubuntu and SDL, as mentioned earlier. Highlighting the characteristics of SDL necessitates that one should always be mindful that the SDL journey of a student goes along 'with or without the help of others' (Knowles 1975:18). Thus, we can say that, in the African context, SDL is mainly promoted through the help of others (thus Ubuntu), be it the educator or other students. The journey is a joint activity and individuals form part of a larger group of people on whom they can rely, and they understand and construct information in collaboration with others. A self-directed learner is someone with the following characteristics (cf. Abdullah 2001; Ertmer & Newby 1996; Guglielmino 2013; Lounsbury et al. 2009; Samson 2013; Tredoux 2012):

- Creativity.
- Being goal-oriented.
- A love of learning.
- Being organised.
- Having self-confidence.
- Having good communication skills.
- Being optimistic.
- The ability to reflect on own learning.
- An abundance of self-motivation.
- A high level of inquisitiveness.
- Being flexible.
- The ability to accept responsibility for own learning.
- The ability to manage time effectively.
- The ability to question rules, procedures and assumptions about learning.
- A strong work ethic.
- Developing beliefs and opinions independently.
- Being self-disciplined.
- Seeing problems as challenges and not as hindrances.
- The ability to see feedback as constructive feedback.
- The ability to learn independently.
- The ability to evaluate own limitations and weaknesses.
- To be informed about one's strengths, abilities and aspects that contribute to motivation.

We believe that it is necessary to shed light on the characteristics of SDL that resonate with the principles and social inclination of Ubuntu. Reflecting on Knowles' (1975) definition of SDL – a person's journey towards SDL happens independently or through the help of others (be it individuals or a group of people). Self-directed learning also entails identifying learning needs, formulating learning goals, recognising learning resources that can be applied in learning, choosing and applying suitable learning approaches, and assessing learning results. To show how Ubuntu promotes SDL, we illustrate the connection between Ubuntu principles and SDL characteristics.

Creativity as an SDL characteristic is not acquired or learnt in isolation. Creativity is one of the characteristics a person should have in the 21st century (Dede 2010; Voogt & Roblin 2012). In 'Human Motivation', a book by Franken (2002:396), creativity is defined 'as the tendency to generate or recognize ideas, alternatives, or possibilities that may be useful in solving problems, communicating with others, and entertaining ourselves and others'. It can be deduced that creativity is underpinned by motivation promoted through people's desire to solve problems, their desire to share what they think and value, and their desire to be encouraged through diverse, new and complex learning (Franken 2002). Creativity is further dependent on the ability to view phenomena in ways not viewed before or change one's perspective on the different phenomena exposed to during the learning situation (Franken 2002). In addition, the process of being creative is related to the context of people and how a solution to a problem is newly developed on an individual basis or in a collective to be used among a group of people (McGuinness & O'Hare 2012). Ubuntu, therefore, expresses collective creative ideas and thoughts where the cohesion of collaborations and communal ownership go hand in hand. What is more, the use of Ubuntu embraces and stimulates creativity.

Love of learning as an SDL characteristic can be cultivated through parents and educators (cf. Renninger, Sansone & Smith 2004). As lecturers who train students to become educators, we believe that a love of learning starts in early childhood. How students are stimulated goes a long way, and whomever the educator is at a particular moment (be it an educator, or a peer, or a group) depends on someone developing a love of learning (Renninger et al. 2004). Having a love of learning may further influence the lifelong learning of a person (Aguilar 2016). Students are encouraged to ask questions to continue discovering and generating answers to such questions, and people are also offered choices regarding what they want to talk about and what resources they want to draw on for understanding or constructing new knowledge (cf. Penman & Ellis 2009). Child rearing in Africa, as traditionally defined, is the 'village', highlighting that the entire community is involved in educating a child. Through the upbringing and educating of a child, learners are prepared to take ownership and a love of learning.

O'Shea (2003) believed that SDL can, among others, build the self-confidence of people. Self-directed students are, among other things, self-confident (Abdullah 2001). Du Toit-Brits (2019) believed that, during students' journey towards SDL, educators should guide them to become confident to solve the problems they face or are given to solve and take responsibility for their learning. That said, if educators model confidence to their students during the learning process, they could become ready 'to be self-directed in their learning' (Du Toit-Brits 2019:7). Considering that the learning community in a class engages socially with each other, one can say that the educator modelling confidence to students is done socially in the classroom. Therefore, building or cultivating self-confidence in students has a social nature. Self-confidence is an essential part of Ubuntu because individuals within the communal need to know their value, and they need to have focus and courage when working together in the interest of the communal.

Good verbal and nonverbal communication skills are social abilities we deem relevant and necessary to discuss. Inner speech starts to develop in early childhood (Blignaut & Du Toit-Brits 2021; Geva & Fernyhough 2019), which implies that one's inner thinking starts at home or as soon as one first makes contact with one's parents or siblings. Nonverbal communication (also referred to as body language) entails how one communicates with one's eyes, face and hands; how one moves around; and how one appears to others (Jacobs 2016). Both types of communication, in our opinion, start with observation through which we learn. Also, we never stop learning to communicate. We believe that most of our communication development happens in our social interactions with each other, and in this case, in the classroom. Through communication, spaces are being created for individuals within the collective to share their deeper meanings of phenomena. Communication is, therefore, crucial in Ubuntu as communication creates a sense of the communal, and the social influence of communication is accentuated.

Being optimistic about the future or having an optimistic orientation to the future is one of the characteristics that need to be in place for SDL to occur (cf. Guglielmino 1977, 2013). Pessimism and optimism are often observed from the people in one's specific cultural community, especially mothers, who project their negativity onto children (Seligman 2006), leading to pessimism, struggling to see life in a positive light. However, as optimism is observed, it is possible to unlearn pessimism (Seligman 2006) by being around positive people and working with others. Thus, the context from which the student comes is essential to cultivate optimism in students. Being optimistic in all situations and conditions is a distinctive aspect of Ubuntu because it conveys optimism as it is a way of life.

A high amount of curiosity is a characteristic of a self-directed learner (Guglielmino 1977). In other words, an inquisitive person may be ideal for the promotion of SDL. Through social engagements such as educational opportunities – for example, where an educator or peers ask valuable questions – inquisitiveness is encouraged and promoted (Price-Mitchell 2015). Educators can be assisted to ask good questions that can trigger curiosity in students about a particular topic. Opportunities offered in classrooms where diverse students from different contexts with different curiosity levels can work together on projects could lead to moments where they inspire each other to be curious about a particular topic (Price-Mitchell 2015). The social element in developing, promoting and nurturing inquisitiveness in students is therefore evident. Through this, we also see collective effort and dependency on others to develop the ability to be curious – an aspect we believe is central to creating educational opportunities resembling 'we-ness' leading to education for us through us.

Flexibility is one of the characteristics that enable students to be self-directed in their learning (cf. Hinchliff 2004; Holtzclaw 1985; Robotham 1995). We believe that flexibility is acquired over time, especially when working with others. When working with others, one needs to be adaptable, and one fulfils many roles that occasionally require one to stand back and refrain from taking the lead. Flexibility is also needed to adapt to unfamiliar environments or situations (Lewis & Williams 1994), such as working closely with people from different contextual backgrounds. Additionally, being flexible requires creative thinking, accepting uncertainties, applying emotional intelligence and changing the focus when working with others (Bailey 2014). Through flexibility and thus the willingness to learn from others, an atmosphere of communal respect is established between community members that also permits for individual development, a sense of communal accomplishment and collective goals.

Considering the information above, it is vital to illustrate how Ubuntu (its principles) and SDL (through its characteristics) are connected. Besides context that plays an enormous role in Ubuntu and SDL, it can be deduced that social interaction strengthens the individual both directly and indirectly. That said, the (social) interdependence that underpins Ubuntu and SDL seems to be the obvious connection. Social constructivism, as mentioned earlier, is essential for this chapter as it focuses on social learning and the construction of knowledge with and through others, strengthening the notion that those involved in the teaching–learning process are socially interdependent. Social interdependence is defined as a '[p]rocess of social interaction where certain common goals are established with other people in such a way that each person's results are affected by the actions of the others' (Serrano 2010:429). The social aspect rooted in Ubuntu and SDL is what constitutes the connection between these concepts. Nevertheless, Ubuntu and SDL's social inclination highlight the 'we-ness' that emerges from the connection. It also indicates a collaborative teaching–learning process that relies on social interaction, cooperation and forming a group of dependent and responsible people to promote the SDL of individual learners in the group.

Forming a collective of people in which a rich knowledge base exists reflects more than one person forming a group and is instead highlighted best through the pronoun 'we'. Thus, the learning community that Ubuntu establishes that contributes to SDL can be envisioned as 'we-ness: a-perfect-fit SDL community for us'. Such an education community includes commonality and sociability. Here, the student requires dialogue in a community by sharing ideas through social interaction, social dedication, and the lecturer and peers' time-spatial presence in scheduled contact opportunities. Communal cohesion and joint coalition in a community are thus promoted.

Lastly, one might argue that there is a philosophical disjuncture between Ubuntu and SDL if SDL is conceptualised in its narrow sense without considering its elaborated definition. The 'self' in SDL might lead to the assumption that SDL has an individualistic inclination and that the focus of SDL is solely on the end goal: to deliver or get a learner that can function autonomously. This conceptualisation is absent of the process and journey an individual embarks on, which is not done in isolation or by oneself and through oneself. Additionally, conceptualising SDL in such a way only reflects that SDL is achieved 'without the help of others', which is only one side of the same coin. As per Knowles (1975) definition of SDL, the other side of the coin unequivocally states that SDL is achieved 'with the help of others'. Understanding SDL within the African context through Ubuntu is central to the principles of Ubuntu. The process or the journey to becoming self-directed through others as in 'I am through others' is epitomised by a reciprocal relationship of giving and taking from each other, thereby highlighting Ubuntu principles in SDL within Africa. In this sense, the process becomes the centre of attention as that is where an individual is strengthened (cf. Markus & Kitayam 1991; Yasmin et al. 2019), shaped, supported, empowered and enabled to function as an individual within a larger group. During this process, care is mutually applied in interactions that include learning opportunities where a sense of social cohesion and one-ness with others of the SDL community comes to the fore. It is also here where the community is established and nurtured by working together in harmony, sharing each other's spaces and knowledge while respecting each other and being responsive to and attending to each other's needs. As a result, students need to undertake joint responsibility for the learning process where 'You do it together'.

■ Wrapping up: The importance of Ubuntu for the promotion of self-directed learning

The central belief of African indigenous education (Magagula & Mazibuko 2004; Mautle 2001) is to learn successfully means to live helpfully and contentedly with family, community and spirits of descendants, hence the significance of 'Botho' (Sotho languages) or 'Ubuntu' (Nguni languages) (Hlela 2018). In African indigenous education, collective learning, oral education and learning through dreams, visions and stories are essential (Waghid 2014). However, the reality is that education has ignored some of these central essential beliefs of African education (Hlela 2018).

In the African context, a vision for education is to support individuals to attain critical communal principles like Botho or humanism (Broodryk 2006). By attaining Botho through education, the individual grows into an endowed collective member who is compassionate, considerate and understanding, who shows feelings, goodness, kindness and sympathy towards others, endorsing collaboration among be-ings (Broodryk 2006). These principles of Ubuntu have been relegated to education because of colonialism and a capitalistic economy, of which the consequence was education without the capability to answer to the necessities and well-being of African indigenous communities (Letseka 2000, 2013, 2014).

So, we can ask ourselves: Why is Ubuntu important for education and thus promoting SDL? To embrace Ubuntu in education, Stanistreet (2019:219) is of the view that, 'with its humanistic ethos and emphasis on interconnectedness', teaching and learning should embrace pedagogics that promotes and support the needs of students, fostering 'a sense of interconnectedness' between 'learning and social community'. Consequently, education ought to embrace Ubuntu-motivated teaching and learning methods (Hlela 2018) that focus more on indigenous systems of thought like Ubuntu (Letseka 2014; Letseka & Ivamu 2011; Parker & Roessger 2020) in order to promote meaningful educational practices which 'foster an ethos of a holistic, transformative and emancipatory educational experience for all' (Oviawe 2016:2). By implementing the principles of Ubuntu in education (Ubuntu pedagogy), an educational approach can be cultivated that focuses on guiding students on how to learn and assisting them to learn to work in more self-directed ways (Abdi 2020; Assié-Lumumba 2017; Bell 2002), thus focusing on promoting self-direction in learning (Bache & Hayton 2012; Parker & Roessger 2020). Ubuntu can empower and support students to gain control and better understand knowledge as they come to know subjects in the SDL process. This notion accentuates that students need to be actively involved in learning and that knowledge and understanding should be developed by communal groups focusing on personal knowledge based on students' lived experiences. Therefore, students must be seen as fellows of a collective in SDL, which may empower them to support and care for each other to attain learning. By working together (e.g. solving problems in contributing to their learning goals) can encourage togetherness and social cohesion and, as such, create a constructive and encouraging cooperative learning atmosphere where knowledge, skills and lived experiences are shared that contribute to the successful implementation of SDL (Miles & Ahuja 2007). Quan-Baffour (2014:424) is of the argument that 'in its essence cooperative learning shares the philosophy of Ubuntu which teaches that it is only through cooperation with others that the individual realises his or her potential'. It is, therefore, our opinion that the learning achievement of students working as a collective in SDL requires the learning achievement of the individual. As a result, individual students' learning achievement is the 'responsibility of the group', given that students also take accountability for their learning.

With the implementation of Ubuntu principles which leads to the promotion of SDL in education, educators can cultivate learning environments (Ukpokodu 2016:155) where students are allowed to function in democratic, autonomous learning environments; with the 'freedom to co-learn in an environment grounded in humanism', they can think critically and implement self-reflection (Letseka 2013). Thus, for the promotion of SDL through Ubuntu, students should be encouraged to work collectively in partaking and interacting with other students in learning environments, embracing learning environments' communal and collective nature. Embracing communal relationships with other students in this communal and collective learning environment is essential so that 'learning communities can fully embrace and value humanism, thus Ubuntu' (Broodryk 2006:32; Parker & Roessger 2020). As seen earlier in this chapter, Ubuntu's beliefs and principles in education ought to deliver a compassionate and helpful foundation where both educator and student should participate as a collective, accentuating the interdependent nature of the SDL process (Broodryk 2006). Interconnectedness and interdependence, as Ubuntu principles, are also grounded in SDL and provide students with learning opportunities directed by a greater longing to learn and understand the importance of self-reflectivity. Ubuntu should be regarded as a relevant philosophy and viewpoint that can serve as a compass in SDL to cultivate accountability under students and enhance their attentiveness to others by supporting them in this SDL journey as a one-ness/we-ness, which is beneficial for the promotion of SDL.

We further argue that there need to be purposeful collective relationships between students within SDL with the goal of a determined and focused enclosure of the principles of Ubuntu that can improve SDL. Functioning within a collective learning community can be responsible for improved support and motivation for students. Also, as collective members, self-directed students can benefit from various viewpoints and feedback that initiates from the collaborative learning environment. We argue further that SDL and collaboration need not be seen as isolated constituents, but SDL needs to be seen as an exploratory learning model in that it combines both constituents of autonomy (SDL) and collaboration, embracing the philosophy of Ubuntu in the heart of SDL. Finally, as a result, students need to work together to motivate and critique, share various perspectives, and reflect on learning materials and the learning process, emphasising collaborative SDL based on Ubuntu.

Based on the information above, it can be deduced that the limitation of this chapter is that scant attention, if any, has been paid to SDL within the African context. That said, the scarcity of academic sources on this aspect has strengthened the need for this chapter. Because of the mentioned limitation, it was essential to highlight the meaning and place of SDL within the African context through Ubuntu, the African philosophy. Strengthening the need for this chapter further comprises the understanding of SDL by, for example, scholars who view SDL in a narrow sense or from a Western perspective, that is, that SDL only leads to the individual being able to work independently. Considering this notion, SDL is promoted with or without others' help, implying that the process is not an isolated one but a collective process whether the focus is on the means to the end or the end itself, which is collective, collaborative and social underpinned by Ubuntu. Lastly, in general, the chapter's information and arguments pave the way for further research that deals with this critical aspect and that research on SDL within the African context is crucial.

■ Conclusion

Having reached the end of the chapter, we highlighted the problem under study, followed by explaining how SDL serves as context and background in this chapter. We elaborated on the African culture, the communal self as an African notion and Ubuntu as African philosophy, followed by a discussion of the rich knowledge base existing in Africa and its inhabitants. Also, we discussed research undertaken in Africa and the African context focusing on SDL. Furthermore, we established a connection between the principles of Ubuntu and SDL characteristics and justified what constitutes such a connection. We ended this chapter by elaborating on the importance of Ubuntu for the promotion of SDL.

Taking the above information into consideration, it is evident that the African philosophy of Ubuntu can be beneficial for promoting SDL, not only for Africa but also globally. Ubuntu pedagogy can promote SDL by supporting educators to foster 'habits of mind' to learn and work cooperatively with diverse others. In this chapter, we underscored that the African philosophy of Ubuntu is beneficial for promoting SDL, as students come from diverse backgrounds with the riches of life experiences and a rich knowledge base that can promote SDL. Self-directed learning needs to be seen as a social (communal) action, focusing on achieving collectively developed learning goals through support and cooperation.

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Chapter 2

The influence of the learning environment on promoting self-directed learning

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Abstract

There are multiple types of learning environments across the educational landscape. However, all students need to acquire essential skills to be successful and should feel encouraged about their learning experiences regardless of their learning environment. The 21st-century student is in search of a learning environment that is explicitly planned to support attentive thinking. They desire learning environments that (1) drive their learning abilities through changing their teaching and learning strategies, (2) give a sense of accomplishment and ownership, and (3) encourage them to be vigorous, engaged participants during the learning expedition. The purpose of this chapter is twofold: first, a literature review is provided on how the learning environment can promote self-directed learning, and second, prerequisites

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that can support higher education institutions (HEIs) to promote SDL are outlined.

Introduction

A learning environment is a miscellaneous podium where operators participate and interrelate to acquire new skills (Guglielmino 2013). Such an environment can be a physical location or culture. A learning environment should enhance students' capability to learn, implying that education should focus on resourcefulness and engaging with learning materials rather than memorising facts (Ozerem & Akkoyunlu 2015). Cultivating an engaging and encouraging learning environment for students needs to be seen as a unique teaching feature (Brandt 2020). Typically, the emphasis is on the classroom (e.g. a physical space like a lecture hall or laboratory) or diverse technologies that can be implemented to cultivate a learning environment. A learning environment should be seen in a wider context and include elements (Du Toit-Brits 2015; Hiemstra 2013; Hiemstra & Brockett 2012; Knowles 1968a, 1968b, 1970, 1975, 1990, 1991, 1993, 1995, 1996; Ozerem & Akkoyunlu 2015) such as:

1. the capability to address students' needs (student individuality)
2. focusing on teaching and learning goals
3. the implementation of interactive learning activities and active instructional procedures and learning resources that support active and engaged learning
4. collaboration, engagement and connectedness
5. capability to create a feeling of security
6. fostering a sense of belonging
7. educators' skills and roles
8. support
9. supporting and embracing a SDL culture and learning climate.

The elements mentioned above can influence students' learning capabilities and success. These elements can bring about a culture and climate conducive to learning in which students can flourish. An effective learning environment can create a positive atmosphere that is conducive to motivation, commitment and SDL. Such an environment encourages interactive instructional procedures and gives a feeling of support. Below is a brief discussion of what the learning environment should comprise for promoting SDL.

Problem statement

For students to stay interested and thrive in learning, they need to have confidence that they can learn and that what they learn is valuable, significant and meaningful (Hairon & Chai 2017). Students should also have a sense of belonging in the learning environment, and they must take responsibility for their learning (Boyer & Usinger 2015; Dabbagh & Kitsantas 2012). This encourages self-directed learners who are confident of making the learning content their own and who take ownership of their learning (Guglielmino 2013; Sze-yeng & Hussain 2010).

Self-directed learning is deemed a vital 21st-century skill (Brandt 2020). Learning environments should nurture and promote inquiry skills so that students can continually take responsibility for their learning to acquire new knowledge throughout their lifespan (Gresham 2018; Hiemstra 2013). There is no value in planning and offering education based on regurgitating what is already known; students must be allowed to discover new knowledge and be exposed to teaching practices that promote SDL and enable students to be active and engaged in the learning process (Du Toit-Brits 2020; ISSDL 2020). Self-directed learning should be recognised as a dynamic, lifelong student capability in education. Having provided a brief discussion of this chapter's problem, it is essential to highlight the theoretical and conceptual frameworks foregrounding this chapter.

Theoretical and conceptual framework

The term *learning environment* has numerous meanings. A learning environment can be defined as (Wilson 1996):

> [*A*] place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities'. (p. 5)

Diverse settings outside of the school context can also be considered learning environments. Therefore, a learning environment is not limited to a 'traditional' environment like a classroom with desks and a blackboard. Moreover, a learning environment can refer to the principles and values of a specific school or classroom and characteristics such as how individuals interact with one another (Cohen 1994).

There are different learning environments, such as (but not limited to) face-to-face, online, hybrid and blended environments; thus, a learning environment can be traditional, virtual or a combination of these mentioned learning environments (Cho, Kim & Choi 2017). Although this chapter's focus is not to provide an in-depth discussion of these learning environments, it is necessary to highlight some of their identifiable features. The first learning environment is a face-to-face learning environment – also known as a traditional learning environment – where learning happens in person and students can ask questions and receive an instantaneous response. The second learning environment is an online learning environment and involves using the Internet; in this case, educators give teaching and learning tasks in advance, and students can finish them autonomously in their own time. The third type is a hybrid teaching and learning environment that allow students to attend classes physically or virtually. The last type is a blended learning environment, and it incorporates synchronous and asynchronous learning approaches (Porter et al. 2016; Tomberg et al. 2013). However, variability in learning environments is vital as one learning environment cannot be superior to another learning environment.

Effective learning environments share the following characteristics (to name but a few) (Prameswari & Budiyanto 2017):

1. Students feel physically and emotionally safe and can be themselves.
2. Students are appreciated, regardless of their abilities, among others.
3. Students can take ownership.
4. Students are supported.
5. Performance standards are recognised and rightfully applied for every student.
6. Students are offered learning opportunities.
7. Students are known to educators.
8. The attainment of educational quality is essential.
9. Knowledge creates meaningful learning experiences.
10. There is interaction between educators, students and the learning content.

It is also important to note that not all learning environments share the above-listed characteristics. These are characteristics of *effective* learning environments. Unequivocally, the above characteristics of effective learning environments grounded in approaches that support students in their learning offer students a place and space with appropriate learning content and opportunities to create social abilities to formulate clear learning goals and receive continuous feedback (Vanslambrouck et al. 2018). To help learners improve their knowledge and skills, specifically SDL skills, it is of paramount importance that appropriate teaching strategies and activities be implemented. Also, according to Klem and Connell (2004), the learning environment must include the following:

> [*O*]ne element which is the school climate which at its most positive, include attention to safety issues, family and community involvement, positive relationships among students and teachers, a strong emphasis on academic achievement, respect for all member of the school community, fair and consistent discipline policies. (p. 112)

This chapter suggests that effective learning environments promote 'active engagement' of students (Prameswari & Budiyanto 2017; Vanslambrouck et al. 2018). For active engagement, students need learning environments that are not as outdated as traditional learning environments but effective learning environments that encourage (Fahnoe 2013; Guglielmino 2013; Hannafin et al. 2014; Moore, Dickson-Deane & Galyen 2011):

1. attentive thinking
2. personal connection
3. student agency
4. authentic learning
5. active learning
6. collaboration and reflection
7. learning experiences that develop inquisitiveness and passion for learning
8. students who see problems as opportunities in learning, to mention but a few.

Moreover, the learning environment should promote student agency: students should be aware of their role as active learning participants. This notion implies SDL – students should be actively involved in planning, assessing and controlling learning. Students' learning environment affects how they learn, their commitment to and interaction with the learning content, their enthusiasm to learn and their well-being and sense of belonging (Dabbagh & Kitsantas 2012; Wanda 2014). The implication is that a learning environment may hinder or promote SDL. Having discussed the different learning environments, the discussion below focuses on the importance to adopt SDL in learning environments.

Self-directed learning

As was stated in Chapter 1, the most agreed-upon definition of SDL is that of Knowles (1975):

> [*Self-directed learning is*] a process 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 for learning, choosing and implementing appropriate learning strategies and evaluating learning outcomes. (p. 18)

Self-directed learning entails the following prominent features (Knowles 1975):

1. Taking ownership of learning – This involves individual responsibility to recognise and determine one's learning gaps and setting learning goals consistent with these learning gaps.
2. Extension of learning – Students ought to engage in cross-disciplinary work promoting collaboration with other students, which they can use to form networks among formal and informal learning (see ch. 10) occurring inside and outside of self-directed environments.
3. Self-monitoring – Students should manage learning tasks, learning time and appropriate resources. They must also take action to meet their identified learning goals.

Furthermore, according to Knowles (1968a, 1968b, 1970, 1975, 1991, 1993, 1995, 1996), SDL involves nine competencies:

1. Accepting the differences in students and the abilities necessary for learning in student-focused education.

2. Seeing oneself as a non-dependent, self-directed individual.
3. The ability to work collectively in the planning of learning and diagnosing needs.
4. The ability to ascertain learning requirements persuasively with the assistance of educators.
5. The ability to interpret learning requirements that are important for the formation of learning goals.
6. The ability to communicate and share with educators as facilitators and partners in learning and taking the initiative to engage with learning resources.
7. The ability to distinguish between learning resources applicable to various learning purposes.
8. The ability to handpick active approaches to employ learning resources.
9. The ability to self-assess the success of individual learning goals.

Educators believe that students should be more in control and accountable for their learning (Claro & Loeb 2019; Du Toit-Brits 2015; Ponton & Carr 2016). However, if educators want to cultivate more self-directed students, there should be an emphasis in learning environments on the above-listed competencies for students to become self-directed. Self-directed students will be more intrinsically motivated, interested in learning, persistent, independent, active agents in learning, self-disciplined, self-confident, goal-oriented, problem-solvers and critical thinkers (Aşkin 2015; Cadorin, Bressan & Palese 2017; Claro & Loeb 2019). To embolden self-direction in learning, educators should make learning more meaningful. Educators can do so by supporting the development of critical thinkers who are accountable for and in control of their learning – this is an essential product of formal education and training because SDL is a natural path to meaningful learning, understanding and effectiveness (Brockett & Hiemstra 1991; Hiemstra & Brockett 2012; Ponton 2016; Ponton & Carr 2016).

An essential requirement for SDL is a strong emphasis on student-centred learning. Educators should be devoted to cultivating SDL in learning environments where active learning is the central focus (Du Toit-Brits 2020; Sale 2018; Song & Hill 2007). The prominence of SDL in individual autonomy, individual responsibility and individual development personifies some of the necessary ideologies of HEIs (Sawatsky et al. 2017).

Adopting self-direction in learning

Embracing self-direction in learning is underpinned by four prerequisites (Tan 2017): first, there must be confidence and mutual trust between the student and educator; second, the student needs to be willing to be self-directed in their learning; third, continuous support must be provided to students to develop and mature in self-directing; and lastly, learning opportunities must be provided to students to grow in their capability and aptitude in self-direction (Du Toit-Brits 2020; Wanda 2014). Educators are required to make a paradigm shift before employing the above-stated prerequisites. Such a paradigm shift entails, among others, that educators need to become conscious and mindful of each student's role in and accountability for the learning process (Slater, Cusick & Louie 2017; Swart 2018). Students need to be educated about self-directed development, underscoring the commitment of individuals who must be involved in continuously taking responsibility for their learning (Francom 2010).

Furthermore, by adopting and promoting SDL in learning environments (Tomberg et al. 2013), students can change from just being educated to being competent, skilled and accountable individuals (Francom 2010). Such a change emphasises the forming and boosting of student capabilities. Additionally, students can be supported to reflect on their capabilities, be specific about their learning goals and realise the benefit of transforming into self-directed individuals (Thornton 2010).

In this chapter, it is proposed that the adoption of self-direction as an approach to learning can lead to a change in HEIs, specifically concerning the improvement of educational practices (Bellanca, Paul & Paul 2014; Broadbent 2017; Hiemstra & Brockett 2012). Students must be willingly involved in all facets of the education process and take responsibility for their learning to improve educational practices (Sawatsky et al. 2017; Swart 2018). Self-direction in learning is an important skill, and educators need to be willing and keen to cultivate 21st-century employability skills in their learning environments (ISSDL 2020; Song & Hill 2007). Also, Knowles (1996) claimed that individuals (students) could become more self-directed as they develop. Before students can become more self-directed, the learning environment needs to facilitate and promote SDL (Dynan, Cate & Rhee 2008; Francom 2010).

■ The contribution of the learning environment to the promotion of self-directed learning

Various elements should be explored to determine what effective learning environments can contribute to SDL promotion (Vanslambrouck et al. 2018). Faculties can play a purposeful role in introducing and implementing SDL in HEIs and establishing learning environments conducive to promoting SDL (Guglielmino 2013; Thomas 2018; Williamson & Seewoodhary 2017). The elements of learning environments to promote SDL are discussed in this section.

Creating an engaging, constructive and effective learning environment for students is a key aspect of meaningful teaching (Brandt 2020; Guglielmino 2013). Generally, the emphasis is either on the physical learning environment (e.g. lecture theatres and laboratories) or on diverse technologies that are employed to cultivate online learning environments (Gresham 2018; Guglielmino 2013; Thomas 2018). Cultivating an effective learning environment is epitomised by embracing (1) student characteristics, (2) educational goals, (3) learning experiences that promote active learning, (4) diverse assessment approaches that inform teaching and learning, and (5) a learning culture that exemplifies an engaging, constructive and practical learning environment (Charungkaittikul 2017). Social, physical, psychological and cultural factors (see ch. 1) often affect students' learning capabilities in the learning environment (Boelens, De Wever & Voet 2017; Fahnoe & Mishra 2013). If the learning environment does not encourage the acquisition of new knowledge and SDL skills, it can be difficult for students to stay interested and involved in the learning process (Gresham 2018; Tomberg et al. 2013). Learning environments should not be regarded as a threat to students' self-directedness but rather as learning podiums to develop SDL skills and to encourage advancing their growth by maturing their SDL skills and, by implication, their self-directedness (Fahnoe & Mishra 2013; Sale 2018). Educators should take responsibility to integrate various approaches/elements in learning environments that would support students in their journey towards self-direction in learning (Porter et al. 2016). In higher education (HE) learning environments, a sense of support for self-direction in learning needs to be emboldened, which is essential to promote SDL (Pane et al. 2018). The next sub-section discusses the elements of learning environments that contribute to the promotion of SDL.

Elements of the learning environment that contribute to the promotion of self-directed learning

In this sub-section, elements of the learning environment contributing to SDL promotion are discussed to determine what such an environment should resemble. The below-discussed elements include embracing an SDL culture, the capability to address students' needs, the feeling of security, fostering a sense of belonging, active instructional procedures and learning resources, educators' skills and roles, collaboration, engagement and connectedness, and support (Alfalah 2015; Brandt 2020). For the purpose of this chapter, only these elements are discussed.

Embracing a self-directed learning culture

A student-centred learning environment that embraces an SDL culture emphasises the student rather than the instructor (educator). To achieve an SDL culture, students need to set their learning challenge following the general objectives. Those students who choose the best possible technique can manage their available time for learning opportunities by remaining motivated and capitalising on their already established skills, awareness and experiences in completing tasks (Thomas 2018). Students are characterised by something distinctive: innate drive/intrinsic motivation and self-determination for outstanding work that enable them to recognise loss of competence/lack of skill (Acar 2014; Aşkin 2015). In HE learning environments, it is essential to build a positive learning community in which SDL can flourish. Learning needs and student learning desires are vital aspects of a learning community. Educators should develop an SDL culture in learning environments where (1) it increases students' creativity, (2) it builds students' self-confidence (confident behaviour) – learners trust themselves and have a sense of control over their learning, (3) it increases students' learning outcomes, (4) it supports students to practise assertiveness, (5) it can contribute to student's progress, and (6) it supports students to achieve their learning goals (Brandt 2020; Claro & Loeb 2019; Gresham 2018).

That said, to promote an SDL culture in a learning environment, interactive learning opportunities should be afforded where students can learn from each other, feel connected, while being part of (belonging to) a supportive SDL culture (Jubraj 2009). Educators need to be seen as guides and supporters in learning environments who provide students with the necessary support and assistance when needed (Boelens et al. 2017; UNESCO 2017). Hence, a learning environment should be created that upholds a strong learning culture where both students and educators' expectations are respected, and students are aware of their role and function in the learning process (Hiemstra 2013; Lopes & Cunha 2017). Such learning environments can be created by encouraging educators to establish learning conditions and situations that enhance students' motivation to take ownership of their learning. Educators' expectations in the learning environment are essential to promote SDL, as 'students will respond positively to educators' enthusiasm, competence and their commitment toward SDL in the teaching and learning process' (Du Toit-Brits 2019:7–8). Educators can therefore motivate students to seek out SDL opportunities. Educators embracing an SDL culture in the learning environment allow students to take control of their learning, by establishing specific online fora in learning environments on learning management systems and podiums where students can discuss numerous focuses that can enable them to share their learning goals, learning needs, learning challenges and best practices and help peers (Banerjee 2013; Beach 2017; Cho et al. 2017). That said, adopting an SDL culture can decrease the educational restraints caused by traditional instruction (Tularam & Machisella 2018). This stance allows educators to shift from traditional instruction towards an SDL learning process that can adjust to students' numerous learning needs, designs and requests.

Capability to address students' needs

In our diverse world, it is not a coincidence that learning environments are equally as diverse. Students come with numerous social, emotional, cognitive, language and learning styles, community cultures (see ch. 1), learning interests and physical abilities (Acar 2014; Du Toit-Brits 2015). Educators need to afford each student the opportunity to thrive in a learning environment where there is an understanding of and support for diverse social, emotional, cognitive, language and learning styles. After all, effective learning environments originate from an understanding of the ways in which students learn. Learning environments cannot still operate as if all students and their learning needs are the same. Educators must gain an awareness of these disparities within students so that they can meet their learning needs in their learning contexts in order for all students to have success in their learning environments (whether in a school or a HEI) (Du Toit-Brits 2015; Vanslambrouck et al. 2018).

To address students' needs in learning environments, educators need to bear in mind prerequisites for student engagement and involvement, control, autonomy, constructed knowledge, skills and attitudes, determination and motivation. These are not supplementary to education, but they are fundamental for effective teaching and self-direction in learning. To promote SDL, an educator should react to students' needs through student-centred learning opportunities, creating an active and effective learning environment where students feel secure, confident, that they belong and that they have the freedom to take responsibility for their learning. Addressing students' needs ought to be underpinned by determination and reflection, which necessitates that learning is seen as an investment in their future (Brand-Gruwel et al. 2014; Gresham 2018). With an active learning approach in learning environments, students' motivation and determination to learn should be promoted, thus directing education on important information and materials, supporting students in their learning process, which will support students to apply what they have learned. When implementing SDL in learning environments, students are involved as 'partners' in the education process, giving them additional responsibility for learning. Educators' use of SDL to address students' learning needs can encourage student participation in learning activities, motivate higher-order reasoning, solve real-life problems and develop critical thinking. By so doing, students' motivation and determination to learn and their abilities and self-directedness can be enhanced.

Furthermore, it is necessary to meet students' needs in HE learning environments to support the development of their self-directedness and instil in them a positive and encouraging assertiveness towards self-direction in learning (Aşkin 2015; Boyer et al. 2015). To promote SDL in learning environments, educators can accommodate these fundamental needs so that students can take responsibility for, authority over and ownership of their learning (Knowles 1996; Lazowski & Hulleman 2016). In addition, students should be allowed to suggest their learning objectives and outcomes (Knowles 1978). Doing so will create a rationale for why the learning is taking place and will ensure that their learning experiences are 'fruitful and creative'. Revisiting learning objective(s) is also essential to check students' understanding to feel 'safe' and confident in the self-directed environment (Hausmann et al. 2009; Kolesovs & Melne 2017).

Creating a feeling of security

The learning environment can contribute to the promotion of SDL if it provides a 'safe' podium for students to freely voice their specific learning needs, which is necessary to thrive academically (Kolesovs & Melne 2017). Feeling 'safe' in such an environment goes beyond students' physical well-being; it is about listening to students' voices, making students feel free, supported and valued in their journey towards self-direction (Lopes & Cunha 2017). Therefore, in learning environments, it is essential that educators consider and uphold a positive SDL culture where students can feel 'safe', resulting in students saying, 'I feel safe, therefore, I can learn'. An essential requirement to promote SDL is to acknowledge the importance of the emotional part of SDL in the learning environment; it should be seen as the 'foundation of learning' (Spear & Mocker 1984). Students who feel 'safe' in their learning environment would develop confidence, motivation, determination and a sense of belonging, which are cornerstones for fostering self-direction in learning (Kolesovs & Melne 2017). For learning environments to promote SDL, educators must share 'power' with students by creating safe environments for rigorous learning and identifying it as an essential SDL condition (Morrison & Premkumar 2014; Sale 2018). 'Feeling safe' and its role in SDL should be encompassed in learning environments where students are facilitated and encouraged to be self-directed. In this regard, Schutz and Lanchart (2002) explained the following:

> [/]n the 2000s, researchers interested in teaching, learning, and motivational transactions within the classroom context can no longer ignore emotional issues. Emotions are intimately involved in virtually every aspect of the teaching and learning process and, therefore, an understanding of the nature of emotions within the school context is essential. (p. 67)

In addition to the above citation of Schultz and Lanchart, I would like to suggest that the emotion of 'feeling safe' also be included in all kinds of learning and learning environments, including HEIs. I hope that this section inspires more research on the vital role of emotion in SDL.

A sense of belonging

Learning environments should have an effective and active learning platform based on self-direction that can inaugurate collaborations and encourage an SDL culture with collaborative learning for SDL promotion. Educators need to maintain positive relations with students, thus ensuring that there are strong relationships between them. By so doing, trust and confidence can be established among students and between students and the educator (Hausmann et al. 2009). This argument is a cornerstone for promoting and encouraging a sense of belonging in the learning environment. A learning environment that promotes SDL instils a sense of belonging in students (Allen et al. 2018). Students' need to belong is essential to learning in all learning environments (Thomas, Herbert & Teras 2014; Whitten, James & Roberts 2017).

Belongingness is a basic human motivation, urging an individual (student) to think, learn, act and strive (Hausmann et al. 2009; Kolesovs & Melne 2017). Self-directed capability is an essential element for students to find their feet in active SDL environments (Boyer et al. 2015). Certain factors influence students' self-directedness. These factors include, but are not limited to, self-esteem, self-motivation and locus of control. In the literature (cf. Chapman et al. 2013; Hausmann et al. 2009; Kolesovs & Melne 2017), a sense of belonging(ness) is described as students feeling safe, accepted, valued and respected as participants of a learning community within a learning environment. Students need to feel connected to a learning community with a sense of self-efficacy in the learning environment. In *Adler's theory of belongingness*, Crandall (1981) stated that, when students have a sense of belonging, they will have a higher 'sense of worth', improved self-confidence and self-determination, willing to take responsibility, be more motivated and have better learning expectations. Conversely, it is also true that if students do not have a sense of belonging, they will feel demotivated with little or no sense of control over and autonomy in the learning process and learning environment.

This chapter proposes that a sense of belonging in learning environments can influence and embolden SDL in learning communities. Belongingness in learning environments can promote SDL skills, resulting in students developing into autonomous, self-esteem, open-minded lifelong 'owners of learning'. Similarly, students should be confidently and personally involved in the learning process and be ready and willing to take ownership (thus be 'owners') of their learning. For students to be 'owners' of their learning (student agency), a sense of belonging is, therefore, a crucial factor (Kolesovs & Melne 2017). Having a sense of belonging in HEIs necessitates that students be involved in the planning of ownership. They must be regarded as planners, teachers, professional development partners and decision-makers. For students to belong, they must also find personal value and freedom in pursuing learning, and they must understand how knowledge is valuable (Martinez-Callaghan & Gill-Lacruz 2017). Building students' ownership is a characteristic that should be encouraged by educators. Educators should focus on giving students the freedom of choice regarding compiling their learning goals, learning activities, the seeking and using of learning resources, and the use of self-assessment in their learning. By so doing, students would be encouraged to use their voice in their learning and to feel that they belong to a specific self-directed community (Chapman et al. 2013). Therefore, to support students to grow and mature in taking ownership of their learning, self-directed communities must be established and SDL activities in learning environments must be created to embolden belongingness, thus allowing students' voices to be heard (Strayhorn 2012; Thomas et al. 2014; Whitten et al. 2017; Yilmaz 2016). To conclude, a sense of belongingness is a necessity for SDL. Belongingness can affect SDL, and the need for belongingness can improve students' self-directedness.

Active instructional procedures and learning resources

Introducing a learning environment with active instructional procedures is a concern of numerous educators. A learning environment that promotes SDL should supply facilities and assist with programs on learning strategies, courses on SDL and workshops on 21st-century skills to support students in finding learning resources (Busljeta 2013; Hiemstra 2013; UNESCO 2014a, 2014b). Additionally, in the learning environment, provision must be made for learning opportunities so that students can connect and obtain the support that can enable SDL (Wanda 2014). Doing so includes accessibility of technical aid to support students when they experience technical problems and guidance on how to adjust to being more self-directed in learning.

To provide more assistance to students in active instructional procedures and learning resources, educators should provide a flexible module structure[2] to assist students during the learning process and adequately meet their diverse learning needs (Ruys, Van Keer & Aelterman 2012; Sulistyoningsih 2020). The generation of personal links to the instructional procedures and learning material can occur with the possibility of increasing students' motivation to learn. Educators must consider student individualities when providing a flexible module layout and structure. According to the module layout and structure, educators must plan the SDL experience to empower students to determine, assess and adapt their learning needs (Hiemstra 2013). To create a learning environment that promotes SDL, educators must further

2. This refers to a structure in which students can give their input according to their specific learning needs.

let students determine their SDL skills so that they have more flexibility and direction in learning activities (Tan 2017).

Moreover, educators should cultivate collaboration between students through cooperative learning, PBL, project-based learning, adaptive prompts to facilitate metacognitive regulation and self-directed multimodal learning. Active instructional procedures refer to a comprehensive variety of instructional procedures that involve students as active, vigorous contributors in the learning process, with their educator as facilitator (Sulistyoningsih 2020). Typically, active instructional approaches involve students working both collaboratively and individually. They vary from brief learning activities (e.g. journal writing, problem-solving and group debates) to lengthier, complex learning activities (e.g. case studies and structured team-based teaching and learning). Educators should use active learning strategies and learning tools to empower and encourage self-direction in learning by putting students at the centre of the learning process.

The role of active learning strategies and activities in learning environments is essential for promoting SDL (Anderson, Fukuda & Anderson 2005; Sulistyoningsih 2020). Active learning strategies[3] need to be implemented in learning environments to encourage, stimulate and support more discourse, an enhanced understanding of the learning material and activities, that will require students to apply higher-order thinking skills (analysis, synthesis and evaluation) (Donker et al. 2014; Sulistyoningsih 2020). Active learning strategies should empower students with SDL skills fundamental to the learning environment that wants to promote SDL (Brockett & Hiemstra 1991). Furthermore, it is imperative that active learning strategies and activities highlight self-direction in learning for students and assess student attainment through a 'set of learning objectives' (Donker et al. 2014; Sulistyoningsih 2020). Active learning strategies and activities in the learning environment should permit students to learn at their own pace, consistent with student learning goals, circumstances and individualities (Hiemstra 2013). However, an effective learning environment is determined not by implementing several learning resources but by an educator to inspire students to acquire new knowledge, SDL skills, positive values and attitudes.

Educators' skills and role

The learning environment can contribute to the promotion of SDL if it brings about transformation of students' and educators' roles, tasks, skills and attitudes. Educators no longer have to be responsible for delivering learning

3. That is, case studies, portfolio development, independent study, cognitive organisers, issue-based inquiry, literature response, 'think-pair-share', thinking aloud, peer-review, round tables, debates, concept mapping and reflection to name a few.

content to students, but they should guide and support students to discover and experience the correct learning content, identify their learning needs and set their learning goals (Brockett & Hiemstra 1991; Hiemstra 2013). Each student's learning process can differ when it comes to timing, approaches, use of learning resources, learning needs and learning goals (Thomas 2018). The role of educators is, as a result, not merely altering but also highly challenging, as they should keep up with diverse learning needs (Sale 2018). This demand relates not only to time but also to the flexibility of educators who must allow for and support various means of working of students (Tomberg et al. 2013).

Educators must be competent and willing to develop learning environments that foster SDL (Brockett 1994; Brookfield 1990, 1993; Hiemstra 2013; Gresham 2018) by creating stimulating and active learning environments through optimal teaching–learning strategies. Students can be best facilitated through a personalised process to assist them to accept responsibility for and authority over their learning, thus assisting students to be more self-directed and academically inquisitive (Lopes & Cunha 2017). This highlights educators' role and responsibility to develop learning environments to promote SDL, and therefore, educators should be self-directed themselves (Grow 1991; Hairon & Chai 2017; Hiemstra 2013). In essence, in learning environments where educators use SDL skills, students tend to participate more in SDL behaviours (Alfalah 2015; Brandt 2020). Therefore, educators are encouraged to promote SDL behaviours and skills by giving students learning possibilities to take responsibility for their own learning, do self-assessments and contribute to designing their learning environments. However, educators need to understand the attributes of a self-directed student (individual), namely, student motivation, goal orientation, self-efficacy, locus of control, self-regulation, self-management, and self-monitoring and reflection (Aşkin 2015). These attributes offer a structure to help students be aware of themselves as students and develop their self-awareness as self-directed students.

Because of educators' altered roles and responsibilities in learning environments that promote SDL, learning tasks must be reformulated. Providing students with knowledge is part of educators' traditional role but loses significance and meaning within learning environments that aim to promote SDL. In learning environments that aim to promote SDL, the following roles and responsibilities of educators are more established (Claro & Loeb 2019):

1. administration and organisation of the learning environment
2. interrelating diverse students with comparable learning needs
3. stimulating students to communicate, interact, cooperate and have self-control
4. facilitating and helping students with self-assessment
5. facilitating and helping students with learning tasks.

To accomplish these roles and responsibilities, educators should (Francom 2010):

1. understand their new role and responsibility as SDL coach, mediator, facilitator, coordinator and enthusiast
2. be the liaison between educator and student on equal grounds in the learning process
3. have clear expectations for each student
4. be able to collaborate with students
5. be able to foster and nurture the growth of students to be self-directed and support them with self-responsible learning
6. to become accustomed to new active teaching–learning strategies for students
7. show an interest in the personality of students.

To conclude, educators should share the control and ownership of teaching and learning with students. Thus, educators should not make decisions in the learning environment; instead, they should assist students in making their own decisions and drawing their conclusions. In this section, it was proposed that educators need to initiate the change from traditional teaching and learning to SDL, thus taking stewardship of promoting SDL in learning environments.

Collaborative learning to enhance self-directed learning

Collaborative learning entails students getting together to construct knowledge and understanding to accomplish a collective objective to enhance SDL. De Laat and Simons (2002) suggested the following in this regard:

> The accelerating developments in our society make it necessary, but not sufficient, to have excellent groups of individuals in a workforce ... people need to be able to work together in solving problems and innovating more accurately and more quickly. (p. 15)

According to Chang (2006), collaborative learning is an instructive method where students function collaboratively and are self-directed to elucidate a problem, complete a learning task and create meaningful learning. Collaborative learning can improve and support student academic attainment in the learning environment (Duckworth et al. 2019), and it can be deemed an essential instrument within the learning environment that supports students' SDL abilities. Abubakar and Arshad (2015) encouraged SDL and collaborative learning in learning environments because they can be successfully combined to cultivate and improve learning. When students participate in joint learning exercises, their 'group work learning' and 'self-learning' are enhanced if instructors can support students in developing practical skills (Fung & Lui 2016).

It must be acknowledged that a collaborative approach in learning is essential, as it supports and empowers students to acquire higher-order thinking abilities that may influence on their learning outcomes.

When implementing collaborative learning in the learning environment to promote SDL, students need to be vigorous contributors to learning. Knowledge is, therefore, not transferred to students; it develops and materialises from vigorous discourse and interaction between those students who want to understand and apply learning concepts and methods (Le, Janssen & Wubbels 2018; Lee et al. 2014). Moreover, to attain effectiveness in collaborative learning in learning environments to promote SDL, group and individual goals and group and individual responsibility should be well-defined (Chang 2006; Lench, Fukuda & Anderson 2015). The facilitator's role is also necessary to attain effectiveness in collaborative learning, and learning must focus on student-centred learning activities rather than being educator engrossed. Students must also be actively involved in learning by helping one another in the learning process rather than looking for answers and explanations from the educator (Ruys et al. 2012). Lastly, collaborative learning is an essential and constructive instrument in the learning environment.

Engagement through communication and interaction

Learning environments can also contribute to the promotion of SDL employing engagement through communication and interaction (Chang 2006; Hiemstra 2013). In education, engagement is about the amount of responsiveness, inquisitiveness, interest, confidence and passion that students demonstrate while learning, which influence their responsibility, involvement, participation and level of motivation to learn (Wang & Eccles 2012).

Learning environments that focus on promoting SDL would empower students to interconnect and communicate with peers and educators. Such learning environments would allow students to develop skills like problem-solving, critical thinking, conflict resolution, self-control and communication, to mention but a few (Umbach & Wawrzynski 2005). Through communication and engagement in learning environments, students are enabled through learning opportunities to identify (1) their learning needs, (2) express their feelings, (3) engage and participate in the planning for their module outcomes and assessment, and (4) identify personal and group goals (Komarraju, Musulkin & Bhattacharya 2010). Through open and respectful communication, students are allowed to make their voices and opinions heard. A learning environment with communication and engagement can thus be considered a 'connected' learning environment that is collective, interconnected and dependable (Komarraju et al. 2010) and supports and promotes a 'productive' SDL experience.

Students often learn successfully when they cooperate and interact with each other and with educators. 'Student–to–student', 'student–to–educator' and 'student–to–content' communication and interaction are vital components of the learning environment to promote self-direction in learning (Chang 2006). Irrespective of the learning media used, HEIs and educators must facilitate appropriate learning engagement and communication opportunities. Research by Garrison (1997, 2003), Moore et al. (2011) and Song and Hill (2007) highlights three different interactions,[4] namely, 'learner–instructor, learner–learner and learner–content interaction'. The fourth kind of interaction identified resembles learner–interface interaction (Hillman, Willis & Gunawardena 1994; Lasfeto 2020).

Interaction and engagement in the learning environment provide communication and critical discussions, which are essential for learning environments to promote SDL (Chang 2006; Hiemstra 2013; Lasfeto 2020). Interaction and engagement help students to better their capability to self-manage their learning. It is significant to increase the interaction and engagement between students, learning resources and educators in an SDL environment so that the necessary support can be provided to students in order for them to take control of their learning. Students can cultivate critical thinking skills and reflect on learning content by interacting. Interaction pays an essential role in promoting SDL in learning environments and educators and students' willingness to engage in SDL (Komarraju et al. 2010). Interaction is thus fundamental to increase the mastery of skills and knowledge needed for SDL in learning environments.

Support

Student support contributes to the promotion of SDL in the learning environment. Support entails what the educator can or should do to support students over and above the formal facilitation of learning content and SDL skills development. Student support has various purposes; however, this is not the focus of this chapter. In this chapter, the emphasis is on showing why support is a necessary element of the learning environment to promote SDL.

All students can be self-directed by nature (Brandt 2020; Fahnoe & Mishra 2013) but they may have distinct learning needs. Thus, educators are responsible for assisting students in their learning by supporting them to determine their learning needs while still acknowledging the significance, role and responsibility of students to decide what they wish and need to learn. Students need support in learning the skills required to implement self-direction in learning effectively. However, creating learning opportunities for

4. Because of the focus of this chapter, I only mention the different interactions that are needed in a learning environment.

student control is more critical than the content to be learned (Hiemstra 1991; Pane et al. 2018). Drawing on the work of Brockett and Hiemstra (1991), Brookfield (1990, 1993), Hiemstra (2013) and Knowles (1969, 1975, 1984), the general approach of self-direction in learning must be geared towards establishing a self-directed climate and culture in which students can take control of and authority over what and how they learn.

Students differ immensely in their need for support in SDL. Higher education students can be self-managed, self-monitored, autonomous students, recognising what they need to learn and how best to do this (Charungkaittikul 2017). In contrast, students may lack SDL skills and may lack self-confidence, self-management, self-monitoring and motivation in their learning. The latter students would require more support to succeed in SDL. That said, most students are uncertain of the expected learning standards, which necessitates educators to be transparent about their progress. Students should be given a chance to (1) control what they wish to learn, (2) grow and develop in self-direction, (3) embark on self-direction in learning, (4) determine the pace and efficiency of their self-direction in learning, and (5) govern how they would assess, determine and show their learning attainment and growth in their learning goals (Brandt 2020; Pane et al. 2018).

Students need to outline their learning goals, and they need to be supported and encouraged (by an educator) to think about and reflect on their learning strategies to support their growth to be self-directed in their learning (Charungkaittikul 2017). Research also shows that educator support is linked to student learning success (Brockett 1994; Brookfield 1990; Hiemstra 2013; Knowles 1975, 2013; Tough 1971).

Higher education institutions do not always comprehend that students need the support to develop into independent self-directed students. Students need to be supported in their journey towards self-directedness if they are not self-directed in their learning. It must also be noted that an educator needs to provide support to students in order for them to grow in their self-directedness (Hairon & Chai 2017). Furthermore, student support requires self-directed educators with in-depth SDL knowledge. The need for student support cannot just be wished away, and the importance of student support for student success is not consistently recognised. However, HEIs comprise diverse student populations, and educators must deal with students who need support (Fahnoe & Mishra 2013). Lastly, establishing a supportive relationship (connectedness) with students is one of the best forms of support that can be provided (Klem & Connell 2004) in learning environments to promote SDL.

To conclude, in this section, the elements that contribute to the promotion of SDL in the learning environment were elucidated. These elements must be purposely conveyed in a learning environment. Self-direction in the learning environment relies significantly on these elements: knowledge, proficiency, trustworthiness, authority, motivation and trust between the self-directed educator and students (Hagen & Park 2016). The challenge is to convey these elements in learning environments in which there are enthusiasm, willingness and preparedness for SDL (Lasfeto 2020). Consequently, learning in HEIs should be deep and lasting and should guide and accelerate students' development from dependence to self-direction and independence in their learning. However, problems could arise when a one-size-fits-all tactic, which does not acclimatise to each student's need to develop into a self-directed individual, is implemented in the learning environment. Therefore, HEIs should design learning environments that contribute to the promotion of SDL. As seen from the above discussion, outlining prerequisites supporting HE learning environments is essential to promote SDL.

■ Conclusion

This chapter discussed elements of the learning environment that can contribute to the promotion of SDL. These elements can be seen as prerequisites for HE learning environments to promote SDL. Higher education institutions that are truly dedicated and committed to providing active instruction need to enhance and promote SDL in their learning environments. Self-directed learning can be promoted in learning environments by (1) embracing an SDL culture, (2) addressing students' needs, (3) making students and educators feel secure, (4) fostering a sense of belonging, (5) employing active teaching–learning strategies and activities, (6) supporting educators' skills and roles, (7) focusing on collaboration, (8) providing opportunities for engagement and connectedness, and (9) providing continuous support. It is proposed that innovative, dependable learning environments with a socio-constructivist-inspired understanding of learning be created in HEIs where the relationship between educators and students needs to be bidirectional in order for students to have the freedom to take ownership of the learning process.

Chapter 3

Diluted self-directed multimodal learning guidelines: Probing online study advice in the context of panic pedagogy

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Abstract

In this chapter, online study advice regarding the shift from face-to-face to multimodal learning was investigated in terms of the requirements related to self-directed multimodal learning. This publicly posted advice comes within a broader worldwide shift to a multimodal mode of delivery because of restrictions in terms of the COVID-19 pandemic. In the context of this research, multimodal learning involved learning online that would also include different modes of communication. Consequently, the theoretical background of

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multimodality is highly relevant to this chapter. This chapter also probed the scholarship around SDL. This qualitative study involved textual analysis of specifically selected online texts that provided guidance towards creating multimodal learning environments. The data analysis of the corpus collected for this chapter was done employing thematic content analysis. The content analysis informed a description of the trends of the online study advice and allowed for the advice in terms of self-directed multimodal learning to be evaluated. From the analysis, it was evident that the online study advice corresponded broadly with the relevant scholarship and showed evidence of reification and support of many principles associated with self-directed multimodal learning.

■ Introduction

The context of the so-called panic pedagogy or panic-gogy (Carver 2020), which is prevalent worldwide because of the COVID-19 pandemic, has had a significant effect on learning through technology. Furthermore, this situation has given rise to some individuals and institutions posting guidelines or advice online towards supporting the transition from face-to-face to online learning. In this context as Lee and Mori (2020:1) observed, 'many students have mastered how to be taught, but rarely learned how to learn' and we now enter a time where students can potentially master how to be taught online, but still not learn regardless of the mode of learning delivery.

Even before this pandemic, providing and looking for advice online has become an increasingly common phenomenon (Wingate et al. 2020), and the sudden transition to a multimodal learning environment has also led to a proliferation of online advice for teachers. The word 'teacher' is used in this chapter as a synonym for lecturers although in some instances in the context of the analysed texts parents can also fulfil this role. In this context, experts and online communities go through a process of reification (cf. Introne & Goggins 2019) or simplification to then provide succinct guidelines for online publication. This research focused on whether such guidelines adhered to the basic principles associated with the theoretical foundations of 'multimodal learning' (Bezemer & Kress 2016; Canale 2019; Jewitt 2013; Olivier 2020a, 2020b; Wentzel & Jacobs 2004) and 'SDL' (Bosch, Mentz & Goede 2019; Brockett & Hiemstra 2019; Gibbons 2002; Knowles 1975; Mentz et al. 2018; Zhu, Bonk & Doo 2020). Furthermore, this chapter links up with scholarship focused on online public advice (cf. Sillence & Briggs 2007; Zaman et al. 2020).

In this chapter, the concept of 'self-directed multimodal learning' (SDML) is probed in terms of the identified online sources. The concept of SDML refers specifically to a pedagogical approach that aims at fostering self-directedness by accommodating the individual student modal preferences, supporting communication for learning through various modalities as well as the blending of the learning, teaching and delivery processes through different modalities (Olivier 2020a, 2020b).

Problem statement

The identified problem investigated within this chapter is how elements of SDML are realised or diluted (or not) within selected online advice texts that focus on the shift from face-to-face to online learning.

Central to this research is the fact that '[t]o help students become independent in their learning, teachers need to consider how to improve SDL competencies of learners' (Lee & Mori 2020:3). Moreover, the context of this research is described by Carver (2020) as follows:

> The idea of being able to just take what you have been doing in a face to face classroom and dropping it into an online course shell has its own problems. But attempting this transition in the midst of a pandemic creates other problems. (p. 134)

The exceptional circumstances of the COVID-19 pandemic make online information very relevant and its accuracy is important. However, the reliability of information in general and, especially, online has been questioned already in the past, especially within the current milieu of the 'post-truth world' (Mackey 2019:2). In this regard, Mackey (2019:1) noted that 'during a time when truth is seen as mutable', consumers of knowledge should have 'an unwavering commitment to the responsible and ethical participation in social networks and the critical reflection on how information is produced, shared, and consumed'. Drawing from this approach to information, in this chapter the nature of online study advice about the shift from face-to-face to multimodal learning has to be explored, especially regarding its adherence to requirements related to multimodal and SDL. The research question posed for this chapter is as follows: How are elements of SDML realised within selected online advice texts that focus on the shift from face-to-face to online learning?

Literature review

Reductionism and online advice

The concept of reductionism is pertinent to online advice when contextually related to a move from more traditional face-to-face learning and teaching towards multimodal learning and within an SDML context where SDL is the target.

Reductionism has long been relevant in the education context. The term is notably used in different contexts and also in reference to various phenomena

(Dupré 2000). In this chapter, *reductionism* refers to extracting and reducing information. For Dupré (2000:402), within the context of the philosophy of science, reductionism refers to 'the thesis that all scientific truth should ultimately be explicable, in principle at least, by appeal to fundamental laws governing the behaviour of microphysical particles'. Reductionism has been applied in different fields and contexts. In this regard, El-Sakran (2019) explored textual reductionism through shortening research articles to posters. Similarly, broad pedagogical concepts are reduced in the creation of online advice texts.

The concept of *advice* is understood as 'suggestions and recommendations with regard to future action' (Lindholm 2019:8). On a linguistic level, advice can be approached in terms of speech acts where it can be considered a directive or request (Lindholm 2019). In this chapter, advice is considered in online texts where the content is described as practical tips, guidelines, considerations or principles.

As stated before, the focus was specifically on online advice. Feng, Zhu and Malloch (2018:364) defined *online advice* 'as recommendations about what to do, think, or feel to cope with a situation faced by an individual or small group' which is also 'a form of supportive communication' and which has been 'a sought or provided through the Internet'. However, Briggs et al. (2002:331) crucially observed that '[t]he Internet is already exerting a huge influence on society, and there are few regulatory bodies to monitor the accuracy of online content'. According to Feng et al. (2018), support is exchanged through discussion fora, social networking websites and other platforms. However, most of the texts used in the corpus researched in this chapter were published on websites and not taken from social networking sites.

Despite limited publications on the nature of online study advice regarding SDML, some research has been conducted on online advice in other fields. This research includes work regarding advice on digital media use (Zaman et al. 2020), online advice for mothers and expecting mothers (Lindholm 2019), mental illness (Brookes & Harvey 2016), health support (Introne & Goggins 2019) as well as health and financial advice (Sillence & Briggs 2007). However, some of the literature regarding online advice focuses more on some form of individualised therapeutic or curative advice (cf. Feng et al. 2018; Wingate et al. 2020), while the focus in this chapter is more on a generic, one-way type of advice posted online. It is common for research on advice to focus on medical and health-related issues; however, there has also been research conducted in educational contexts (Lindholm 2019).

Despite most early research on advice being conducted in face-to-face settings, it is clear that this type of research is also increasingly being done in online contexts (Lindholm 2019). The effect of online study advice is relevant to this research. In this regard, Briggs et al. (2002) noted that people are increasingly influenced by online advice and that source credibility, personalisation, as well as predictability are instrumental in whether the advice would be followed or not. Online advice also varies between expert advice that can be requested to static information published online (Lindholm 2019; Sillence & Briggs 2007). The data used in this chapter pertain to the latter type of online advice.

Multimodal learning

For the sake of this chapter, multimodal learning is understood mainly in terms of the levels of individual, interactional and instructional multimodality (Olivier 2020a). The focus here is on learning that takes place through the use of online modalities. Furthermore, the chapter draws on the principles underpinning multimodality (Bezemer & Kress 2016; Canale 2019; Jewitt, Bezemer & O'Halloran 2016; Kress 2010) and online learning (Cope & Kalantzis 2017; Garrison 2017; Moreno & Mayer 2007; Picciano 2019). The focus of multimodal learning is not just on how technology is integrated into the learning process but also on the semantic and semiotic resources employed in the process.

Increased use of technology in the wider education context has consequently led to more opportunities for multimodal learning. Garrison (2017:1) observed that '[r]ethinking conventional education in light of technological developments and the need for higher-order educational outcomes is shaking the foundation of the educational enterprise'. However, in a sudden move to online learning, as was the case with COVID-19, differences between face-to-face and online learning were emphasised, and this situation made the option of using blended learning obsolete for a while. In harking back to Garrison's remark above, the educational foundations have not just been shaken, but irrevocably changed – possibly even changed forever. Hence, taking a snapshot of the online study advice at this time provides an insight into how experts and, to a lesser extent, popular writers regard the way this transition should have taken place. Nevertheless, through this process, the multimodal nature of learning became more prominent.

The level of individual multimodality (Olivier 2020a, 2020b) also seems highly relevant in online learning contexts. In support of this view, Kizilcec, Bailenson and Gomez (2015:737) found in their research regarding instructional videos that their 'findings highlight learning preference as a critical individual difference to consider in the design of multimedia instruction'. This level of multimodality also alludes to the importance of differentiated, individualised and possibly even adapted approaches for consideration within an online environment. However, such approaches would firstly rely on sophisticated learning environments and learning management systems and secondly require sufficient data collected from students throughout the process followed up by pedagogically driven analytics.

Regarding interactional multimodality, modes of communication also pertain to online learning. Despite the affordances of using different modes of communication in learning through attending to different learner preferences, it is essential to consider cognitive load. Therefore, the learner is dependent on the intrinsic, extraneous and germane cognitive load not exceeding a student's working memory resources (Kizilcec et al. 2015; Sweller, Van Merriënboer & Paas 2019).

Finally, in terms of instructional multimodality, the blending of face-to-face and online learning has increasingly become a feature of HE. However, in this chapter, the focus is specifically on online learning. The online learning environment is also multimodal in nature as different modes of communication are combined within learning management systems. Multimodal learning is furthermore combined within the concept of SDML in this chapter, and SDL as a construct is thus also considered.

Self-directed learning

The approach to SDL in this chapter ties in with the extensive scholarship on this phenomenon (Bosch et al. 2019; Brockett & Hiemstra 2019; Gibbons 2002; Knowles 1975; Mentz et al. 2018). For Gibbons (2002), SDL involved:

> [*A*]ny increase in knowledge, skill, accomplishment, or personal development that an individual selects and brings about by his or her own efforts using any method in any circumstances at any time. (p. 2)

This definition not only emphasises both knowledge and skill but also makes the personal aspirational aspect prominent. Furthermore, as with the classical definition by Knowles (1975), for Gibbons, SDL is a process through which an individual takes charge and determines how it is conducted. Prevalently, Merriam and Bierema (2014) described SDL as being a process and a personal attribute as follows:

> SDL as a personal attribute refers to an individual predisposition toward this type of learning, and comfort with autonomy in the learning process. SDL as a process is an approach to learning that is controlled by the learner. (p. 63)

In this context, the attribute and the process are relevant to the discussion as these aspects also informed the analysis of the online study advice.

Methodology

Research design and paradigm

This qualitative research, which was conducted within an interpretivist paradigm (Tracy 2020:51), explored public online study advice regarding SDML. This research demonstrated a basic qualitative study (Merriam 2009). The type of textual analysis, conducted in this chapter, is also commonly used in similar qualitative studies (Tracy 2020).

Sampling

This research involved purposive sampling of publicly available online study advice regarding multimodal learning as posted online from the period of January to October 2020 by various institutions and individuals. This period was specifically selected to coincide with an increase of such posts related to a worldwide move to online delivery modes of learning because of the COVID-19 pandemic.

To inform the data collection process, the inclusion criteria employed on a search engine included: (1) openly published webpages, (2) from the period noted above, (3) written in English, and (4) with a thematic focus on providing tips or advice for online learning and transitions to this mode of delivery. After a wide search, the number of identified texts was reduced, through the addition of additional keywords limiting the search to online advice related to COVID-19 and multimodal contexts, from 176 to the 12 sources that were ultimately chosen for this research based on them adhering to the inclusion criteria, being text-based and substantial enough for linguistic and content analysis. The selected documents were copied into text documents for the aim of analysis.

Data collection

A process of searching, screening and data analysis was followed, much along the same vein as the online research by Zaman et al. (2020). In approaching the stated online study advice or guidelines, this research was done within the context of metaliteracy; the researcher thus assumed the role of a metaliterate researcher who 'is a critical consumer of information, continuously developing effective questions, verifying sources of information including authorship, and always challenging his or her own biases through metacognitive thinking' (Mackey 2019:1).

The advantages and challenges regarding research with online documents have been clearly described by Merriam (2009). In addition, it is evident from this source that limiting research to online texts excludes certain views and allows for certain biases in terms of the search mechanism to be employed. Most of the sources consulted were labelled as advice guides or articles, although some were institutionally created support documents.

In Table 3.1, the corpus is summarised in terms of the abbreviations used in this chapter, the bibliographical references, types of sources as well as the number of words.

Data analysis

The first level of analysis focused on meaning by exploring the nature of the content in the identified texts and the semantic value of online study advice regarding SDML within the corpus. Finally, the content itself was then analysed inductively (cf. Merriam 2009) in terms of how the subject matter agreed, diverged or extended related aspects from the scholarship on multimodal learning and SDL. Trustworthiness was ensured through detailed description of the data collection and analysis processes that were followed and the use of two iterations of analysis by the researcher.

Research ethics

Various online sources were considered for this study; however, for the sake of research ethics, only documents that were openly published on websites were considered. Moreover, for the sake of privacy and confidentiality, no texts were taken from social media or any comments added to websites by users (in cases where comments were possible) were considered or even copied in

TABLE 3.1: Summary of the corpus.

OAS	Bibliographical reference	Type	Words
OAS1	UCT (2020)	University institutional advice	1052
OAS2	FutureLearn (2020)	General advice from an online course repository	1066
OAS3	The Conversation (2020)	General advice from an online news website	884
OAS4	ACS (2020)	General advice from an online company	1643
OAS5	Resilient Educator (2020)	Commercial teachers' resource website	453
OAS6	Gewin (2020)	Advice in an academic journal	1041
OAS7	UP (2020)	University institutional advice	2296
OAS8	UJ (2020)	University institutional advice	988
OAS9	OSU Center for Teaching and Learning (2020)	University institutional advice	1833
OAS10	Kapp (2020)	General advice from an individual on a professional social media website	2890
OAS11	Sandars et al. (2020)	General advice by a group published openly in a journal	5853
OAS12	Snelling and Fingal (2020)	General advice from two individuals on a professional organisation's website	2227

OAS, online advice source; UCT, University of Cape Town; UJ, University of Johannesburg; UP, University of Pretoria.

the raw analysis documents. As per national guidelines, as in this case '[r]esearch that relies exclusively on publicly available information or accessible through legislation or regulation usually need not undergo formal ethics review' (Department of Health 2015:8).

Importantly, Tracy (2020:115) observed that '[w]hen analyzing online data, it is important for researchers to carefully consider privacy policies and people's likely expectation for their work being used in research'. Consequently, this research focused only on openly published online study advice as a data source. Furthermore, throughout the process, research ethics requirements in terms of online content (cf. Whiteman 2012) were adhered to.

Results

From the analysis, it was evident that broadly the online study advice regarding SDML agreed with the relevant scholarship and showed evidence of reification. However, there were instances where such advice would be reductionist or focused on a specific context.

Some broad categories were also identified as some sources focused on general advice (OAS1, OAS3, OAS4, OAS5, OAS6, OAS7, OAS9, OAS10, OAS11 and OAS12), while others listed a number of specific resources or applications (OAS2) or even advice specific to an institution (OAS1, OAS7, OAS8 and OAS9). Some sources are also a bit more focused on a specific field, such as OAS11, which provides general advice but also elements specifically related to the medical context.

Initially, corpus linguistic software, AntConc 3.5.8, was employed to probe the texts in terms of word frequency. A summary of the top five lexical words related to the focus of this chapter is listed per source in Table 3.2. Proper nouns are excluded.

The words in the table are listed in order of frequency: from highest to lowest and the frequency presented in brackets after each word. The values have been normalised to 1000 words to make comparison possible.

The summary of the top five relevant lexical words per online advice source clearly shows the central role of students (or 'learner') in all the texts. However, this does not necessarily imply a student-centred approach. The terms 'online' and 'learning' are also prominent as these were key terms used in searching for the sources. However, from Table 3.2, it is also possible to determine the prominence of teachers (OAS2), parents (OAS2), videos (OAS3 and OAS10), teaching (OAS4), feedback (OAS5), assessment (OAS7 and OAS8) and interaction (OAS9). For a text specialising in a specific field, the term 'medical' (OAS11) was also prominent.

TABLE 3.2: Top five relevant lexical words per online advice source.

OAS	Top five lexical words relevant to the topic				
	1st	**2nd**	**3rd**	**4th**	**5th**
OAS1	Student(s) (24.7)	Learning (19)	Course (11.4)	Online (8.6)	Teaching (7.6)
OAS2	Teachers (17.8)	Students (15)	Online (14.1)	Parents (14.1)	Learning (12.2)
OAS3	Student(s) (28.3)	Online (18.1)	Learning (11.3)	Video(s) (11.3)	Teaching (7.9)
OAS4	Student(s) (25)	Teaching (12.8)	Content (7.3)	Learning (7.3)	Online (6.7)
OAS5	Students (17.7)	Online (8.8)	Time (8.8)	Class(es) (8.8)	Feedback (6.6)
OAS6	Student(s) (29.8)	Online (9.6)	Teaching (9.6)	Class (4.8)	Instructors (4.8)
OAS7	Student(s) (24.4)	Class(es) (10.9)	Online (10)	Data (6.5)	Assessment (6.1)
OAS8	Students (26.3)	Learning (19.2)	Module (13.2)	Online (13.2)	Assignments (8.3)
OAS9	Student(s) (44.7)	Course(s) (12.5)	Interaction(s) (12)	Content (10.4)	learning (9.8)
OAS10	Student(s) (10.7)	Online (8.7)	Instruction (6.9)	video(s) (5.9)	classroom (5.5)
OAS11	Online (13.7)	Learning (13.2)	Learner(s) (10.4)	Medical (8.5)	education (5.3)
OAS12	Student(s) (13)	Learning (13)	Online (12.6)	Parent(s) (9.4)	Teacher(s) (8.5)

OAS, online advice source.

An SDML scorecard, as shown in Table 3.3, was developed by the researcher, based on key sources on SDL and multimodal learning, and the analysed sources were measured against this scorecard.

From the SDML scorecard, most sources emphasise a relationship and environment conducive to learning. However, when it comes to specific elements of SDL, only selected sources overtly referred to relevant aspects. Furthermore, student-centredness, interaction, active and interactive learning were also quite prominent. Nearly, all the sources highlighted the importance of collaboration. Within the context of multimodal learning, the emphasis was on sources recommending the use of different modes of communication and the integration of different modes of delivery in instruction. However, apart

TABLE 3.3: Self-directed multimodal learning scorecard analysis.

Criteria	OAS1	OAS2	OAS3	OAS4	OAS5	OAS6	OAS7	OAS8	OAS9	OAS10	OAS11	OAS12
S1 Establish a learning-friendly relationship with learners	•	•			•	•		•		•		•
S2 Create an environment that is physically and psychologically comfortable	•	•	•	•			•	•		•	•	•
S3 Prompt interaction, discussion and cooperation			•			•	•			•	•	
S4 Let students take responsibility for their own learning needs			•			•					•	•
S5 Let students set goals						•					•	
S6 Let students choose human and other resources						•					•	
S7 Let students plan and implement learning				•							•	
S8 Let students evaluate learning processes and outcomes											•	
S9 Facilitate learning and not direct teaching												
S10 Student-centredness			•	•	•				•			
S11 Active and interactive learning	•		•	•					•			
S12 Prompt problem solving										•		
S13 The teacher acts as a resource												

Source: Brockett and Hiemstra (2019), Garrison (2017), Kasworm (1983), Knowles (1975), Lee and Mori (2020), Merriam and Bierema (2014), Olivier (2019b, 2020a, 2020b), and Tekkol and Demirel (2018).
OAS, online advice source.

Table 3.3 continues on the next page→

TABLE 3.3(Continues...): Self-directed multimodal learning scorecard analysis.

Criteria	OAS1	OAS2	OAS3	OAS4	OAS5	OAS6	OAS7	OAS8	OAS9	OAS10	OAS11	OAS12
S14 Provide resource repository								•				
S15 Teacher validates and evaluates												
S16 Promote critical thinking								•				
S17 Facilitate collaboration		•		•		•	•	•	•	•	•	
S18 Use real-world content and examples											•	
M1 Regard learning as communication												
M2 Individualise learning to individual modal preferences								•				
M3 Use different modes of communication				•	•	•		•		•	•	•
M4 Integrate various relevant technologies and modes of learning	•	•					•	•			•	•
M5 Consider different modes of delivery								•			•	•
M6 Promote metaliteracy and a critical approach to resources												•
M7 Let students actively create resources for learning									•	•	•	
M8 Maintaining a social, cognitive, and teaching presence			•	•		•				•		•
M9 Create opportunities for reflection									•		•	

Source: Brockett and Hiemstra (2019), Garrison (2017), Kasworm (1983), Knowles (1975), Lee and Mori (2020), Merriam and Bierema (2014), Olivier (2019b, 2020a, 2020b), and Tekkol and Demirel (2018).

OAS, online advice source.

from maintaining a social, cognitive and teaching presence, most other aspects related to multimodality were not present in most sources.

In the analysis, specific attention was also paid to principles of planning lessons for SDL as identified by Gibbons (2002:43–45) and how they were realised or not within the advice:

- Teach students the skills they need to take control of their learning activities.
- Shift the emphasis of the program from content to productivity.
- Introduce new practices in gradual gradients of complexity.
- Make new ideas familiar by connecting them to students' lives.
- Develop in students the attitudes necessary for success.
- Change from telling to asking and from lecturing to interaction.
- Launch the student on a hero's journey of discovery.

These principles generally resonate with content drawn from the online advice sources (OASs). Prompting students to take control of their learning is noted (OAS4, OAS5, OAS7 and OAS9) while supporting them to be able to do it (OAS10). The focus is shifted from the content to doing something in an incrementally complex way (OAS9). Linking new knowledge with prior knowledge (OAS9 and OAS11) and the real world (OAS11) is definitely supported by the sources. A shift in emphasis from teaching to learning in an active manner is also evident. Finally, placing students and their motivation and aspirations central to the learning process is key to online learning success according to the OASs (OAS1, OAS3, OAS4, OAS7 and OAS9).

Several broad themes were evident in the analysis, and they are briefly discussed below.

Accessibility

An important aspect is having access not just to the multimodal online environments but also to the resources themselves. This pertains to physical access (OAS12) and also to the type of document, graphics or video file used. Also, being able to print resources also relate to this aspect as in some cases, students might not have constant Internet access or have a preference for a resource in a printed medium. It was suggested in OAS8 that content be available not just online and that teachers are encouraged to '[p]resent materials (in PDF format) and activities (in Word format) in your module to enable students to download and work offline' (UJ 2020:1).

Relating to accessibility is also supporting students who might have problems accessing information and also coping within the new environment (OAS4). These issues also relate to a broader emphasis on no and low-tech environments.

No and low-tech approach

The literature supports the need for the so-called no or even low-tech approaches when moving to a multimodal environment (Carver 2020). The main reason for this approach is that there are, not only in South Africa but also globally, inequalities in terms of access to digital technologies (Carver 2020). A number of sources emphasised low-tech or other approaches that were not Internet data-usage intensive (OAS3, OAS7, OAS8 and OAS10).

Within this theme, the analysed sources highlighted that videos should be short (OAS3, OAS8 and OAS10) and can be accessed on phones (OAS3 and OAS7) and that transcriptions of video content be included (OAS8). In OAS8, it is suggested that teachers '[k]eep online learning design simple and not data intensive' (UJ 2020:1). In OAS7, the preference for low data solutions is expressly mentioned (UJ 2020):

> [*A*]ll lecturers will to some extent use in-video assessment or YouTube links. If a low data solution, eg [*sic*] PDF file or Discussion Board, will assist the students in reaching the module outcomes, consider using these options instead. (p. 3)

Consequently, teachers should ensure accessible content on different mobile devices and not just computers.

In terms of video length, most sources just indicated they are short. However, in OAS8, specific maximum duration guidelines are provided (UJ 2020):

- Recorded lectures: 3–5 min.
- Virtual sessions: a maximum of 6 min.
- Voice-over PowerPoints of under 5 min.

Despite the useful guidelines, this specific document seems to contradict itself with some overlap and conflicting guidelines such as the indication that initially information should be limited and be manageable versus the recommendation that as much material as possible be made available. However, the essence of keeping videos short seems to be clear and in line with the literature (cf. Olivier 2019a). Similarly, OAS10 also recommends limiting pre-recorded videos to 2-min – 6-min segments and emphasises the importance of good audio above video or images in terms of quality.

Technology should be in support of pedagogical goals and not be a goal in itself. In addition, the use of technology should also not become a barrier. To support these two statements, OAS8 proposes that teachers '[u]se technology with the purpose to support your teaching and your students' learning: the simpler, the better' (UJ 2020:2). The use of technology is determined by the structure and preceding process planning involved in multimodal learning.

Structure and planning

With a move towards multimodal learning, teachers are encouraged to implement a clear structure, divide content strategically and scaffold. What might be missing from the sources is that students should play an active role in planning learning as is required for SDML. In this regard, certain structural and planning aspects were evident in the corpus, as is shown in Table 3.4.

Outlines and expectations should be set out in a straightforward manner, and content should be made manageable in terms of volume and order. Furthermore, teachers are encouraged to regularly engage with students and also keep communication channels open by engaging with students and through bidirectional feedback. However, many multimodal aspects of SDML were apparent, as is shown below in terms of asynchronous and flipped classroom approaches.

It is suggested that learning should be asynchronous (OAS1, OAS3, OAS4, OAS6 and OAS8), although in at least one source (OAS11) synchronous online discussions and also asynchronous online tutorials are preferred. Although practical, an asynchronous approach can be detrimental in terms of the immediacy, active and collaborative nature of the learning taking place. However, it is apparent from the literature that both asynchronous and synchronous learning have different advantages and contexts where they are most appropriate (Hrastinski 2008; Ogbonna, Ibezim & Obi 2019). In OAS6, it is also noted that teachers should not rely on live video as there might be technical challenges.

TABLE 3.4: Structure and planning trends per source.

Trend	Sources
Clear outline and expectations	OAS1, OAS5, OAS7, OAS8, OAS11, OAS12
Content broken down in smaller parts	OAS1, OAS3, OAS8, OAS11, OAS12
Structure through learning pathways	OAS1, OAS8
Scaffolding	OAS1, OAS4
Regular engagement	OAS1, OAS4, OAS6, OAS7, OAS9, OAS12
Interactive	OAS1, OAS3, OAS4, OAS9
Repetition in structure	OAS3, OAS10
Organise intuitively	OAS4
Multimodal content	OAS4, OAS7, OAS11
Use examples and demonstrations	OAS4, OAS5, OAS11
Frequent and effective feedback	OAS5, OAS6, OAS11, OAS12
Shorten lectures when transferring to video	OAS6, OAS8, OAS11
Flipped classroom approach	OAS7, OAS11
Add a frequently asked questions area	OAS7
Create curiosity	OAS10
Use a narrative	OAS10, OAS11
Employ social media	OAS11

OAS, online advice source.

As shown in Table 3.4, a flipped classroom approach is a recommended way to handle online classes. From the literature, it is clear that a flipped classroom approach, where traditional classroom activities in terms of content are conducted at home and homework or application is handled in the class, has advantages in terms of improving learning performance (Akçayır & Akçayır 2018; Strelan, Osborn & Palmer 2020). In this regard, OAS11 recommends (Sandars et al. 2020):

> [*A*] flipped classroom approach should be used with learning activities, such as reading a book chapter or journal articles or watching a video, before the online lecture and with interactive learner activities and opportunities to ask questions about the pre-learning during the lecture. (n.p.)

From the advice in the sources, it is evident that the online content should be structured so that it is easily navigable for students. To this end, in OAS8 it is urged that teachers structure their 'online module in a clear, logical way that will make it easy for students to navigate and find what they need to learn' and that a 'clear learning guide/path' is provided to students (UJ 2020:1). An essential aspect for both SDL and multimodal learning is resources.

Resources and reuse

The OASs provided little information regarding students' roles in resource selection. However, the multimodal nature of resources for online learning was evident. From the analysis, it emerged that content might need to be divided or grouped into smaller sections. In this regard, it is posed in OAS8 that teachers can '[d]ivide topics or themes into smaller, more manageable assessments or assignments that require less reading and research time online and more application and critical thinking skills' (UJ 2020:2).

The issue of reusing material can be associated with an open pedagogy approach and open educational resources (OER) (Olivier 2019a, 2020b). The analysed sources also supported the concept of reuse of resources (OAS1, OAS3 and OAS7). OAS11 references curation of open resources in terms of videos and also notes that for any student-created content (Sandars et al. 2020):

> [*I*]f the resource is of suitable quality and does not breach copyright, making it available as an open educational resource (OER) to benefit learners beyond the institution should be considered. (n.p.)

In OAS1, the following is noted: 'There is not much time to prepare. What resources from previous years can you reuse? What external resources are available?' (UCT 2020). OAS3 and OAS7 even stated that OERs be considered which would also be relevant for easy and free sharing.

However, what lacked from the sources in terms of SDML was recommendations regarding students selecting an appropriate resource.

The sources did not only refer to resources but also refer to the learning process and how it should be active.

Promoting active learning

Active learning is noted explicitly in OAS3 and OAS9. It is suggested that students can be encouraged to address specific issues or watch specific sections in videos prompted by teacher instructions (OAS3). For OAS9, '[s]tudent-content interaction is all about having students DO something with the course content or topic' (OSU Center for Teaching and Learning 2020). Hence, the emphasis is on students actively taking part in their own learning through doing which resonates with what is expected within SDML.

As within the context of OAS9, merely reading or listening, which implies receiving information passively, might not lead to students engaging and reaching outcomes, and consequently, active learning is recommended to be followed by some form of reflection. Such reflective practices have, according to the literature (Gencel & Saracaloglu 2018), the potential to support SDL and by implication SDML. In this regard, Lee and Mori (2020) found that reflective practice can be considered a significant predictor of students' competencies regarding SDL. In OAS11, reflection is also mentioned, and it is indicated that it starts with a so-called a moment of surprise (Sandars et al. 2020) which can be prompted by students lacking specific knowledge or skills and that such a process should be supported through teacher facilitation.

Prompting problem-solving is mentioned only to a lesser extent in the corpus of OASs. For example, in OAS10, teachers are advised to '[a]sk a thought provoking question' and '[c]reate curiosity and a compelling reason for watching the entire instructional recording' (Kapp 2020). The narrow association between SDL and problem-solving ability is also noted in the literature (Havenga et al. 2013; Kim & Shim 2018; Luo et al. 2019).

The social aspect of learning is also crucial to SDML as SDL does not imply learning in isolation (Brockett & Hiemstra 2019).

Establishing and maintaining a social presence

In SDML, social interaction is essential as, in terms of SDL, Knowles (1975:18) highlighted that students should be able to identify 'human and material resources for learning'. However, the perception exists that student independence would be at the cost of collaboration. From the sources, the importance of independent learning for students was also raised (OAS12).

Online technology opens more avenues for interaction between teachers and students, and within a sudden move to an online environment, it is clear that compensation is required for the social interaction associated with the face-to-face environment. But in the OASs, there were clear elements of reductionism of complex collaborative learning aspects.

Many of the sources promoted the idea that teachers need to check in with students and have continuous contact (OA2, OAS4, OAS6, OAS7, OAS8 and OAS12). It was further stated that obtaining continuous feedback from students can also inform practice (OAS4, OAS6, OAS7 and OAS8). Essentially, as is stated in OAS10, '[t]he human connection is key' (Kapp 2020), and this needs to be supported in an online context.

Teachers' concerns regarding engagement are worded as follows in OAS2: 'One of the biggest concerns for teachers is how they will continue to engage students and keep an eye on their progress from afar' (FutureLearn 2020). In response to such a concern, a practical recommendation made in OAS7 is that '[g]roup cohesion is enhanced by addressing students by name if you respond to a post, using inclusive pronouns such as we, us, our group and the use of salutations' (UP 2020:4). Another suggestion in OAS11 is that if a learning management system 'has an audience-response component, this can be used to increase learner engagement in the activities and to maximise the learning opportunity'; otherwise, questions can be posed directly (Sandars et al. 2020). In OAS10, it is proposed that questions are put to online classes to prompt conversation.

Furthermore, on a practical level, OAS1 makes the following recommendation: 'Use icebreakers, the discussion forum and chatroom where possible to give that feeling of connection' (UCT 2020). However, some sources indicated that direct teaching through online group communication should be avoided (OAS3); hence, this is also in support of a more student-centred approach as is relevant for SDML.

Establishing or maintaining social interaction between students and not only from the teacher is also important. In OAS6, the following recommendation is made: 'Make sure students support each other. Don't try to do everything yourself' (Gewin 2020). Within OAS9, these questions are posed (OSU Center for Teaching and Learning 2020):

> [*H*]ow will students work together to ensure that they feel like part of a learning community and have the opportunity to collaborate, think critically, be intellectually challenged, and make meaning with others? (p. 296)

and '[h]ow can students work with others while isolated in their homes?' (OSU Center for Teaching and Learning 2020). OAS9 also highlights the advantage of creating a learning community and engaging higher-order thinking through student–student interaction.

This collaboration, which is essential for SDML, also implies that different modes of communication and interaction, and consequently, the multimodal nature of online environments, are crucial. This was also evident from the analysed sources.

Different formats as well as modes of interaction and instruction

Because of connectivity and access issues, different formats and modes of delivery might be required for online classes and in order to support SDML. In essence, this aspect relates directly to the different aspects of SDML and the student needs thereby implied with individual multimodality.

Multimodality is also considered in the advice. Firstly, multimodality needs to be considered in terms of content. In this regard, in OAS1 the following is stated: 'Create multiple formats for learning materials' (UCT 2020). Within OAS7, it is recommended that teachers '[b]e present and available in different modes *during regular scheduled class time*' (UP 2020:3 [emphasis in the original]). Furthermore, in OAS11 it is stated that '[t]he use of multimedia ensures more efficient gains in knowledge and skills as information can be presented using combinations of several different media' (Sandars et al. 2020). Some sources stated that there is no single solution for all contexts (OAS2) and that the multimodal content, such as photographs or video, should relate to students' experiences (OAS11). Furthermore, the use of different appropriate tools is also advised (OAS12).

Secondly, multimodality is also regarded within the context of online communication. OAS8 also refers to different modes as it is noted that students should be informed about the 'delivery modalities' and the 'modes of communication' (UJ 2020:1). It is also declared in OAS11 that '[i]t is important to ensure that the communication is two-way so that learners have diverse avenues to seek advice and guidance' (Sandars et al. 2020).

As regards face-to-face mode of delivery versus an online mode, it is apparent that the amount of content needs to be reduced. So, it is suggested in OAS6 to keep the essence of a lecture and that '[i]nstructors need to identify a few specific things that they want their students to learn, and focus on those' (Gewin 2020:295–296). It is also suggested that the class size determines the nature of the online approach. For large classes, this might mean separating the class into smaller groups (OAS8, OAS11). Hence, within the context of SDML, the facets of the instructional multimodality need to be adapted to the needs of classes and individual students.

The type of communication in the learning sphere is also affected by the online medium and approaching learning in an asynchronous manner. It is noted in OAS11 that in this context (Sandars et al. 2020):

> There is a lack of nonverbal communication in asynchronous discussions, even with the use of Emojis ('smiley faces' and 'thumbs up' symbols), and this can lead to a lack of trust between the participants, with the inevitable reduced contribution to the discussion. (n.p.)

Consequently, despite the affordances provided by online contexts regarding the use of different mediums, there might be less semiotic resources available in terms of nonverbal communication.

Through the use of different modes of communication, engagement can be facilitated with and between students. This aspect is essential in terms of supporting emotional and affective aspects of the learning process, especially in the COVID-19 and similar contexts where students may feel isolated or be affected by other aspects of their lives, which may impact negatively on their learning.

Emotional and affective issues

Affective issues are particularly essential in terms of motivating students to learn. Specifically, within the context of this chapter, additional support might be required. Consequently, not only should the students be supported in terms of their emotional state (OAS1 and OAS10) but also should the teachers be supported to share their own emotions (OAS3 and OAS7) and personality (OAS4). Establishing that students and teachers are in this situation together is echoed in OAS10 as it is recommended that teachers '[b]e positive, be a host and let everyone know you are in this together' (Kapp 2020) and that they maintain what OAS12 calls the 'human connection' (Snelling & Fingal 2020).

Teachers should consider that students might feel isolated and should, therefore, maintain regular contact (OAS8 and OAS9). It is recommended that the emotional dimension, that is lost because of the absence of a physical presence, be compensated through descriptive written interactions. OAS7 makes this suggestion: 'Include the use of emotions while you write to compensate for the lack of facial expressions in the online environment' (UP 2020:4).

In OAS1, the following is posed to teachers: 'Be kind to yourself and empathic to your students' as well as 'Encourage an environment of caring and support. Be flexible: exceptions may need to occur around course requirements' (UCT 2020). In OAS7, it is stated that as 'students may feel isolated, it is essential to create a sense of community and care' (UP 2020:4). Hence, even through the multimodal learning environment, such a feeling of being a community and caring can be supported. A practical way to gauge emotional issues would be to follow this recommendation by OAS1: 'Seek student feedback about their workload, emotional state, learning preferences, and learning pace' (UCT 2020).

These issues around affective variables in the learning context and, specifically, motivation are highly relevant for successful SDML. In terms of SDL, Zhu et al. (2020) found that motivation affects SDL in terms of self-monitoring and self-management. From the sources, an essential additional part of SDML, student agency, was also prominent.

Student agency and flexibility

In this chapter, SDML is closely regarded within the concept and process of SDL. As SDL requires students taking charge for their own learning, this also implies some flexibility on the side of online courses. To this end some of the OASs prompt teachers to make recording rather than live stream videos to not only address technical access challenges but also allow for viewing students' own time and pace (OAS3, OAS4, OAS6, OAS7 and OAS8). OAS8 also suggests that teachers '[a]dopt a flexible approach to how you approach online teaching – things may not work as planned' (UJ 2020:1). Such flexibility can also provide affordances for students to approach their learning in a more personalised manner through which the three aspects of SDL, self-management, self-monitoring and motivation, could also be supported.

Interestingly, there was also clear evidence of support for SDL specifically in the advice albeit not necessarily named SDL. OAS7 notes that teachers should 'encourage students to prepare independently for each class' (UP 2020:1). In OAS6, it is highlighted that teachers 'set up their courses so that students can pursue self-paced enquiry – exploring the topic under their own initiative' (Gewin 2020:296). Therefore, learning should be planned to allow students to learn not only at their own pace but also, importantly, on their own initiative. This emphasis on student initiative ties in with the definition of SDL by Knowles (1975), where individuals specifically take the initiative for their learning. Besides, *initiative in learning* is also one of the factors measured by means of the Self-Directed Learning Readiness Scale by Lucy M. Guglielmino (Brockett & Hiemstra 2019).

It is furthermore advised that students take ownership of their learning. In OAS3, it is suggested that students take control and the following is noted: 'You can set up online group spaces for small groups of students and ask them to support and consult with one another before sending emails to you directly' and 'Encourage students to use the communication tools they prefer' (The Conversation 2020). Likewise, in OAS6 (Gewin 2020), it is stated that:

> [*A*]sking students what they hope to get out of the online course, and how you can best serve them, offers instructors ideas for teaching and gives students ownership of the process. (p. 296)

Elements of supporting SDL were evident in the sources (OAS4 and OAS11) although with elements of reductionism. For example, in OAS4, the following recommendation is made to teachers: 'Give your students trust and a little leeway and you'll be amazed by how hard they'll work to get their work done' (ACS 2020). It is also even recommended by some sources that teachers make use of students' expertise (OAS5, OAS10). Overall, these issues pertain to creating an environment and process that is student-centred. For OAS9, this implies an interaction between students and content, other students and teachers. On a more practical level, it is also encouraged that teachers be flexible in terms of deadlines and class attendance (OAS5) as well as the way assessments are completed. To this end, the use of handwritten assessments that can be photographed and then uploaded is even suggested (OAS8).

In OAS11, the following statement is made regarding SDL, and this supports the importance of student choice in terms of resources (Sandars et al. 2020):

> Learners become self-directed, with increased motivation and engagement, since they can select online tutorials from a range of different online tutorials that meet their own learning goals at a time and place that fits in with their other demands. (n.p.)

This accentuates the importance of SDL in the SDML and, specifically, the transitioned online context focused on in this chapter. A further level of student agency is students being involved in creating content. In OAS11, it is suggested that students are involved in co-creating content, and this supports even further student agency and a positive move towards SDML.

Another aspect noted in the data was that of assessment, and this should also be considered an indispensable element of the SDML process.

Assessment

Limited information was included in the OASs regarding assessment. However, it was proposed that assessments be used as a way to gauge attendance and participation through automatically marked quizzes, for example, (OAS3) or determining who the students are and what challenges they might experience (OAS8). In OAS6, the following is remarked 'the most successful virtual teachers conduct frequent assessments, and check in by phone, text or email with each student – most often with those who are struggling' (Gewin 2020:296). Similarly, OAS7 also supports the idea that assessments prior to classes can be used to determine students' preparedness and inform what is done in class meetings.

It was also suggested that various types of assessments are implemented. In OAS8, it is stated that teachers should employ different assessment strategies and make use of the different tools on the learning management system. The following examples of tools are also specifically mentioned: 'short question types, voice answers, portfolios, discussions, journalling [*sic*] and blogs' (UJ 2020:2).

The issue of feedback was also raised in the sources. Feedback is described in OAS8 as critical and that '[c]onstructive feedback will enhance learning' (UJ 2020:3). This source (UJ 2020:3) provides three useful and practical recommendations:

- Consider smaller assignments so that feedback is possible.
- Develop a detailed rubric to simplify feedback.
- Compile a list of standard, constructive feedback remarks that can be copied and pasted into assignments when marking.

Using assessment as a feedback mechanism, the SDML process can be informed, and this would also allow teachers to identify specific challenges experienced by students.

Students with challenges or special needs

In a move to a multimodal environment, it is essential to consider additional requirements from all students and also students with special needs. According to OAS6, students who struggle should be identified and supported. Also, in OAS11, it is recommended that analytics from the learning management system inform student support.

In OAS8, this aspect is worded as follows: 'Make provisions for your students who have challenges using technology' (UJ 2020:3), and some contact details for technical support is listed. However, the specific reference to special needs was not observed in any of the OASs, and this would be an area that would require further attention in this genre of advice texts.

Throughout the SDML process and specifically within the OASs, the role of the teacher cannot be ignored, despite the centrality of the student.

The role of the teacher

Despite physical distancing between student, class and teacher through online learning, the focus can potentially still be increasingly student-centred. In this regard, it is essential to not completely ignore the role of the teacher in the process. The sources advise that teachers set clear and reasonable expectations and specific instructions (OAS3, OAS4, OAS5, OAS8 and OAS11) and be available regularly (OAS7 and OAS9).

It is suggested by sources that teachers be available at set times (OAS5 and OAS7) and at least be available by email. In OAS8, it is even suggested that a set response timeframe is shared with students so that they know when to expect a response. Teachers should also support students to be able to use the online environments used for classes (OAS11). These aspects provide, within SDML, a framework through which students can make use of the teacher as a resource.

Teachers beginning part of the learning process can be supportive of successful SDML. It is suggested that online presentations and videos should not just include content but also include the teacher's face (OAS3, OAS10). This aspect not only supports the notion of a teacher's presence (Garrison 2017) but also supports of the empirical research confirming the advantages of including teachers' faces in videos (Kizilcec et al. 2015). In terms of including teachers' faces in this context, it is essential that they are positioned carefully as to not become a distraction.

Discussion

From this data analysis, it is clear that the OASs covered many diverse aspects and that facets of SDML and elements conducive towards successful SDML were identified. However, they were reduced and diluted to an extent. From the SDML scorecard analysis, an apparent spread of both SDL and multimodal learning aspects was present in the OASs. However, creating a positive and comfortable environment, collaboration and embracing different modes of communication and learning were the most prominent.

From the inductive analysis of the contents of OASs, the main themes focus on accessibility, following a no and low-tech approach, having clear structure and planning as well as promoting active learning. Furthermore, it was evident that in the multimodal environment, a social presence is established and maintained within the context of different formats and modes of interaction and instruction. The SDML process also required recognising emotional and affective issues in terms of students as well as supporting student agency and broader flexibility in the learning process. Finally, certain issues around assessment, students with challenges or special needs as well as the key role of the teacher were raised.

An aspect that was lacking from the analysed OASs was opportunities for collaboration for critical engagement or inputs regarding the advice. Introne and Goggins (2019) have shown how collective community processes could be beneficial for effective online study advice. The different types of sources also had an impact on the generalisability of the advice. While most of the sources consulted were not intended for a specific institution, they were relatively generic and applicable for different contexts. However, in some cases, such as OAS7, a lot of the information – although published publicly – was specifically aimed at staff and students of the specific institution.

Limitations

Certain limitations were evident from this research. This research is in no way exhaustive in covering all online publicly published advice. Hence, it is recognised that the sampling is relatively random and not all-inclusive. In addition, this chapter was limited to online study advice published in English. In a similar way as the research by Zaman et al. (2020), it is a drawback for this research that it is limited to public online study advice, and future studies could explore the private and institutional spheres in this regard. Also, in line with Zaman et al. (2020), extensions of this research could involve empirically testing some of the findings and probing actual understanding and practices based on the advice. Finally, out of the nature of the documents analysed for this research, it cannot be assumed that advice texts would necessarily be conceptualised to consider the aspects of SDML focused on in this chapter.

Cogitation

This research was prompted by the fact that, at the start of worldwide lockdowns because of the COVID-19 pandemic, I observed repeated references on social media and elsewhere online to 'low-tech solutions', what seemed to be advice to water down the online learning experience for the sake of efficiency and access. This perception of *online learning lite* or *drive-through instant online learning* may have served as the impetus for this research. However, through the analysis of the identified online study advice texts, I journeyed with authors who were sharing years of experience or epiphanies from sudden immersions in online learning. In a quest to search for and measure degrees of SDML in the texts, I read the advice (asynchronously) together with thousands of teachers to find not only self-direction but also definite accommodations of various facets of multimodal learning imbedded in the advice. In reflection, it is essential, within the context of this research, to advise authors and their readers act critically and interrogate all aspects of advice peddled online.

Conclusion

This study explored the online nature of SDML in online study advice while specifically focusing on whether such guidelines adhered to the basic principles associated with the theoretical foundations around multimodal learning and SDL. This qualitative research involved an analysis of such advice from a corpus of selected online texts and found that complex pedagogical concepts were reduced or diluted as was expected from a genre like OASs. This chapter determined that despite little overt reference to either SDL or multimodal learning, many principles and aspects acting in support of SDML were identified in online study advice. As sources, like the OASs analysed in this chapter, are published online and may have a great impact, it is recommended from this research that academics working within SDML and related fields engage further with this type of communication in order to inform more comprehensive educational practices in terms of completed and ongoing research. In addition, it is also essential for teachers who might consume content like the OASs approach such sources in a critical manner in order to inform their practices sensibly.

Chapter 4

Exploring microworlds as supporting environments for self-directed multimodal learning

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Abstract

This chapter focuses on environments that support the fostering of SDML. This research drew on constructionism as theoretical lens and its implementation by means of microworlds. The aim of this chapter is to determine what features of microworlds enable them to be supportive multimodal learning environments for SDL. The design features of selected microworlds are investigated, focusing on the requirements of SDL, problem-

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solving, opportunities for collaboration and the specific resources available to students and facilitators. The qualitative study that this chapter is based on was completed from within a pragmatist paradigm and involved document analyses and multimodal content analyses to do an exploratory evaluation of the selected microworlds. The exploratory evaluation focused on the creation of a rubric for evaluation of the features of microworlds. Specific aspects in the selected microworlds were identified that can potentially support SDML.

Introduction

In order to foster SDL in a learning situation, the environment – which is often multimodal in nature – needs to provide a supportive context. Self-directed learning is considered an approach or process by which learners take control of their own learning (Brockett & Hiemstra 2019; Francom 2010; Gibbons 2002; Knowles 1975). It is not a new concept and was a major means for learning before organised formal educational institutions were established. The control exercised by learners can be seen at various levels, and different models place different emphases on the factors involved in the SDL process (Bosch, Mentz & Goede 2019; Brockett & Hiemstra 2019; Tredoux 2012). With regard to enabling environments for SDL, research has been done on learning management systems, amongst others (Tredoux 2012). This chapter specifically focuses on constructionist microworlds as supportive environments for SDML. For the sake of consistency of sources, and to distinguish SDL as a separate phenomenon, both SDL and SDML are used in this chapter.

The areas of SDL, microworlds and multimodal learning are well researched in existing scholarship. This informed the literature review of this chapter. The rubric for evaluation was created from the literature on supportive environments for SDL. Literature on the design, efficacy, contexts and learning models of microworlds guided the features of the microworlds that were evaluated. Finally, the rich multimodal nature of microworlds enabled us to create another lens to link the results. For the envisaged exploratory evaluation of the selected microworlds, we drew on the SDL guidelines proposed by Gibbons (2002) as well as the variables identified by Brockett and Hiemstra (2019).

Problem statement and research questions

Central to this research is probing what elements found in the selected microworlds would enable them to be supportive learning environments for SDML. Therefore, the main research question posed for this exploratory evaluation was as follows:

- What features of microworlds enable them to be supportive learning environments for SDML?

The subquestions that supported the main research question were as follows:

1. What design features of microworlds match the requirements of SDL?
2. What aspects of multimodal learning are supported by microworlds?
3. What specific features of the microworlds contribute to setting up and solving problems?
4. What opportunities are there in microworlds to support collaboration?
5. What resources are available to learners and facilitators for microworlds in the SDML context?

Constructionism

This research is built on constructionist scholarship. *Constructionism* is considered a learning theory that was developed by Seymour Papert (cf. Noss & Hoyles 2017, 2019) which builds on the constructivism of Jean Piaget. The core idea of constructionism is the construction of a public entity in a context that is meaningful to learners (Noss & Hoyles 2017; Papert 1980). The link between SDL and constructionism was also clearly established by Clinton and Rieber (2010) in the context of learner-centred studio-based education, as well as by Rojprasert, Neanchaleay and Boonlue (2013) within the context of constructionism with regard to new media in Thai HE.

The construction can be of any artefact, whether digital (like a computer program or artwork) or physical (models, instruments or objects), which is meaningful to the learner. The first implementation of constructionist ideas came in the form of LOGO – a programming language designed especially for learning in the 1960s and 1970s. LOGO enabled learners to construct graphics based on simple commands. More than 300 implementations of constructionist ideas have since been made, though not all are under active development as of 2020 (The Logo Tree Project 2020). Such learning applications that have a constructionist framework of learning have been termed *microworlds* (cf. Girvan, Wickham & Tangney 2016; Noss & Hoyles 2017, 2019).

Microworlds

In this section, we look at literature around microworlds in the context of this study. Firstly, we look at how microworlds are defined as well as exploring aspects of multimodality inherent to them. Furthermore, the four microworlds that form the sample of this study are briefly described. Finally, the core design features of the microworlds and the support that they provide to the learners are considered.

Microworlds as multimodal learning environments

Microworlds are specially designed learning environments that allow learners to explore ideas in a safe manner within a multimodal environment that may simulate real-life situations. The word *safe* is used in this context, as these environments allow learners to explore, implement and construct without any negative consequences detrimental to their learning. Papert (1987:80) defined a *microworld* as 'a simplified piece of reality which you can explore, and again there's no right or wrong'. Noss and Hoyles (2017:6) further described this concept as an environment that acts as 'a concrete embodiment of a knowledge domain or structure'.

Edwards (1995) provided a set of criteria for a microworld and also discussed the inherently embedded nature of multiple representations in microworlds and their effect on the learning process. The idea of multiple representations closely relates to multimodality. In this chapter, *multimodality* (cf. Bateman, Wildfeuer & Hiippala 2017) is deemed as an essential part of learning with microworlds. Rieber (2004) described three aspects of representations involved in learning in microworlds: reduced cognitive load, clarifying the problem space and revealing immediate implications.

Since 2000, some implementations of microworlds have become exceedingly popular, and some are used by millions of learners worldwide. Some notable examples of software in this regard are Scratch[5] (Resnick et al. 2009), Turtle Blocks[6] (Bender & Urrea 2015), NetLogo[7] (Tisue & Wilensky 2004; Wilensky 1999) and GeoGebra[8] (Hohenwarter & Fuchs 2005). This chapter focuses on these examples of microworlds. We note that, except for GeoGebra, the other three applications are direct descendants of LOGO, with the lead developers of these associated with Seymour Papert: Walter Bender for Turtle Blocks, Uri Wilensky for NetLogo and Mitchel Resnick for Scratch. With the proliferation of the Internet, these microworlds now have online interfaces and fora through which learners can communicate and collaborate with peers and mentors across the world. This has also led to the creation of a large pool of learning resources, many of which are available as OERs. In light of this background, we performed an exploratory evaluation of the features of microworlds that enable learning environments that support SDML.

5. https://scratch.mit.edu/about 'Scratch is designed especially for ages 8 to 16, but is used by people of all ages. Millions of people are creating Scratch projects in a wide variety of settings, including homes, schools, museums, libraries, and community centers'.

6. https://www.sugarlabs.org/ Turtle Blocks is a part of SugarLabs, which has over '3 000 000+ Users'.

7. https://ccl.northwestern.edu/netlogo/index.shtml 'NetLogo is a multi-agent programmable modelling environment. It is used by many tens of thousands of students, teachers and researchers worldwide'.

8. https://www.geogebra.org/about 'GeoGebra is a rapidly expanding community of millions of users located in just about every country'.

Design features of microworlds

Microworlds are specifically designed for learning. They include features that help learners to experiment and explore various possibilities that the tools in microworlds allow. Broadly speaking, all microworlds share some common design features that are well summarised by the *Scratch Design Goals* (Scratch 2012): 'If Scratch was a room, it would have a low floor, wide walls, and a high ceiling'.

Though the above quote specifically relates to Scratch, these design principles are applicable to other microworlds. One can even argue that these are the essential features of an application to be called a microworld. The room metaphor is apt to explain the context of learning:

- **Low floor:** It typically relates to the entry point of these applications; they are easy, and little or no prerequisite knowledge is needed.
- **Wide walls:** It refers to the scope of creating different types of artefacts with the applications to address various needs of learners.
- **High ceiling:** It refers to the fact that the applications can be used to make complex artefacts as well, and there is no limit to what can be accomplished. A 'turtle' can be used to explore complex concepts in physics and mathematics; see, for example, *Turtle Geometry* (Abelson & DiSessa 1986). Scratch has been used to create complex animations, games and applications. GeoGebra has been used for exploring differential equations and calculus (Mhohen 2008). NetLogo is a modelling tool for researchers working on complex systems (Tisue & Wilensky 2004; Wilensky & Rand 2015), and researchers use it to develop models of natural phenomena.

Other than these, *tinkerability* (i.e. the ability to tinker, change or adapt) is another essential feature of constructionism and hence also of microworlds. Tinkering does not have a fixed definition, but it is seen as a playful style of exploring and experimenting. Resnick and Rosenbaum (2013) provide a good explanation of what tinkering entails:

> We see tinkering as a valid and valuable style of working, characterized by a playful, exploratory, iterative style of engaging with a problem or project. When people are tinkering, they are constantly trying out ideas, making adjustments and refinements, then experimenting with new possibilities, over and over and over. (p. 164)

In addition, Resnick and Rosenbaum (2013) also make the following pertinent statement:

> We see tinkering as a style of making things, regardless of whether the things are physical or virtual. You can tinker when you are programming an animation or writing a story, not just when you are making something physical. The key issue is the style of interaction, not the media or materials being used. (p. 166)

A key implication of tinkerability is that it allows *epistemological pluralism* – that is, it allows for different styles of learning, knowing and expressing (Turkle & Papert 1992). The idea of epistemological pluralism has particular significance for SDL, as it is a learner-centric feature that empowers learners with different backgrounds and approaches to make meaning. Tinkerability would thus be crucial in providing learner agency in the context of SDL, as learners play a central role in planning and managing their learning through this process.

The four microworlds are multimodal in nature and differ slightly in terms of some implementations and features. Turtle Blocks and Scratch are examples of visual programming languages (also called *block programming languages*). In a visual programming language, instead of typing commands, visual blocks are combined (like LEGO® blocks) by drag and drop to create programs. Visual programming languages have several affordances for learners, which allow even novice learners to create programs with ease (e.g. see Repenning 2017).

GeoGebra is an interactive programmable graphical simulator for mathematical objects that allows learners to construct mathematical artefacts. GeoGebra is a dynamic mathematics application to combine *geo*metry and al*gebra* views and also has features of statistics (spreadsheets). GeoGebra is also a visual programming language (but not a block programming language) in the sense that learners do not have to write syntax in text format. Instead, they can use the tools visually to create mathematical objects. For example, to create an intersection point between two lines, an *Intersection Tool* is used at the point of intersection, or two objects to be intersected are selected.

The design considerations for NetLogo-like environments with a focus on visualisations of different types are discussed in detail in Kornhauser, Wilensky and Rand (2009). NetLogo provides options for displaying various active agents and can display data of parameters in the model through numbers, graphs and colour-coded visual shapes which can change dynamically. These visual shapes, called *agents* and *patches,* can be programmed to behave and interact according to the requirements. Although NetLogo is a text-based programming language (in this way it differs from the other three applications), the syntax is human readable – one can make sense of the commands by reading them. For example, the command 'create-turtles 20' would create 20 turtles.

Self-directed multimodal learning

In this section, we look at literature around SDL with a focus on multimodal learning. We define SDML and look at aspects of multimodality and multimodal learning relevant to the present study. Finally, we consider the principles of SDL-enabling environments that are reported from the literature.

From self-directed learning to self-directed multimodal learning

As noted in the introduction, the focus in this chapter is on the fostering of SDL through the use of microworlds in the learning context. However, as such environments are inherently multimodal, it is also logical to extend the research to the concept of SDML. Where the literature specifically relates to SDL, the term is used separately; however, for the purposes of this chapter, SDL is regarded as being inclusive of SDML.

Self-directed multimodal learning can be defined as a pedagogical approach through which SDL is promoted within a context where individual modal preferences of learners are recognised; communication is done multimodally; and different modalities are employed in the blending of the learning, teaching and delivery processes (Olivier 2020a, 2020b). Four levels of multimodality are relevant for SDML: individual multimodality (relating to individual learner modal preferences), interactional multimodality (modes of communication), instructional multimodality (modes employed for learning) and institutional multimodality (mode of delivery) (Olivier 2020a, 2020b). When microworlds are used in the learning context, they are relevant in all four stated levels. However, in this chapter, the focus is specifically on interactional and instructional multimodality.

Multimodality and multimodal learning

As multimodality is central to the way learning is approached in this chapter, the theoretical basis of multimodality should also be considered. Multimodality is not only ubiquitous to electronic media but wider society is also inundated with different forms of communication (Bateman et al. 2017). In this process, the concept of a *mode* is highly relevant, as it refers to a resource that is used to create meaning and can include text, images, sounds, gestures and various moving images (Bateman et al. 2017). In the context of this chapter, the *medium* (i.e. the vehicle through which communication takes place) would be a microworld and its interactive components. The meaning-making elements used in microworlds are *semiotic resources*. In concrete terms, the multimodality paradigm is highly relevant when learning is regarded as a communicative act.

As multimodality builds on semiotics (i.e. the study of signs), it is also relevant in this chapter to consider the different signs and meaning-making elements found in the identified microworlds. The social semiotic (Kress & Van Leeuwen 2006) approach followed in this chapter draws on systemic functional linguistics of M.A.K. Halliday (cf. Unsworth 2008). This is highly relevant, as with the semiotic resources available in the microworlds, 'the structures of language have evolved (and continue to evolve) as a result of the meaning-making functions they serve within the social system or culture in which they are used' (Unsworth 2008:1). In the context of this chapter, online 'texts' such as microworlds employ aspects of different semiotic systems, specifically language, and also graphical and programmable systems.

For the sake of any analysis of a multimodal environment, such as the microworlds identified for this research, certain elements must be considered. Firstly, the phenomenon of a *canvas* is highly relevant and this refers to (Bateman et al. 2017):

> [*A*]nything where we can inscribe material regularities that may then be perceived and taken up in interpretation, regardless of whether actual, virtual (digital), simply produced, performed physically in time, or the result of a complex technological process. (p. 87)

Hence, microworlds might have a specific element that acts as a canvas on which communicative signs are imposed or placed. In addition, canvases can also contain many subcanvases which include some semiotic content.

Microworlds as enabling environments for self-directed learning

Self-directed learning, as espoused by Knowles (1975), has three major components: the learner, the teacher and the study materials. The nature of dynamic interaction between these three components determines the extent of the supporting environment for SDL. Francom (2010:33) provided four major prescriptive principles of enabling environments for SDL:

1. Match the level of SDL required in learning activities to student readiness.
2. Progress from teacher to student direction of learning over time.
3. Support the acquisition of subject matter knowledge and SDL skills together.
4. Have students practise SDL in the context of learning tasks.

We drew on these four principles to construct a rubric to analyse the microworlds we selected for this study. The features and design aspects of the selected microworlds were evaluated in the context of these principles, supported with relevant examples.

Methodology

We employed two approaches for the methodology: an exploratory evaluation and a multimodal content analysis. The exploratory evaluation centred on the creation of a rubric for evaluation of the features of the selected microworlds. The rubric was based on research already done on supporting environments for SDL. Secondly, the microworlds were analysed in terms of multimodality

(Bateman et al. 2017; Bezemer & Kress 2016) and multimodal learning (Olivier 2020a, 2020b) in general.

Research paradigm and design

This exploratory study was done within the pragmatist paradigm (Cohen, Manion & Morrison 2011:23), as the focus was on 'what works' and a practice-driven approach in which the research 'adopts a methodologically eclectic, pluralist approach to research, drawing on positivism and interpretive epistemologies based on the criteria of fitness for purpose and applicability'. As regards the evaluation of the selected microworlds, this research drew on methods related to document analysis (Cohen et al. 2011) as well as content analysis from the perspective of multimodal research (Bateman et al. 2017).

Sampling and data collection

Environments identified for this research were selected by means of non-probability sampling and purposive sampling (Cohen et al. 2011). Data collection involved written reflections made while using the identified software and screenshots. Written permission was obtained to include the screenshots in this chapter.

We have chosen four popular microworlds for this study: Scratch (ver. 3.17.1), Turtle Blocks (ver. 2.72), NetLogo (ver. 6.1.1) and GeoGebra (Classic ver. 6). These four microworlds fulfilled the following criteria:

1. Large user base: typically, thousands to millions.
2. Both online (browser-based) and offline (stand-alone) versions.
3. Platform independent: work on all major operating systems (GNU/Linux, Windows, Mac OSX and Android/iOS).
4. Main interface is available in several languages: GeoGebra (70+ languages), Scratch (60+ languages), NetLogo (45+ languages) and Turtle Blocks (10+ languages).
5. Active online fora rich in OERs: all the online versions of the applications include a repository of user-generated programs and discussion space and allow user-generated content to be licensed under Creative Commons licenses.
6. Released with free software licenses:
   - GeoGebra: GeoGebra license (source code is licensed under GNU General Public License [GPL], but commercial use is prohibited from ver. 4.2 of release).
   - Scratch: Berkeley Software Distribution ver. 3.
   - NetLogo: GNU GPL ver. 2.0.
   - Turtle Blocks: GNU Affero General Public License (AGPL) ver. 3.

7. Actively under-development as of 2020. Public repositories of the projects for development show the activity status of the applications:
   - o GeoGebra: https://github.com/geogebra/geogebra
   - o Scratch: https://github.com/LLK/scratch-gui
   - o NetLogo: https://github.com/NetLogo/
   - o Turtle Blocks: https://github.com/sugarlabs/turtleblocksjs
8. Actively researched for pedagogical aspects: numerous educational and research studies have been conducted involving these applications.

Data analysis

Bateman et al. (2017:218) suggested approaching any multimodal content as being sliced into 'canvases', which allows the analysis of different aspects of software in this case. This allows for inductive qualitative analysis of the identified environments, and we could then gauge whether these environments, as microworlds, were supportive for SDML. In this exploratory evaluation, the research also drew on the methods of existing research done on microworlds: for example, the work of Noss and Hoyles (2019:8–10) on ScratchMaths, and Tsur and Rusk (2018) using Scratch.

Results

The results were derived from the exploration of the selected microworlds, using a rubric containing principles of SDL-enabling environments. The evaluation explored the feasibility of using these microworlds as supporting environments in the SDL context. The second aspect explored was the multimodal nature of the environment and to what degree this was supportive of multimodality and SDML.

Rubric for the evaluation of a self-directed learning-enabling environment

The literature presents four basic principles that are needed to foster an enabling environment for SDL. Below, each of these principles is expanded upon in light of the features of microworlds, and relevant examples are provided in each instance.

Matching the readiness of learners

All microworlds considered here offer a wide spectrum of possibilities, from very basic to very complex activities. The used cases of these applications ranged from primary school to university level and were very flexible in their implementation, catering to specific requirements and abilities of learners.

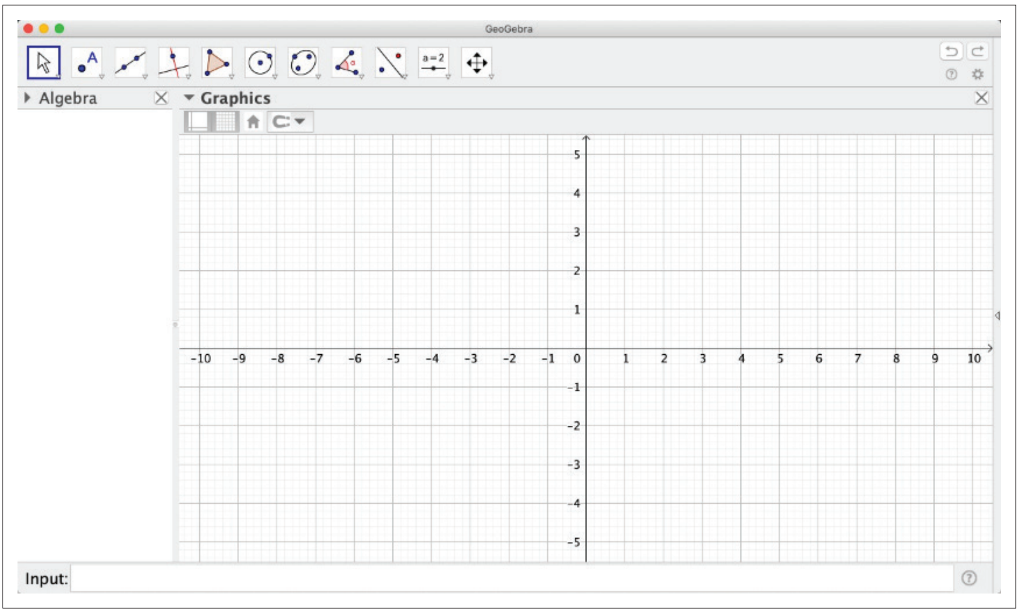
☐ *Low threshold for learners who are novices*

All four microworlds that were considered had a low threshold for novice learners as a design feature. Learners could therefore begin with some of the basic tools to create objects and did not need any prior experience in using the applications. In the case of NetLogo, there was a default ready-to-use pre-existing library of models. In the other three applications, no default pre-existing model library exists, and such model files have to be downloaded.

In the following, the basic user experience of the various programs is described.

GeoGebra: Opens a blank canvas, with basic tools at the top (Figure 4.1). The visible tools can be customised to meet the requirements of learners. For example, advanced tools can be hidden from the view of inexperienced learners. Also, the spreadsheet view, algebra view or the geometry view can be hidden as required by the learning context, and such views can be saved.

Note the position of the tools at the top, algebra view is on the left, geometry view is the part with the grid and there is a text input box at the bottom. New objects can be created on the canvas by clicking on the tools and then clicking on the canvas.

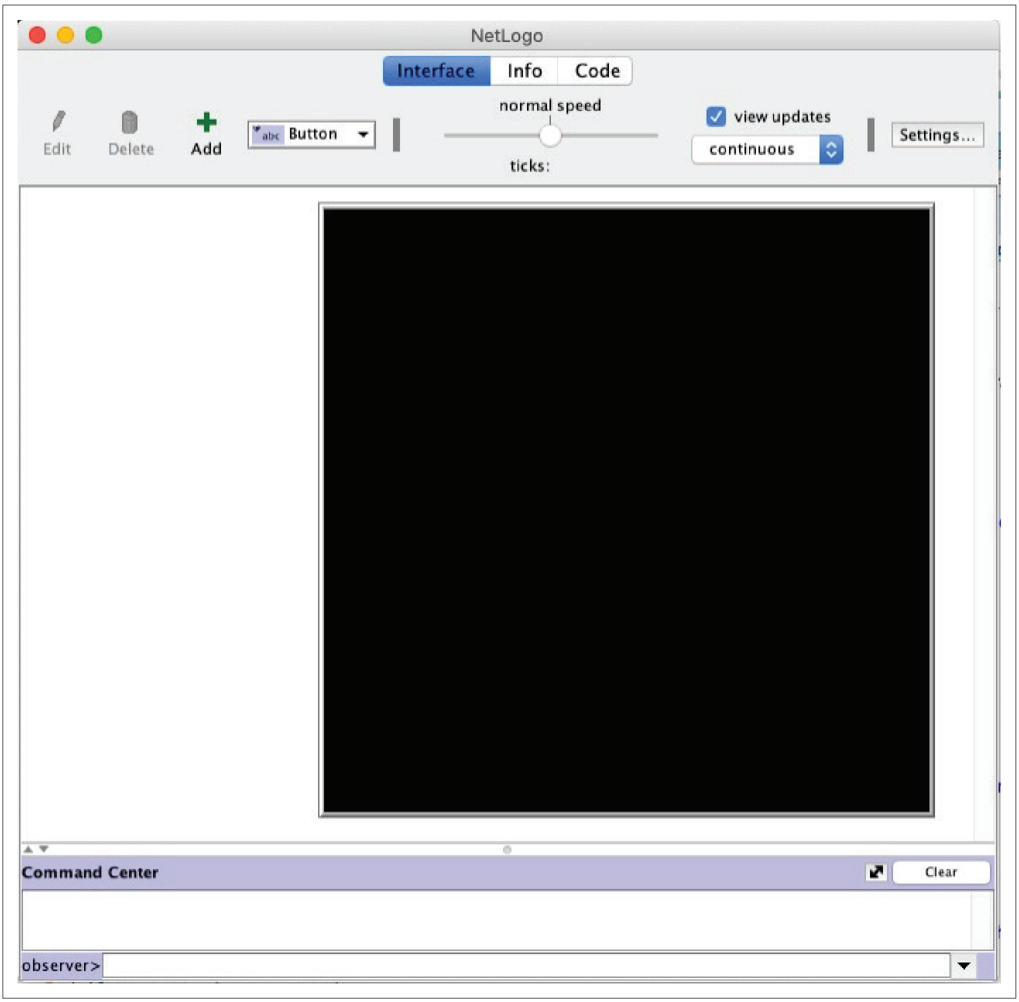


Source: Screenshot taken from GeoGebra, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.1: The default blank canvas of GeoGebra.

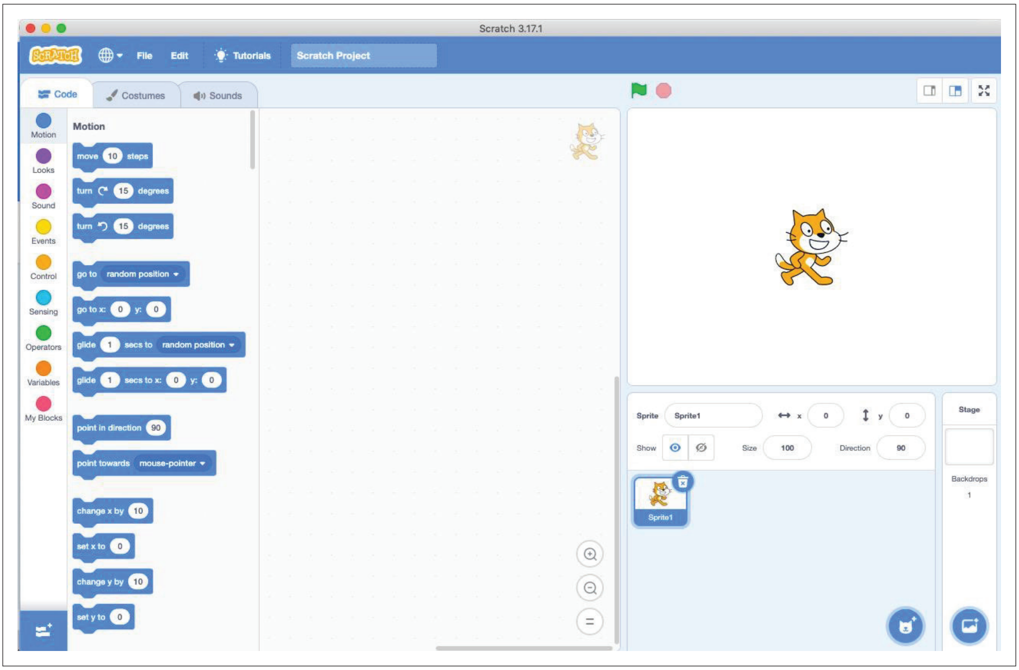
NetLogo: Opens a blank canvas and has an extensive inbuilt library of readymade curricular models (Figure 4.2). These models can be loaded and explored by learners. There is no need to start the programming right away to use the application.

Note the control buttons at the top and command centre at the bottom which accepts text commands. To create new objects, one must go to the 'Code' tab and type commands or type commands in the command centre.

Scratch: Opens a blank canvas with tools (Figure 4.3). The basic tools are present. Learners can load pre-saved files or can start programming with the blocks. Note the blocks in the left panel and their colour-coded classification.



Source: Screenshot taken from NetLogo, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.2: The default blank canvas of NetLogo.



Source: Screenshot taken from Scratch, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.3: The default blank canvas of Scratch.

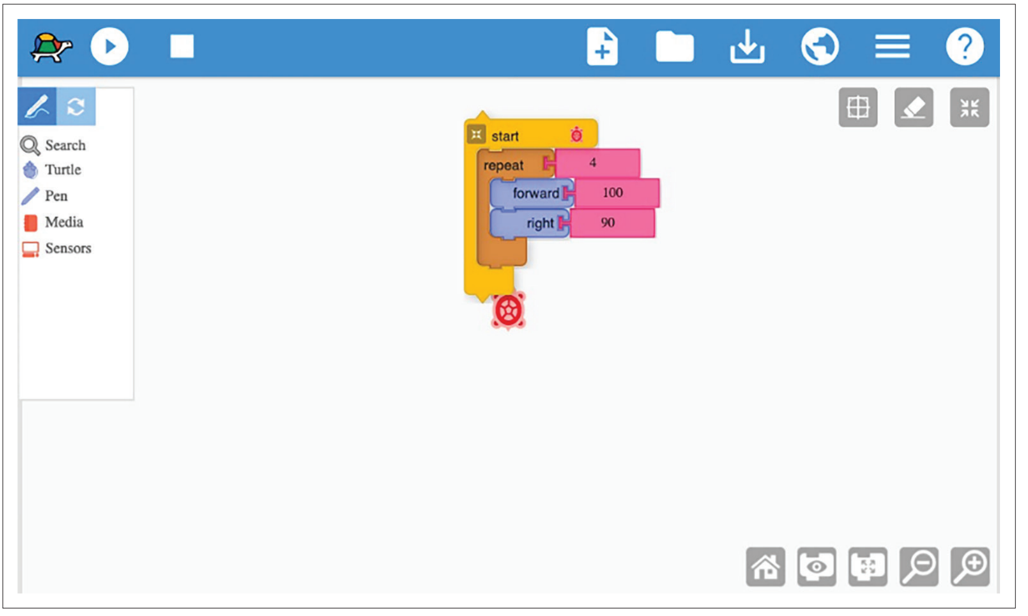
The blocks in the left panel can be dragged and dropped in the middle panel. Clicking on the blocks in the middle panel executes them. The result of the execution is seen on the right-hand side in the screen with the cat (a 'sprite').

Turtle Blocks: Turtle Blocks opens a default program with blocks for drawing a square (Figure 4.4). The basic tools are present. Learners can load pre-saved files or can start programming with the blocks. Additional blocks are available in the left panel. There is no separate canvas for results; the turtle and the programming blocks share the same space.

☐ *Comparing the various microworlds*

From a novice perspective, Turtle Blocks presents the easiest entry point, followed by Scratch and GeoGebra, while NetLogo might be the most challenging because it involves textual syntax. Simple applications that can be used by primary school learners can be developed in both Scratch and GeoGebra. Turtle Blocks was also part of the software stack (SugarLabs) developed for the One Laptop Per Child project[9] and has been deployed mostly in primary and secondary schools.

9. http://laptop.org



Source: Screenshot taken from Turtle Blocks, date unspecified, written permission obtained to reproduce and publish this image.

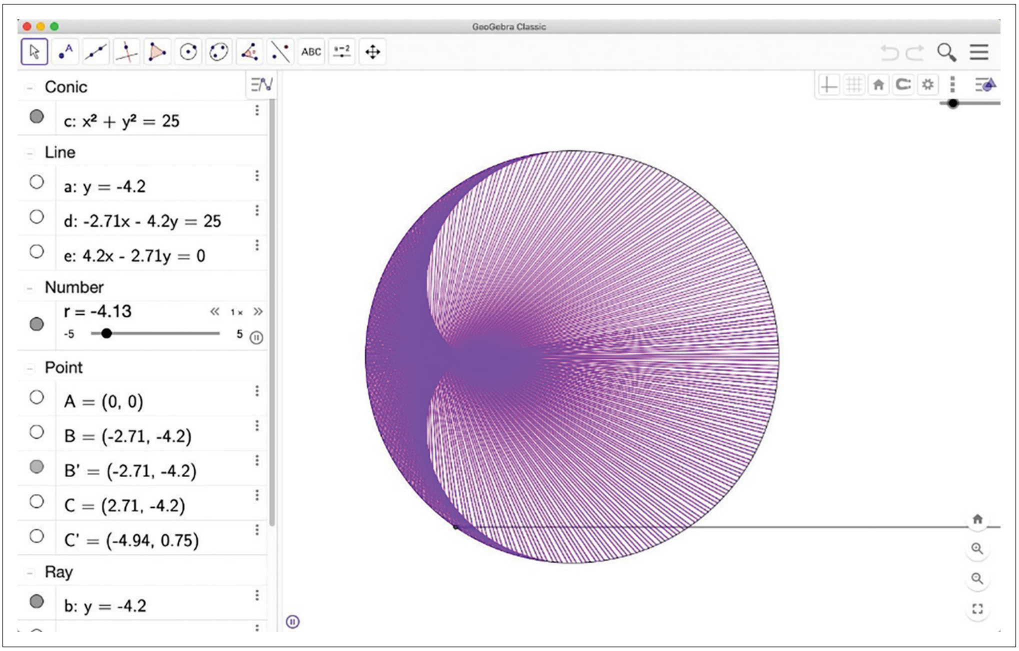
FIGURE 4.4: Turtle Blocks opens a default program for drawing a square.

There are two ways of addressing the issue of matching the readiness of learners in microworlds. One way is to open a pre-designed file to meet learning requirements, and the other way is to start learning on the blank canvas itself. Both approaches can be used with different levels of learner readiness. As an example of the former approach, interactive books that have specific learning objectives, including assessments, can be created in GeoGebra; the second approach may entail learning tasks that require learners to create and save their own files.

☐ *High or no ceiling for advanced learners*

While microworlds can be tuned to the requirements of novice and young learners, the same tools can be used to create complex programs. This option is used to create the *cardioid* curve (a heart shaped curve, as shown in Figure 4.5) which results after reflection from a circular shape. Note the different mathematical objects present in the algebra view in the left-hand panel.

GeoGebra: Features like sliders, trace path (Figure 4.5), logical operations, value checker and conditional programming and scripting options can create visual proofs, art forms, dynamic simulations and interactive books from basic and advanced concepts in mathematics. Similarly, it is possible to create



Source: Screenshot taken from GeoGebra, date unspecified, written permission obtained to reproduce and publish this image.

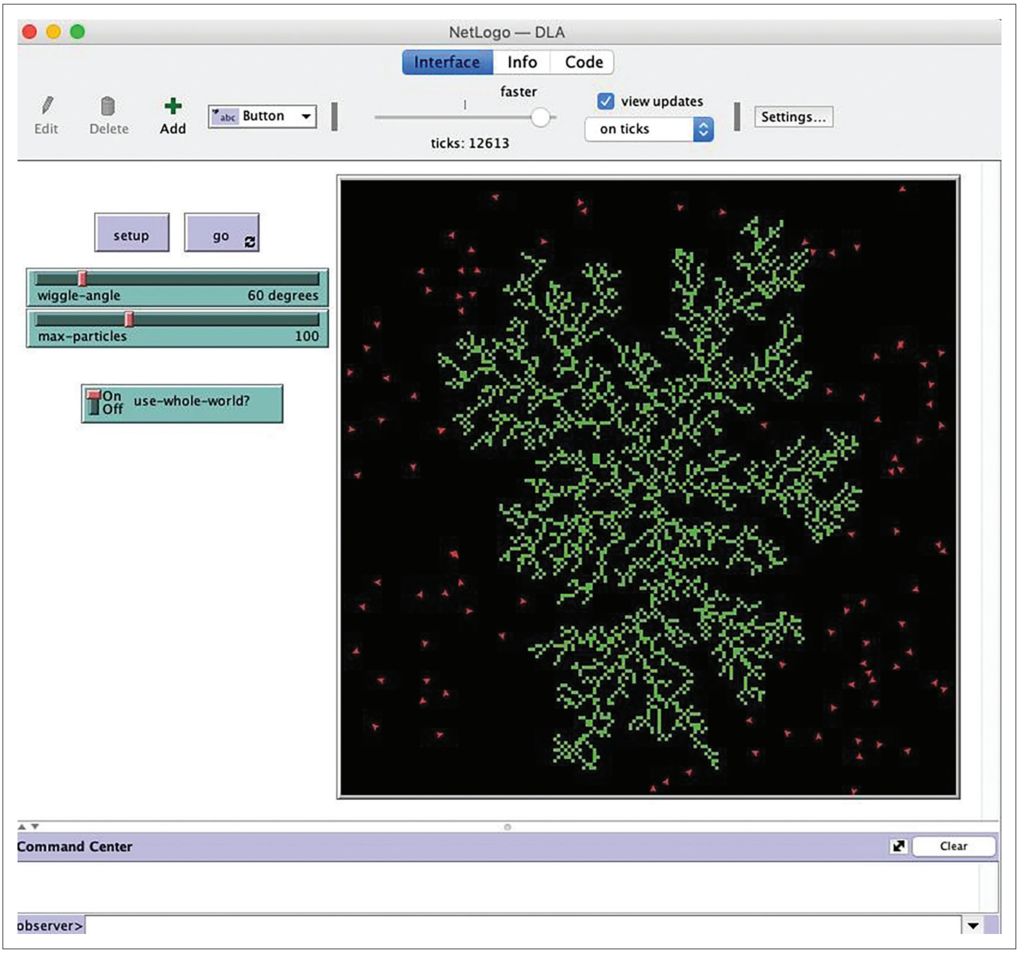
FIGURE 4.5: The 'Trace' option in GeoGebra.

problems and games based on providing correct solutions, as assessments in various forms can be embedded in the simulations.

NetLogo: Most of the models in the NetLogo library are curricular models (e.g. gas-law models) that present a complex-systems approach to these models. These curricular models require a user to understand a few complex requisite concepts. Although substantial background information to explore and understand the model is given on the 'Info' page, learners should have some prerequisite knowledge of the basic concepts. The NetLogo simulations allow learners to explore the models by varying the parameters and studying their results. NetLogo[10] is also used by complex systems researchers to create models of various natural phenomena (Figure 4.6).

Scratch: Scratch allows learners to create many complex games (Figure 4.7), animations and applications that can use the variety of available editing and multimedia options. Learners can create their own 'sprites' and sounds. Scratch can also be used with external electronics and sensors such as Arduino and Raspberry Pi, thus opening up immense possibilities of design and construction.

10. For an extensive list of research publications using NetLogo as modelling tool, see http://ccl.northwestern.edu/netlogo/references.shtml.

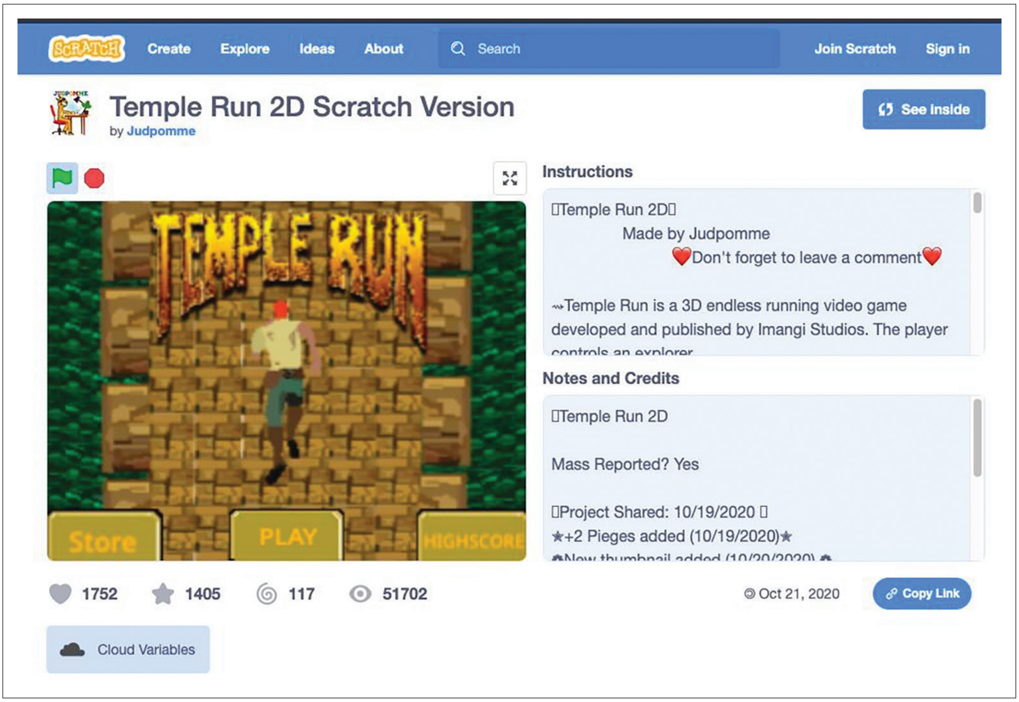


Source: Screenshot taken from NetLogo, date unspecified, written permission obtained to reproduce and publish this image.

FIGURE 4.6: A model of diffusion limited aggregation (DLA) using NetLogo (Wilensky 1997). This model is present in the models library of NetLogo.

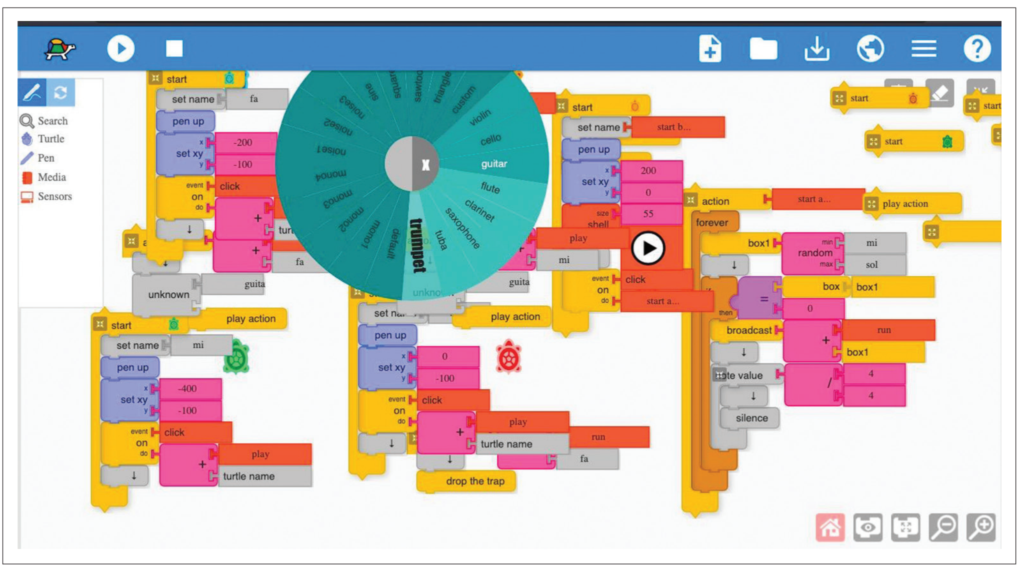
Turtle Blocks: Turtle Blocks has advanced options such as logical operations, music (Figure 4.8) and external sensors that can be used to create complex programs. Turtle Blocks can also be used in conjunction with external electronics and sensors such as LEGO Mindstorms, 3D printers, Raspberry Pi and Arduino.

Starting from very basic, learners can advance to very complex constructions involving rich learning experiences, involving both conceptual knowledge and computational thinking. The concrete objects of the programs – such as lines and points, turtles, patches and sprites – on which learners operate provide ‘objects to think with’ for both computational and conceptual thinking and for providing a link between sensory and abstract knowledge (Papert 1980). Such concrete objects, the ‘objects to think with’, whose behaviour can be



Source: Screenshot taken from Scratch, date unspecified, written permission obtained to reproduce and publish this image.

FIGURE 4.7: A game developed in Scratch by user *Judpomme*[11] with keyboard controls and sounds.



Source: Screenshot taken from Turtle Blocks, date unspecified, written permission obtained to reproduce and publish this image.

FIGURE 4.8: A complex musical game *Mouse Traps*[12] written in Turtle Blocks.

11. https://scratch.mit.edu/projects/436249717

12. https://turtle.sugarlabs.org/index.html?id=1590509582567639

modified and explored, are at the core of constructionist learning, and they also provide a link between the individual and social world. Thus, we see that, in the case of all four microworlds, the learning context can be fine-tuned to the requirement or level of learners, which is the first criterion of an SDL-enabling environment.

☐ Progress from teacher to learner direction

The second criterion for enabling SDL relates to progress from teacher to learner direction, as learners should take charge of the learning process (Knowles 1975). This concept ties in with what Brockett and Hiemstra (2019) describe as personal responsibility or the fact that learners assume ownership of the learning process. Furthermore, in the context of microworlds, enabling SDL can be realised by giving learners autonomy in selecting their own projects and increasing their agency in the goals and execution of the project. The teacher plays the role of a mentor in helping learners achieve their goals for the project independently or collaboratively. This is the approach suggested by constructionism as well. This aspect ties in with previous literature specifically showing the affordances of constructionism in SDL in a multimodal context (Rojprasert et al. 2013). According to the constructionist approach, learning would best happen when the project is personally relevant to the learner, and the artefact is a public entity where constructionism (Papert & Harel 1991):

> [*S*]hares constructivism's connotation of learning as 'building knowledge structures' irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (p. 1)

Thus, constructionism resonates with the idea of a learner-centric approach instead of a teacher-centric one. By adding the aspects of personal relevance in its wake, the role of the learner becomes important in the process.

Enabling learners to create their own projects: All four microworlds enable learners to explore the creation of their projects while at the same time also allowing exploring pre-existing projects. The projects can be curricular or non-curricular and can have open-ended goals. Also, the existing projects can be saved locally to create a copy of the project, thus allowing learners to reuse the existing code. Therefore, the process by which learners select the projects should be carefully attended to and depends on the way microworlds are implemented in the classroom. When used in a strictly instructionist manner, even a microworld can lead to a very teacher-centric mode, thus not enabling SDL. The degree of freedom given to learners to select and execute their own projects would be an indicator for both SDL and constructionist learning.

This aspect of SDL-enabling depends crucially on how microworlds are implemented.

Support the acquisition of subject matter knowledge

The four microworlds have different ways of supporting learners' acquisition of subject matter knowledge. In this regard, Turtle Blocks, Scratch and GeoGebra are different from NetLogo. Activities that make use of subject matter knowledge from other sources, like classroom discussions and textbooks, can be designed to be carried out by students.

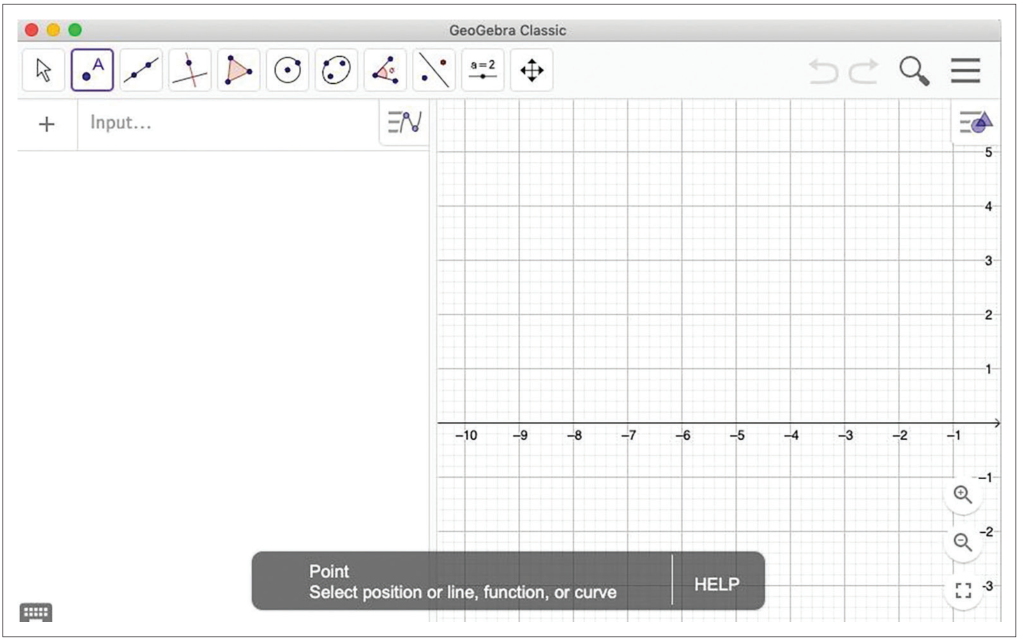
Available help

With the online modes available in the current versions of all microworlds considered here, we can categorise the help available in online and offline modes. Online help is typically what learners would get when they post their work or issues on online fora where other learners can view and comment on the submitted work. Such help is not available to learners if they do not have Internet access. Online fora can also provide help through available tutorials, user manuals or looking at already existing projects, posting problems and issues on fora. Thus, online help can be rendered in both synchronous and asynchronous modes. Offline help typically includes the help that is bundled with the applications, such as user manuals, tool tips and examples with basic use. Such help can be accessed without using the Internet.

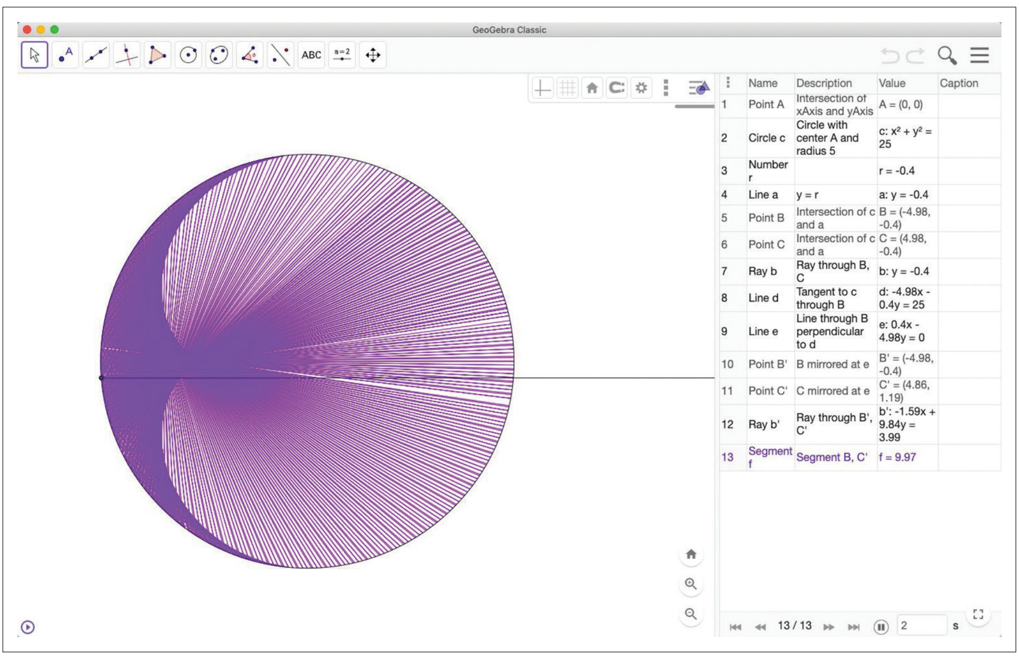
Inbuilt help: Technical

GeoGebra: No inbuilt help is available in the form of a user manual or tutorials. The sections in the 'Help' menu go to the online user manual and tutorials. Technical help is available in the form of tooltips which appear when the cursor is on the tools (Figure 4.9). The tooltip help in GeoGebra is in the form of a short text indicating the way the tool can be used. In this figure, the 'Point Tool' is selected, and the tooltip help indicates that the user needs to select (click on) a position (in the grid) or another mathematical object like a line, function or curve. Doing this would create a point on the plane or on the mathematical object.

The 'Construction Protocol' of the cardioid example in Figure 4.5 is presented in Figure 4.10. This protocol provides a step-by-step sequence of how the file was created, indicating the type of object and associated actions. When a file is opened in GeoGebra, the user can also access the 'Construction Protocol' (Figure 4.10). This is a history of how the constructions in the file were done and is a helpful feature when the user is trying to learn about constructions using GeoGebra.



Source: Screenshot taken from GeoGebra, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.9: Tooltip help in GeoGebra.



Source: Screenshot taken from GeoGebra, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.10: Construction protocol, indicated by the table on the right hand side, of the cardioid example shown in Figure 4.5.

NetLogo: The user manual is available locally in the form of browser-based web pages and can be accessed from menu Help > NetLogo user manual (Figure 4.11). The user manual contains information on how to use NetLogo as well as tutorials explaining the commands. For easy referencing, there is also a 'Dictionary' for all command syntax.

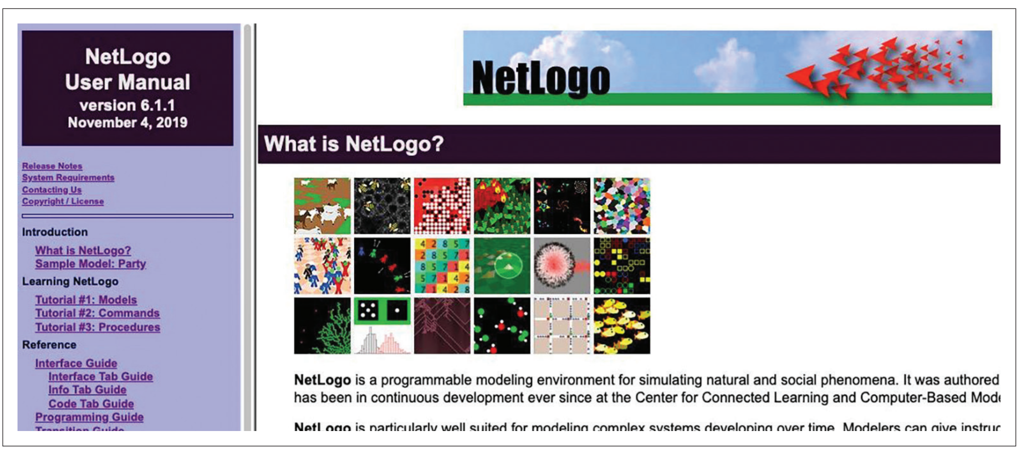
Also, for each of the programs in the models library, the source code is available via the 'Code' tab (Figure 4.12); this allows users to explore the model by changing the program and seeing the results. The 'Code' tab shows the code used for creating the model. Figure 4.12 shows the code for the DLA model shown in Figure 4.6 (Wilensky 1997).

Scratch: There are several simple tutorial programs (Figure 4.13) available under the Tutorials tab. These tutorials use short animated GIFs (Figure 4.14) to teach how various blocks are used and are easy to follow. The tutorials use a sequence of short animated GIFs (typically for a few seconds) instead of long videos and do not have a voice-over. A given animated GIF only explains one short action, which might be helpful for novice learners.

Turtle Blocks: In the case of Turtle Blocks, only basic help (Figure 4.15) about the interface is available in offline mode. There is no inbuilt help available for using the blocks. The user manual with description of the blocks is available online.

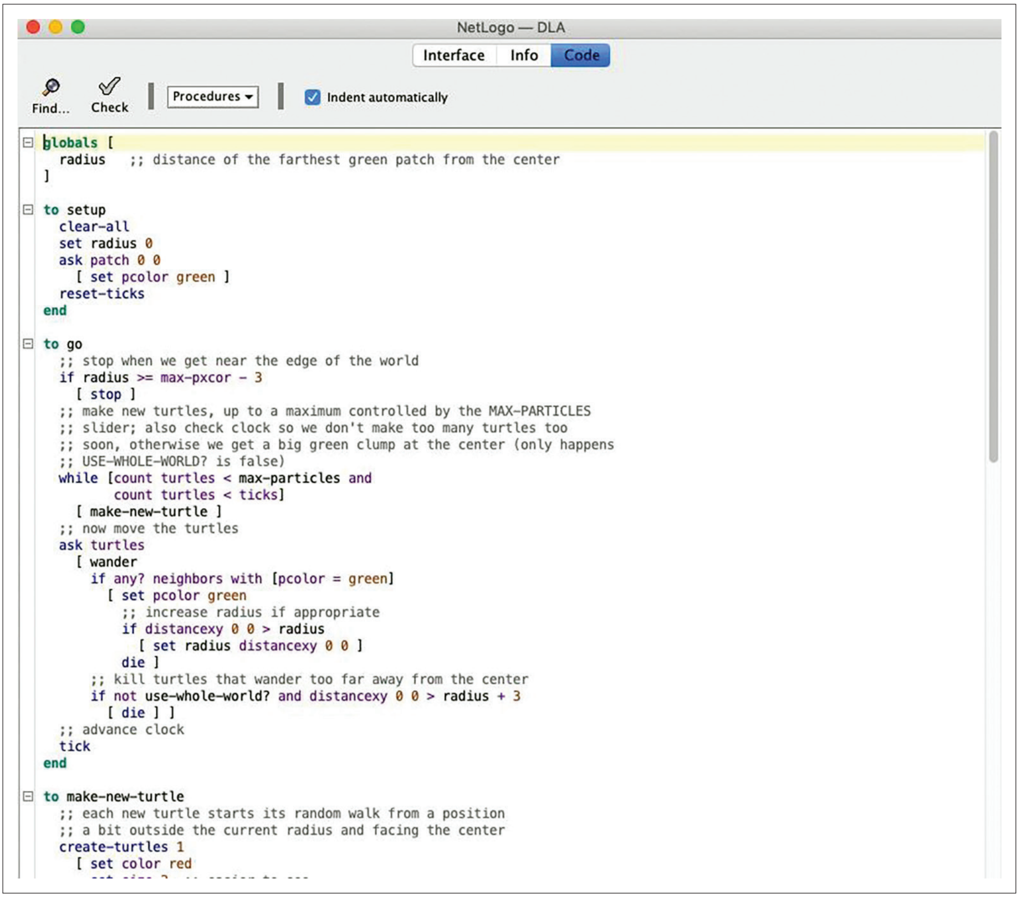
☐ *Inbuilt help: Pedagogical*

GeoGebra: GeoGebra does not have any inbuilt pedagogical help with the application. One can think of GeoGebra as a geometrical construction box which allows users to construct a variety of mathematical artefacts.



Source: Screenshot taken from NetLogo, date unspecified, written permission obtained to reproduce and publish this image.

FIGURE 4.11: The locally available NetLogo user manual.



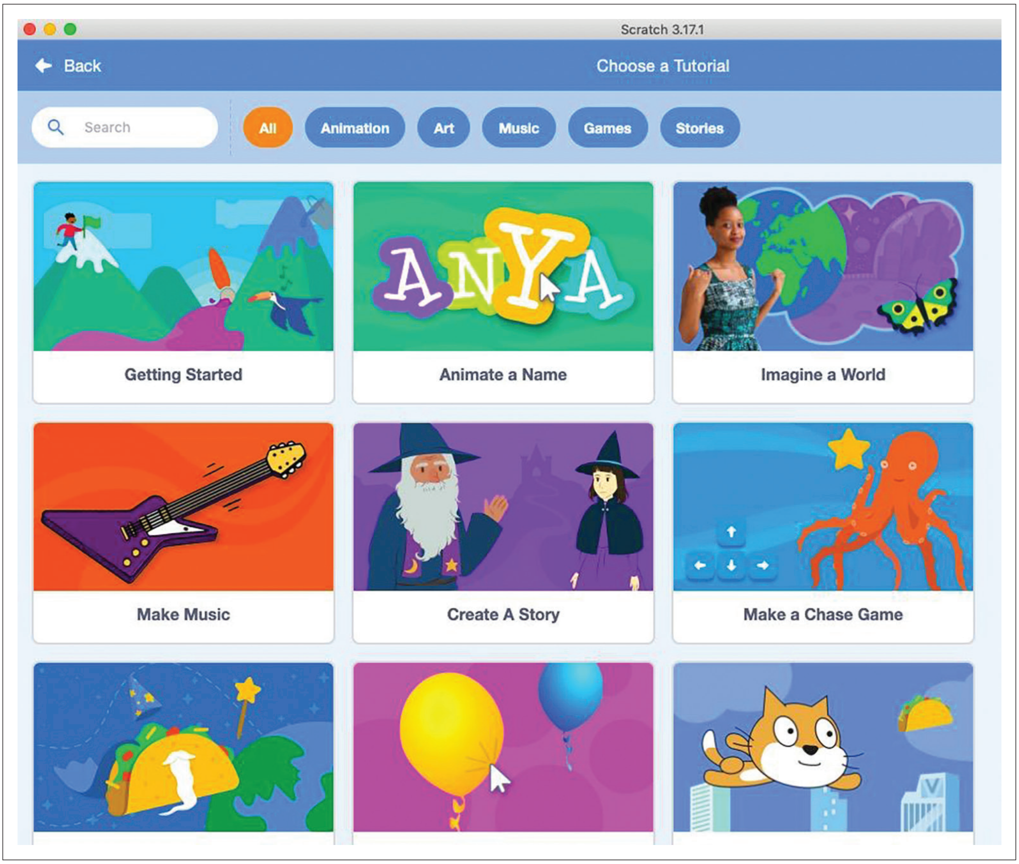
Source: Screenshot taken from NetLogo, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.12: NetLogo 'Code' tab.

NetLogo: NetLogo models explain a great deal about the model, including basic notions and interesting notes on the model, in the 'Info' tab (Figure 4.16).

Scratch and Turtle Blocks: Scratch and Turtle Blocks do not have 'pedagogical' content but can be used to express a variety of imaginations, topics and themes. The presence of media in various forms – such as graphics, audio and text – makes them versatile tools suited for such explorations and expressions.

☐ *Online resources: Open educational resources*

GeoGebra: The online repository[13] has over a million classroom materials and tutorials licensed under Creative Commons by SA-NC Ver. 3.0 and above. The



Source: Screenshot taken from Scratch, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.13: Tutorial programs in Scratch categorised according to animation, art, music, games and stories.

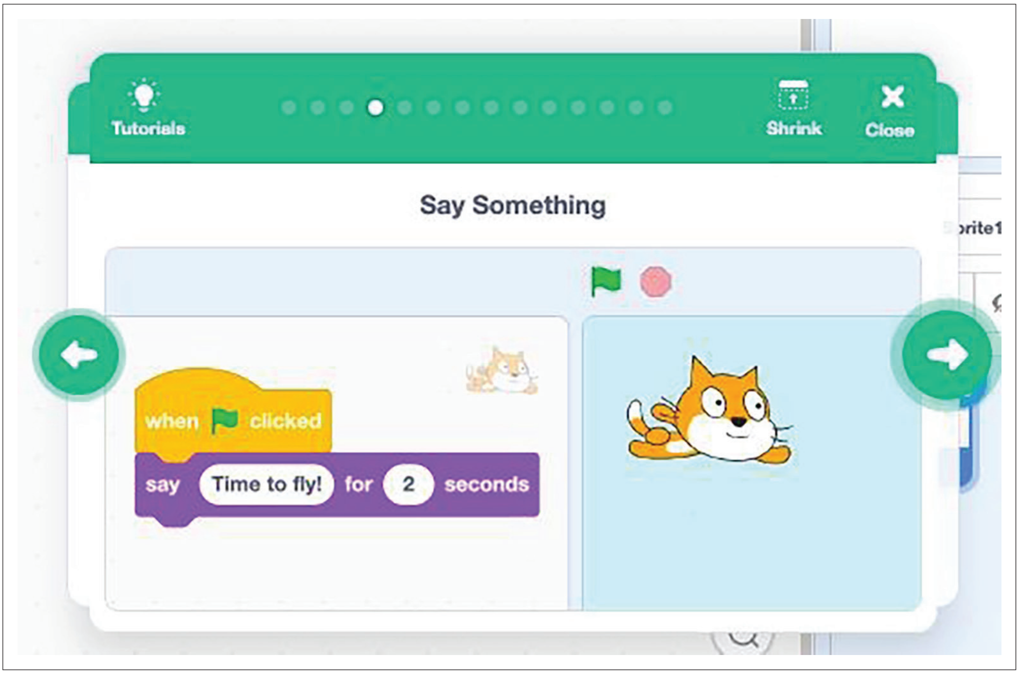
resources include interactive simulations, visual proofs, visualisations of mathematical constructions, books and assessments which are tagged with topics and grades.

NetLogo: The models in the NetLogo models library are available online[14] and are searchable. The online platform also has sections to discuss the model and look at the source code, version control and derivatives of the model. All the models are released with Creative Commons licenses (although the specific license terms for a given model can vary).

Scratch: The online repository of Scratch[15] has user-generated content that is available under Creative Commons by SA Ver. 2.0 license. The projects are classified into different categories depending on the type of project.

13. See http://geogebra.org.

14. See http://modelingcommons.org/.



Source: Screenshot taken from Scratch, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.14: Detail of a tutorial in Scratch.

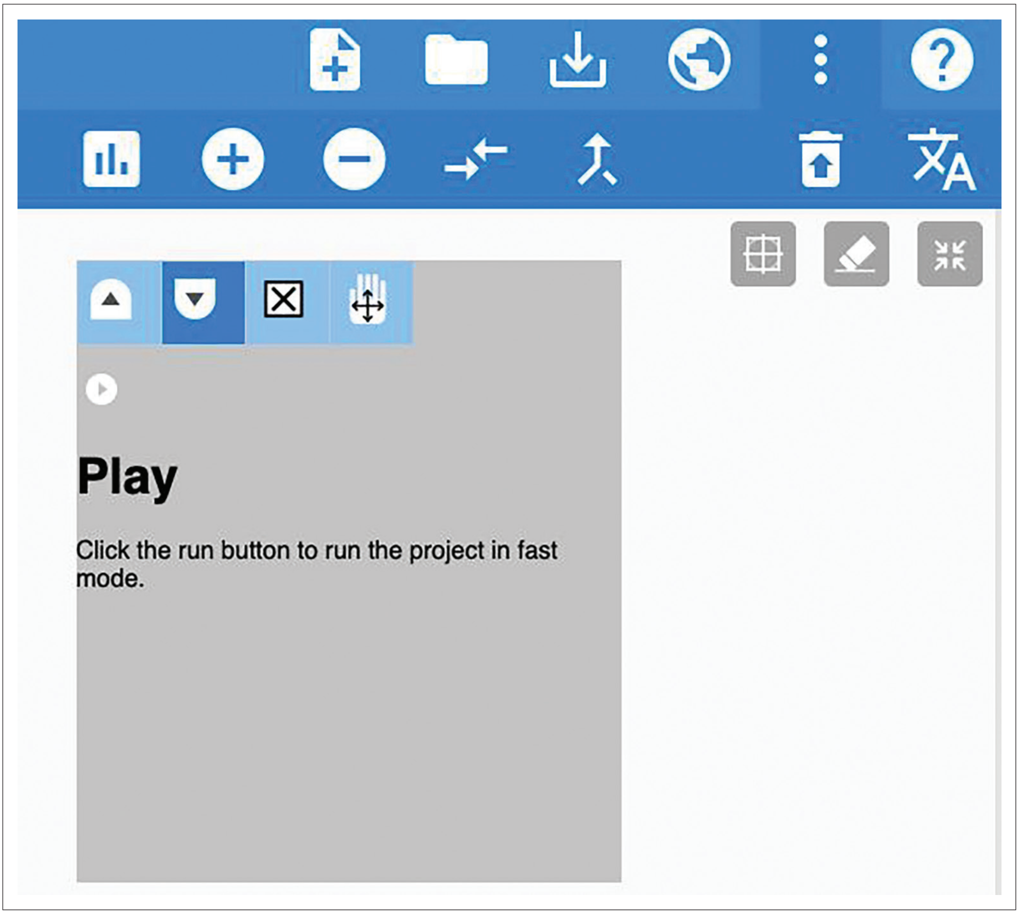
Turtle Blocks: Turtle Blocks has a 'Global' option in the interface where users can share their content to the worldwide community. The files are arranged according to categories. The license term is not explicit and is assumed to be AGPL.

All the online resources can be played online or downloaded for local use. Thus, we see that, in all four microworlds, there are rich online resources in the form of OERs that can be utilised by learners as needed. The presence of such resources potentially allows learners to set the goals for their own learning and would thus enable SDL.

Online support groups

Active fora are associated with the microworlds for discussing technical and pedagogical difficulties. Earlier, support was in the form of mailing lists (which still exist), but now online fora are more active in this regard.

15. See https://scratch.mit.edu/explore/projects/all.



Source: Screenshot taken from Turtle Blocks, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.15: The help in Turtle Blocks to explain the working of the interface.

GeoGebra: The multilingual online help forum[16] comprises categories such as Questions, Comments, Problems and Ideas.

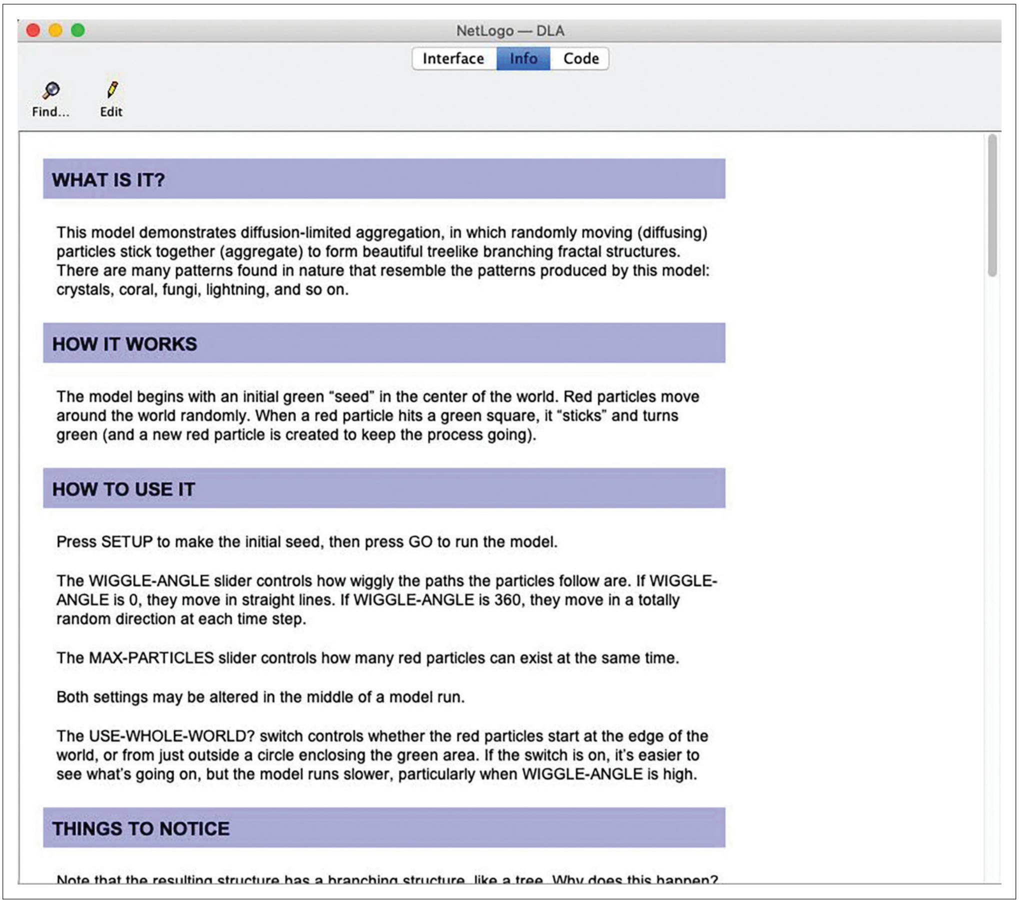
Scratch: The multilingual online help forum for Scratch.[17] It is active in several languages and has sections on projects, help among other topics.

NetLogo: NetLogo has two active online user groups. One is a Google group[18] which handles both pedagogical and technical queries. Stack Overflow

16. See https://help.geogebra.org/.

17. See https://scratch.mit.edu/discuss/.

18. See https://groups.google.com/g/netlogo-users.



Source: Screenshot taken from NetLogo, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.16: NetLogo 'Info' tab.

also has several topics pertaining to NetLogo. Other than this, the Modelling Commons[19] website is another forum for discussions of the models.

Turtle Blocks: The online help forum is in the form of a wiki.[20] It is, however, not as actively maintained as the other three applications.

Apart from these fora, for all the applications, GitHub repositories can be used to submit bugs and new features to the programs. Thus, there are multiple platforms and modalities in which learners are supported in microworlds.

19. See http://modelingcommons.org/.

20. See https://wiki.sugarlabs.org/go/Activities/Turtle_Art/Help.

Multimodal aspects of learning with microworlds

This section involves an analysis of the four microworlds as multimodal texts by means of metalanguage of multimodality (Bateman et al. 2017; Bezemer & Kress 2016; Kress & Van Leeuwen 2006). Some specific elements for each of the microworlds are highlighted, after which some general observations are discussed.

GeoGebra

GeoGebra is the least multimodal environment of the four. However, it still has elements of multimodality built in. In this regard, it involves a canvas with two subcanvases. However, additional canvases or frames (Bezemer & Kress 2016) can be prompted by the user in order to use certain tools and then set specific variables.

As with NetLogo, GeoGebra to an extent relies on the user having some mathematical knowledge, as the environment relies heavily on subject-specific semiotic affordances in GeoGebra (Bezemer & Kress 2016). This environment is also fairly interactive and changes can be instituted by the user. Because of the specific mathematical restrictions, this microworld is also highly scripted (Bateman et al. 2017).

Unlike the other three microworlds, position is a very important semiotic resource or mode (Bezemer & Kress 2016). Within the mathematical context, positioning is actually a focus, as it has specific communicative and semantic value.

Just as with the input of different media formats, the microworlds support the creation of varied media artefacts as output. Some of the major formats are visual, auditory, verbal and algebraic (equations). Visual formats may include shapes, colours, animations, movements, line drawings and graphs with interactive elements embedded. Options to export the active screen or output in various formats exist in all microworlds. Some of the major output formats include, but are not limited to, visual (JPG, PNG, SVG, PDF, EPS), verbal, videos/animations (animated GIFs), code (text, code blocks, LaTeX, nlogo), data (in form of text, tables, spreadsheets), audio (music and sound effects), Cartesian graphs (with data), drawing files for plotters and/or 3D printers, and control for external electronics and displays. Thus, in both input and output, the microworlds are rich in different modalities that they can produce and process and thus can cater to different learning styles.

NetLogo

NetLogo also has elements of multimodality; however, it can be considered less interactive. As the emphasis is more on the user modifying existing values and conditions rather than creating syntax, this environment can be considered even more highly scripted (Bateman et al. 2017) than the first two environments, unless users are capable of editing the NetLogo Code.

This environment also involves a canvas with different subcanvases, depending on the selection made in the models library. It is evident that NetLogo draws from an extensive set of semiotic affordances (Bezemer & Kress 2016). However, users must be informed about the social semiotic conventions of the different disciplines and topics realised through simulations. The information provided under 'Model Info' does provide some instructions and background.

The emphasis here is on users engaging with entering information changing the circumstances shown in the simulations; consequently, the complementary function (Bezemer & Kress 2016) of user input is more prominent. The changes instigated by the user can also result in a transformative or semiotic change (Bezemer & Kress 2016). However, at one level, syntax is less important in this environment, as that has been scripted, and the user is passively involved in intra-modal transformation of what is provided in the main subcanvas.

☐ Scratch

Scratch shows various elements of multimodality and has already been analysed within this context (Birchfield et al. 2008). According to Birchfield et al. (2008:5), 'Scratch incorporates multimodality through the integration of sound player modules within the primarily visual environment'. The analysis that follows was based on the various aspects of multimodality relevant to the identified canvases within the Scratch environment.

The Scratch environment utilises multiple canvases or frames (Bezemer & Kress 2016) through which meaning is conveyed. The three main canvases comprise a code list, programming and preview canvas. As a multimodal environment, Scratch relies heavily on visual and syntactical grammar. It is also quite significant that this environment supports a number of languages, as the instructions depend a lot on the semantic values of the words listed throughout the environment.

On the left, under the heading 'Code', various text-based commands and properties – *semiotic resources* in this context – are listed in what we call the *code list canvas*. This provides the meaning potential and grammar for this microworld. This canvas is highly multimodal, as this section includes elements that convey meaning through colour, text and shape. To this end, various colours indicate whether a semiotic resource relates to motion, looks, sound, events, control, sensing or acting as an operator or variable. There are also customisable semiotic resources that can be defined under 'My Blocks' as well as creation of user 'sprites' and sounds.

This microworld can be considered moderately scripted (Bateman et al. 2017), and the elements in the first canvas provide the syntax for the user of this microworld. Yet, the user is in control of how the syntax is utilised. This canvas is essential to the SDML process, as through the range of elements available on this canvas, there is a wide resource potential available for learners. It is a key element of SDL for learners to be able to select resources as they need them (Knowles 1975).

The canvas in the centre of the screen (the *programming canvas*) allows for semiotic resources to be combined in order to form computer programs. Here, the way in which semiotic resources are grouped and ordered are of importance. On this canvas, students can take charge and make use of the provided resources in order to create new meaning. Through the use of variables within the semiotic resources, which could include typed words and numbers, various properties and actions are highly customisable, allowing for interactivity. In this canvas, the image–text relation (Kress & Van Leeuwen 2006) is quite important as the shape contributes to meaning in a general sense, but in many cases, the text elaborates, qualifies and specialises the property or action, for example.

The *preview canvas* displays a realisation of the commands and inserted canvas elements through the use of different sprites or pictures that can be animated through this process. In a sense, the elements placed on the programming canvas act in a performative manner to lead to action within the preview canvas. The preview canvas can also be customised through different backgrounds, which can contribute towards communicating a specific context for the communicative acts performed here.

The code list canvas can be considered as being fairly non-interactive, while the programming canvas is highly interactive (Bateman et al. 2017) through direct user intervention. However, the preview canvas is quite unique as it is non-interactive but still active through action on the programming canvas by providing immediate feedback, which leads to instructions on the programming canvas being previewed here.

□ Turtle Blocks

Like Scratch, the Turtle Blocks environment also shows various elements of multimodality and uses a programming syntax that also involves shapes, colours and words to convey meaning. Scratch is different in that this environment basically only has one canvas through which users can both provide input and see the output in the same area. However, this process from input to output also involves a form of transduction (Bezemer & Kress 2016), as the verbal as well as graphical program is acted out through movement. Hence, meaning is changed from one mode to another.

To program in Turtle Blocks, the user needs to select, order and place programming semiotic resources or modes in an ensemble (Bezemer & Kress 2016) in order for the program to work. An interesting feature is the fact that variables are graphically plugged into certain commands. Hence, semantic relationships between various parts are established visually. Consequently, phrases are formed through shapes. Another example would be the Repeat loop, which has roughly the shape of a 'C' and encapsulates all the commands to be repeated within the two arms. So, there is less evidence of punctuation and rather framing (Bezemer & Kress 2016) between and inside elements. There is also evidence of this environment being highly scripted (Bateman et al. 2017), with the user having a lot of control over how the syntax is structured.
As with any communicative act, using Turtle Blocks also entails a process of encoding, transmission and decoding which is realised through actions performed by the turtle avatar placed in the centre of the screen. In terms of spatial arrangement as mode (Bezemer & Kress 2016), various menu elements are placed around the main canvas. Apart from the menu on the left that includes some text, the rest of the menu elements are exclusively graphical. Generally, these icons are reliant on users' knowledge of the meaning of the icons. This property emphasises the social aspect of interactional multimodality in this environment. So, through building on existing semiotic affordances (Bezemer & Kress 2016), these icons draw on existing practices and reinforce and extend their use.

Microworlds as multimodal texts for self-directed multimodal learning

From the analysis, various elements of multimodality could be discerned from the microworlds. Varying degrees of interactivity and user involvement is possible. However, both verbal and graphical semiotic resources and modes are utilised throughout. The socially mediated communicative aspect does come through quite prominently, as users might have to be informed about the social conventions and knowledge related to a particular discipline in order to effectively use the environments. This pre-knowledge would also influence successful SDML. In addition, the different microworlds form unique semiotic landscapes (Kress & Van Leeuwen 2006) that can be utilised by teachers for SDML.

As different elements in the analysed microworlds contain semiotic modes, they fulfil the three metafunctions: ideational, interpersonal and textual (cf. Kress & Van Leeuwen 2006). On an ideational level, there are elements of representation of the world around us and even personal experience, as users are involved in the creation of the text presented on the screen. Key to the ideational level is the logical function, as logical and semantic relationships are visualised and constructed in all four microworlds. At an interpersonal level, the environment itself does not necessarily relate to any social interactions; however, as was noted earlier, in regard to interaction and learning, these microworlds have separate vibrant user communities that attend to this aspect. The textual function is quite prominent in all four microworlds, as they all form coherent wholes. As such, the individual microworlds have context-specific rules and syntaxes that adhere to the social rules set by the creators and even the communities of the microworlds. Through transduction (Kress & Van Leeuwen 2006), users can plan and prepare certain actions in one model (perhaps verbal, or visual combined with verbal), while in another canvas or subcanvas, the actions are displayed visually.

To utilise these, microworlds for SDML would require teachers and learners to understand the communicative aspects relevant to these multimodal texts. Consequently, the learning process would also involve some form of support towards visual literacy relevant to these contexts.

Findings and recommendations

In the last two sections, we have seen different design features of the selected microworlds as well as the pedagogical and technical support that is available to learners. In this section, we discuss these features in the context of the research questions.

Self-directed learning and microworlds

The first research subquestion, pertaining to SDL support, enquired about the design features that match the requirements for a supporting environment for SDL. The metaphor of a room with a low floor, high ceiling and wide walls perfectly encapsulates one of the requirements for an SDL-enabling environment – that of matching the readiness level of the learner. We have seen that, from very basic applications, microworlds can be used to construct complex projects. Thus, depending on where the learner is, a microworld can be used to match learners' abilities.

The second principle of progress towards a learner-directed approach depends on the implementation of microworlds with learners. While the constructionist paradigm calls for public projects that are personally relevant to learners, all the implementations may not deploy it in this manner. Microworlds can be used in a very regimented manner without any autonomy for learners. In such cases, even if microworlds are used, they would not enable SDL or entail constructionist learning. The change of the role of teachers from traditional knowledge givers to enablers can be quite challenging.

When projects and their goals are selected by learners, and teachers play the role of facilitators in completion of the projects, microworlds can potentially provide a good environment for enabling SDL.

Numerous learning resources and support mechanisms are available for all four microworlds, as can be seen from our limited survey. Learning resources available as OERs make their distribution, use and adaptation easy. Both inbuilt and online help for programming and pedagogical issues are exhaustive and online fora can help resolve any new challenges that learners face. The microworlds have well-established support mechanisms for acquisition of knowledge by learners on their own, thus actualising the third principle of enabling SDL.

Finally, the fourth principle relates to students practising SDL within the context of performing learning tasks. The idea of learner autonomy is also relevant to this principle, which, in turn, implies the way microworlds are implemented. Microworlds present several avenues where learners can practise SDL in the context of learning tasks. In this regard, the feature of tinkerability of microworlds discussed earlier is highly relevant. Tinkerability of microworlds allows learners to explore and experiment on their own. Learners can also choose to tinker already existing projects to explore and experiment, a feature that is present in all four selected microworlds. As such, the process of tinkering is self-directed, and the spirit of tinkering would be lost if teachers directed it externally. Another germane concept is that of epistemological pluralism in the context of microworlds. By allowing different approaches to learning tasks via tinkering and complementing different learning styles, the enabling of epistemological pluralism puts the learner in focus. Epistemological pluralism is also relevant for the first principle relating to matching learner readiness. Learners can also practise SDL by participating in online fora, posting questions and solving problems. Such an activity can be personally rewarding and is self-directed aligned with the interests of each learner.

Thus, overall, microworlds, if implemented with a learner-centric approach, can potentially provide an SDL-enabling environment.

Multimodal learning and microworlds

At the start of this research, the following research question was posed: What aspects of multimodal learning are supported by microworlds? The wider affordances of multimodal learning were considered, as the focus of this research was not only on SDL but also how it is realised through SDML.

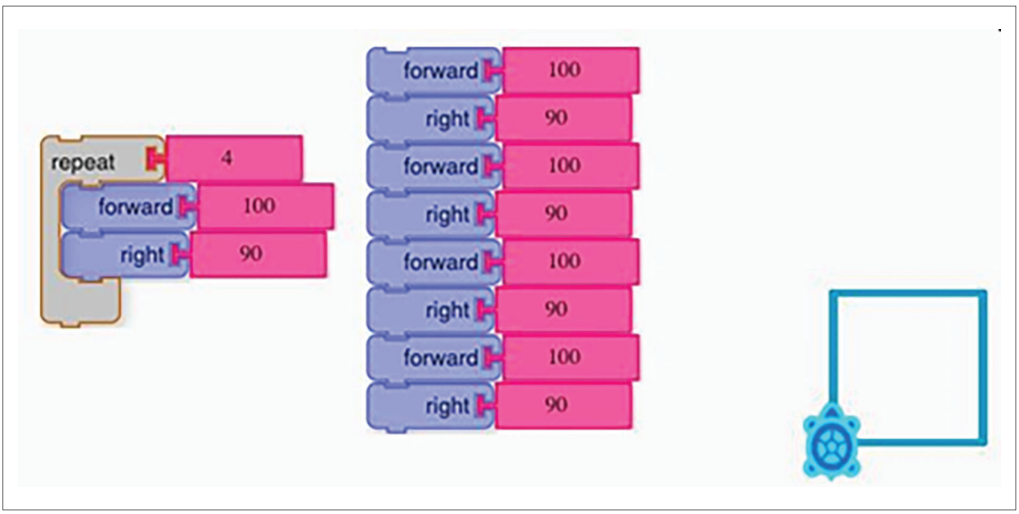
It is clear that the analysed microworlds are highly appropriate resources to use within a context of individual multimodality (Olivier 2020a, 2020b). In this regard, at this level, students draw on their personal modal preferences to support their learning. The varied forms of input and output from microworlds support this, despite an overemphasis on nonverbal and visual features. However, the multimodal nature of these environments would be supportive to learning, especially as regards the transfer of sensory modalities.

Furthermore, at the level of interactional multimodality (Olivier 2020a, 2020b), microworlds highlight effective multimodal communication. The verbal and visual semiotic resources utilised in microworlds allow for unique semantic potential, but in some cases, users should first acquire the syntax of each environment in order to effectively function and ultimately learn through the aid of microworlds. The highly customisable nature of multimodal interactions in microworlds is supportive towards SDL and ultimately SDML.

All microworlds can also potentially be used within an instructional multimodality context as part of online or even blended face-to-face and online learning experiences. The nature of microworlds would allow for both teacher- and peer-supported or more independent learning activities. Depending on the strategies employed by teachers, microworlds can at an instructional multimodality level be employed to foster SDL.

Problem-solving and microworlds

Microworlds enable learners to set up and solve problems in diverse ways. In most cases, there are multiple ways in which a particular problem can be solved. There is no 'right' or 'wrong' solution (Figure 4.17), and this is precisely the meaning of a 'safe space' in the definition of a microworld. Such a 'safe space' implies diverse ways of learning, which, in turn, leads to the idea of epistemological pluralism.



Source: Screenshot taken from Turtle Blocks, date unspecified, written permission obtained to reproduce and publish this image.
FIGURE 4.17: Two ways of solving a 'problem'.

Both program blocks produce the same output. Closely associated with this is the feature of tinkerability of microworlds. Having such a feature enables learners to discover novel solutions to problems on their own, thus creating 'Aha!' moments. Finally, microworlds present learners with 'objects to think with' which help in posing and solving problems. 'Objects to think with' allow externalisation of memory and reduce cognitive load of learners. In such cases, learners can concretise abstract problems and clarify them in a problem space (Rieber 2004). The implications on any conjectures while solving problems are obtained at once, as learners can 'tinker' to solve a problem. Thus, microworlds provide a safe space to pose and solve problems and provide learners with scaffolding in the form of 'objects to think with' and features that allow tinkering.

Collaboration and microworlds

In the pre-Internet era, collaboration in microworlds was in the form of groups of students working together on projects. Although offline collaborations are possible, we limit our discussion here to online collaborations. The basis of collaboration is the ability to share work with peers. The presence of online fora and dedicated platforms to share work allows virtual collaboration between learners with ease. For this to be possible, the licensing of the content under Creative Commons is crucial to allow for remixing of the content as it allows the users to use content generated by others without difficulty.

Stahl, Rosé and Goggins (2017) presented a novel way of using GeoGebra in an online collaborative environment. Similarly, the online version of NetLogo[21] is specifically designed to enable online collaborations between people using the same models and has features supporting collaborations. In the case of Scratch, both forum-based and studio-based collaborations are possible, and the online interface supports this well, using either the backpack- or the remix tool. In the case of Turtle Blocks, learners can share their work with others and remix the work freely using the 'Global' option.

Online user platforms and appropriate licensing have thus made it easy for collaboration in microworlds.

Resources and microworlds

The following question was also posed at the start of this chapter: What resources are available to learners and facilitators for microworlds in the SDML context? This issue is highly relevant, as to facilitate SDL as a process, learners must be able to select appropriate resources (cf. Knowles 1975).

21. See http://modelingcommons.org/.

The resources available in microworlds occur at both micro- and macro-levels. At a micro-level, learners can make use of semiotic resources used to communicate with and through microworlds in order to solve problems, run a particular process or set of instructions, or do an experiment. This aspect of micro-resource selection is highly relevant for both individuals and interactional multimodality and can also be considered an important part of SDML.

At a macro-level, learners make use of not only microworlds themselves but also supportive texts and resources. All four microworlds discussed in this study have a wide variety of resources in various formats that can help learners and facilitators in the SDML context. Multiple tutorials are available for learners (both novice and advanced), and for teachers, teacher manuals are available.

Also, it is significant that these resources are available as OERs, which makes their distribution at scale, contextual adaptation and remixing possible. For example, contextual adaptation is evident in the number of languages in which such resources (including user interface) are available.

Limitations

This research entailed an explorative evaluation of microworlds in the context of SDML. There are several limitations to this research. Firstly, this research was confined to microworlds as data source, and consequently, the perspectives of learners and their experiences with microworlds in this context are absent and the study is limited to potentialities of SDL-enabling environments. Secondly, this research did not include any observations of the actual use of microworlds by users or within classroom contexts. Lastly, the selection of four specific microworlds also limits the generalisability of the findings for all possible microworlds or even these in future iterations, as they may have other advantages and/or disadvantages.

Recommendations for future studies

From the discussion, some possible areas for future research also emerged. Future studies in this field can focus on learners and facilitators using microworlds in the context of SDML. Furthermore, microworld classroom implementation in the context of SDML could also be explored, with a specific focus on learner agency in collaborative practices in the microworlds supporting SDL. The challenges and opportunities for novice and expert self-directed learners in the use of microworlds and assessments in microworlds in SDML can be investigated. The potential of learning analytics of microworlds in SDML can be researched further. The affordances of microworlds for SDML and metacognition could also be source of further scholarship.

Conclusion

In conclusion, this study aimed to explore what features of microworlds enable them to be supportive learning environments for SDML. To this end, the design features with the potential to support SDL as well as aspects of multimodal learning were investigated. We also covered elements that would be conducive to problem-solving and collaboration. Finally, the resources available to learners and teachers as facilitators were considered.

The features, resources and fora of microworlds as SDL-enabling environments were evaluated. Our analysis indicates that microworlds can be potentially well adapted for SDL, although not without caveats. The importance of learner agency in constructionism is brought into practice via the features of microworlds and, as such, resonates with the principal ideas of SDL. The presence of online platforms and fora allows for diverse expressions of learner self-directedness and opens new avenues for collaboration with peers and mentors. The inherent multimodalities in microworlds are indicative of the versatility in the manner in which they can be used by different learners.

In this context, Papert's idea of 'learning to learn', which can be actualised in microworlds, is especially relevant for SDL. While many learning theories focus on 'pedagogy' (which literally means 'art of teaching'), constructionism, in contrast, focuses on learners and uses the term *mathetic* (meaning the 'art of learning') as a learning principle (Papert 1980). In this context, a quote from Papert is apt in enabling SDL: 'The kind of knowledge that children most need is the knowledge that will help them get more knowledge' (Papert 1993:139).

All microworlds discussed in this chapter are based and can be accessed on computers and the Internet (for online platforms) and could pose potential challenges for wider implementation in terms of access to connected computers. This can be especially challenging when implemented in the context of the Global South.

This research was done through the lens of constructionism, and the scholarship of microworlds and SDML provided a theoretical basis. The exploratory evaluation and a multimodal content analysis of the four selected microworlds showed promise in light of Francom's (2010) principles of enabling environments for SDL. Moreover, the microworlds showed evidence of not only supporting multimodal learning but also involving various elements of multimodality that could be supportive of effective SDML.

Chapter 5

Identifying adaptive prompts to facilitate metacognitive regulation during online learning

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Abstract

Prompts adapting to students' learning needs during engagement with online tasks are starting to receive increasing attention at school and university level. This is one attempt of the digital-education movement set in motion to improve, develop and promote SDL skills, as part of a personalised adaptive

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approach to teaching and learning. In addition, SDL skills include learning skills such as goal setting, the use of suitable planning strategies, monitoring strategies and managing the time spent on a task when evaluating the extent to which the learning outcomes were obtained. As these skills become needed for deep learning in the 21st century, prompts reflect growing interest in the field of personalised and adaptive learning systems. While adaptive learning is a promising field for education, stakeholders need to be familiar with how technology facilitates important metacognitive regulation behaviour, such as planning, monitoring and evaluation. However, few studies have combined previous research on how technology facilitates metacognitive regulation with adaptive prompts. The purpose of this chapter is therefore twofold: (1) it offers a literature review on technology-based adaptive learning with an emphasis on the use of adaptive prompts to promote SDL, and, based on this review, (2) proposes a conceptual framework to support research in this field by providing evidence for the conditions of prompting. A review of the literature revealed various categories of metacognitive prompts for the domains of metacognitive regulation, including prompts to aid in planning, monitoring and evaluating on either a novice, transition or expert level.

Introduction

Prompts present a form of scaffolding, also called guidance, which could appear in the form of sentence-starters, hints or checklists that provide clear, interactive guidance through a cognitive guidance system (Davis 1996). Adaptive online learning environments have the objective of enabling learners' learning by adjusting such interactions with web-based or online tools and content in e-learning environments (Boaler et al. 2018). In these environments, prompts can serve as a useful tool to scaffold learning. The setting up of learning scaffolds, such as prompts, in online learning tasks is rarely personal and adaptive. Findings of research (e.g. Azevedo et al. 2010; Boaler et al. 2018) indicate learning with metacognitive tools (such as adaptive prompts) in online environments and involve the deployment of metacognitive regulation (or self-regulation) skills. Although such skills are essential for online learning in general and for personalised and adaptive learning in particular, we believe there is little literature on how, for example, metacognitive regulation can be assisted by technology-based adaptive prompts.

Although the importance of personalised and adaptive learning is generally recognised and despite the fact that adaptive and personalised learning systems create digital learning experiences, there is limited literature on how metacognitive regulation can be promoted as a state or ability of SDL in this context, as the initial search using metacognition in technology-based adaptive learning's keywords in Harzing's Publish or Perish software package shows. In our view, this is because of the fact that adaptive learning systems in particular form 'complex' learning environments from a technological and instructional point of view. At present, however, metacognitive regulation is often recorded methodologically with questions, questionnaires or interviews (see e.g. Jagals & Van der Walt 2018). However, this type of measurement before or after the learning process seems to fall too short to cope with the complex interaction of instructional goals, technological possibilities and individual needs (Little & McDaniel 2015). Less frequently, we find studies with direct observation. In our opinion, however, it is a possibility to obtain differentiated results on this topic on the basis of prototypical or developed applications, when it is directly observed how the promotion of SDL can take place through adaptive prompts or scaffolds and which learning effects result on learning behaviour or even learning performance. In a cyclical process, both the applications and the research questions could then be differentiated or further developed. On the basis of these reflections, the primary research question that this chapter addresses is: How can adaptive prompts facilitate metacognitive regulation during online learning *to promote self-directed learning?*

■ Theoretical basics

Adaptive online learning typically involves technology procedures in an arrangement with generated data to monitor learning process and, by doing so, applies these data to adapt the teaching process to meet learner's learning needs (Azevedo et al. 2010). Yokoyama and Miwa (2020) defined adaptive learning as those data-driven results that inform the approaches to teaching and remediation, modified according to each learner's online behaviour, demonstrated by their level of attainment, and subsequently anticipating what content, instruction and assessment the learner requires at a particular stage during learning. This is in tune Bath and Bourke's (2010:2) blended learning modes which are often described as technological supportive learning that is self-directed in nature.

Metacognitive regulation, in light of this process, refers then to the behaviour to plan, monitor and evaluate the learning experiences (Little & McDaniel 2015). To plan, the learner can select a particular task or strategy, read a question more than once or draw a diagram to better understand what the task requires (Jagals & Van der Walt 2018). A learner who monitors will continually check if the task calls on specific and relevant prior knowledge and skills, and aim to meet these task requirements. A learner might monitor task performance by checking their answers and make sure the strategy they apply is working for them. At the end, the learner can identify and correct any misconceptions about the task and revise where necessary. To evaluate the progress, the learner can decide if the solution is correct, is meaningful or holds some practical significance. A learner could, for instance, evaluate when asking: 'Is this correct?'

Specifically, to prompt enables learners to plan, monitor and evaluate through the defining characteristics of the metacognitive regulation dimensions. These metacognitive regulation prompts should then refer the learner's thinking to and about the behavioural strategies that they employ when they plan, monitor and evaluate the learning experience (Little & McDaniel 2015).

In such personalised and adaptive learning situations, prompts need to be personalised to adapt to leaners' needs as they aim to facilitate metacognitive regulation, which develops over time (Imhof, Bergamin & McGarrity 2020). When designing an adaptive course there's always the option not to prompt or to prompt or to prompt adaptively with categories and subcategories developed to impose prompts across these conditions as: (1) no prompts, (2) non-adaptive prompts, and (3) adaptive prompts. In this sense, the setup of applicable prompts for non-adaptive and adaptive conditions considers specific prompts for each dimension of metacognitive regulation. For instance, a learner who is perceived on average level in a standardised test can be assigned to a category of transition learners where they receive prompts to aid them towards an expert category. However, learners who perform above average in the test are assigned to a category of expert learner, where they receive prompts to help them revise their inferences and prior knowledge to be effective for high-knowledge learners.

Self-directed learning in online learning

The purpose of applying personalised and adaptive learning techniques is to provide adaptive feedback in the form of hints or recommendations that, in this case, are associated with regulatory domain of metacognition. As such, the prompts are believed to steer the meta-level operations (such as planning, monitoring and evaluation) to promote a personalised process of SDL. In this process, the typical behaviour indicated by Knowles (1975) would be stimulated to '(1) take initiative, (2) to diagnose learning needs as in the case of prompting reflective questions for monitoring, (3) formulate learning goals, (4) identify resources for learning, select and implement learning strategies, and evaluate learning outcomes'. In addition, Lounsbury et al. (2009) explained that:

> [*S*]elf-directed learning is 'a disposition to engage in learning activities where the individual takes personal responsibility for developing and carrying out learning endeavours in an autonomous manner without necessarily being prompted or guided by other people' (such as a teacher, parent, or peer). (p. 411)

Taminiau et al. (2014) pointed out that SDL skills include learners' choice of learning paths outlined according to their own learning needs. This requires the use of self-assessment, or monitoring of the self, to reflectively know which task to select and how to determine, and follow, the path for learning. Monitoring is therefore an indicator of the domain-specific knowledge and skills that are reflected upon at a certain moment during the task. In Taminiau et al.'s (2014) research, scaffolds were built into an adaptive learning system through a series of task-selection advice on selecting appropriate tasks. The advice served as prompts to elicit SDL skills, including learners' self-assessment and task selection strategies. Learners who follow the advice (prompts) showed developed domain-specific skills that are needed for solving the tasks. In the current project, the task was designed mainly to create recurring opportunities for learners to self-assess their own knowledge, or the limitations thereof is believed to assist them in articulating their thoughts, and this fosters a shared understanding.

Metacognition in online learning

Tarricone's (2011) conceptual framework of metacognition suggests that metacognition consists of three interlinked concepts: (1) metacognitive knowledge, which refers to the declarative, procedural and conditional knowledge about the self/person, task and strategy, (2) metacognitive regulation, which refers to the planning, monitoring and evaluating behaviour, and (3) metacognitive experiences, referring to personal reflective judgements and feelings of knowing. The distinction between these concepts involves knowing (or being aware of) one's cognition, managing (or regulating) cognition and experiencing the self as learner or thinker. In online learning environments, a computer serves as a metacognitive tool in adaptive and personalised learning and emphasises the state (current or contextual) of metacognitive behaviour (Khiat 2017). Approaches for assessing this metacognitive behaviour in adaptive learning systems research involve a variety of methods and seem to depend on the nature of the measure (Azevedo et al. 2010).

In most cases, it seems that metacognitive knowledge is assessed offline, before and after the engagement with the adaptive learning system (Ozturk 2017), whereas metacognitive regulation is assessed before (in terms of prior knowledge and skills), during (with meta-data of task engagement) and afterwards (through simulated-recall with reflections on recorded screen playback) (Veenman et al. 2014). There seems to be some confusion in the literature as to when the authors are measuring self-regulation or metacognitive regulation. Self-regulation includes the dimensions of planning, monitoring and evaluation. As Hoffman and Nadelson (2010:247) state, self-regulated 'individuals are cognitively engaged, use self-regulation strategies to plan, monitor, and evaluate learning …'. Researchers seem to use self-regulation and metacognitive regulation interchangeably. Because metacognitive regulation can act as a trait and a state in problem-solving (Azevedo et al. 2015), indicators of metacognitive regulation are needed to measure this construct online and during task-engagement.

Research into metacognitive regulation focuses on how learners monitor and control their thinking, beliefs and strategies (Hadwin, Järvelä & Miller 2011). As learners can regulate their behaviour, cognition and affective experiences, this regulatory behaviour can be considered as observable actions to show or indicate the metacognitive skill of planning, monitoring or evaluating. Pudło and Pisula (2018) explained that reaction time can be determined to categorise and validate metacognitive indicators of planning, monitoring and evaluation.

Adaptive prompting as a metacognitive design perspective

Lu et al.'s (2012:171) theoretical framework of web-based SDL was utilised in this analysis as it provides the necessary 'structure categories, dimensions, and aspects'. Research on prompts as forms of scaffolds to enhance SDL, adaptive and personalised learning is still new in the field of mathematics education. Education stakeholders, including mathematics teachers, curriculum developers and administrators, need to become familiar with ways to facilitate metacognitive regulation in adaptive learning environments. The problem is that few studies have synthesised research in this field to identify and develop prompts to facilitate regulation behaviour such as planning, monitoring and evaluation. As metacognitive regulation can promote SDL skills (Jagals & Van der Walt 2018), an overview of relevant literature is critical to enhance mathematics education stakeholders' understanding about adaptive learning. To address this need, a literature review was conducted.

Scaffolding is defined as the assistance given to a learner during task-engagement when they need it and gradually removing some or all of the scaffolds as learning progresses (Davis 1996). Research indicated that scaffolds in technology-based adaptive learning environments are useful for learners to regulate their learning (Veenman et al. 2014). Metacognitive scaffolds can therefore be regarded as those scaffolding required to facilitate metacognitive regulation skills, by providing examples, prompts and hints on how, when and what to plan, monitor and evaluate – in other words, the prompts draw the learner's attention to the declarative, procedural and conditional knowledge (Imhof et al. 2020). Examples of metacognitive prompts that serve as scaffolds that can be implemented in an online learning platform include the providing of scaffolding messages or prompts based on a literature review, as well as the availability of examples of similar tasks during task-engagement.

Scaffolds can also include a diagnosis during which a computer program or online platform prepared with a unique learning algorithm will intervene in the learning process by having diagnosed a particular learning habit and therefore adapts the system by providing a different protocol, or self-diagnoses during which a learner can reflect on the provided hints and prompts as cues to facilitate the planning, monitoring and evaluating behaviour associated with metacognitive regulation (Azevedo et al. 2010). For illustrative purposes, some examples of the underpinning characteristics of these indicators of metacognitive regulation skills and behaviour in online platforms are outlined in Table 5.1.

Neubrand and Harms (2017) explained that prompts can serve as independent variables that call onto particular skills during the engagement or solving of online tasks. In personalised and adaptive learning environments, these prompts need to scaffold the personalised learning as they aim to promote the learner's capacity to draw on and execute their metacognitive regulation behaviour, which progresses over time because of the familiarity of the prompts and the awareness of the prompted skills (Neubrand & Harms 2017). Three different categories to develop and impose such metacognitive prompts include the determined prompt conditions as: (1) no prompts, (2) non-adaptive prompts, and (3) adaptive prompts (Neubrand & Harms 2017).

TABLE 5.1: Characteristics of adaptive learning systems as metacognitive tools.

Online tasks	**Description**	**Indicators as measurements**	**Source suggesting the approach**
Learners make instructional decisions regarding learning goals	1. Setting learning goals 2. Sequence instructions 3. Looking for and collecting resources 4. Organising and coordinating the resources 5. Make decisions regarding the resources to use to support learning goals or task 6. Modify in these decisions in order to attain the learning goals	Digital adaptive flashcards Behavioural screen capture Bliki (blogs and wikis) Think aloud protocols	Merten and Conati (2006) Gordesky et al. (2018) Huang and Yang (2009) Veenman et al. (2014)
Learning should take place in a particular context and should be situation-based	Determine: 7. how much support is needed 8. what types of contextual resources may facilitate learning, 9. when to seek contextual resources 10. the utility and value of contextual resources	Online questionnaires Behavioural screen capture	Butler and Winne (1995) Pengnate and Antonenko (2013)
Models, prompts, and supports self-regulatory processes	11. Activating prior knowledge 12. Planning, creating subgoals 13. Learning strategies 14. Feeling of knowing 15. Monitoring 16. Evaluate 17. Motivational (e.g. self-efficacy, task value, interest, effort) 18. Affective (e.g. frustration, surprise, delight)	Think aloud protocol Prompts Online questionnaires Eye tracking (fixations) Stimulated recall Facial expressions Reaction time Self-reports on traits	Ozturk (2017) Winters, Greene and Costich (2008) Veenman (2005) Azevedo et al. (2010)

Figure 5.1 illustrates these different conditions along with corresponding categories of prompts that are aligned with particular metacognitive regulation behaviour.

The setup and design of applicable metacognitive prompts for the condition of non-adaptive and adaptive prompting consider specific categories and types of prompts for each dimension of metacognitive regulation. For instance, prompts first need to align with the specific planning, monitoring and evaluating activities as determined by the task and are anticipated by the task sequence or level of cognitive difficulty (Neubrand & Harms 2017). An adaptive system must therefore be set up to assign to learners, on an individual basis, a particular condition of prompting, in such a manner that they will benefit from the prompt – which will scaffold the type, category and prompt conditions. Following this, the system also assigns to each learner a category within that condition. Such a prompt-by-category condition will therefore differ in each case.

In the study by Neubrand and Harms (2017), for instance, learners were assigned to prompt conditions according to their performance in a standardised test (such as Annual National Assessments or Trends in mathematics Science Surveys common in mathematics and physical science programmes). Learners' test performances further assist to being assigned to the applicable prompt condition categories (i.e. the learner is on a novice, transition or expert level). Learners who then measure with a low performance profile in the standardised test, therefore, are assigned to a category of novice learners based on their prior knowledge. These transition stage learners receive prompts that enable them to improve their performance in the subject so that they can achieve a

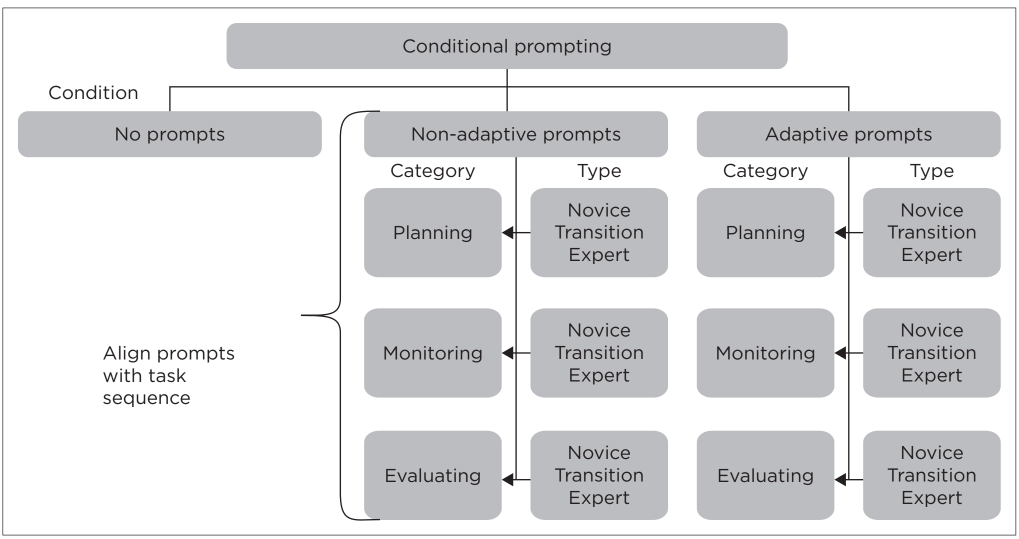


FIGURE 5.1: Hierarchy of prompting conditions: Types and categories of prompts.

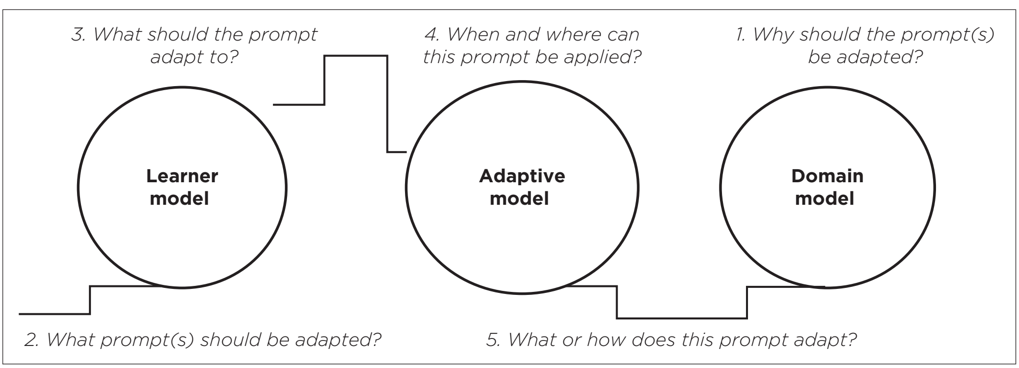
higher performance. Learners who then measure on an average level in the standardised testing are then assigned to a transition level where they receive metacognitive prompts that aid them towards an expert stage. Learners who perform above average in the standardised test are then assigned to a category of expert learner, where they receive set prompts to help them revise their inferences and prior knowledge, and in so doing, they can be more effective as high-knowledge learners (Neubrand & Harms 2017).

Personal and adaptive learning systems

Collectively, the theoretical basics outlined above inform the development of a conceptual-theoretical framework for this study, illustrated in Figure 5.2.

The framework depicted in Figure 5.2 serves as a broad outline of the preliminary conceptual-theoretical framework of this project, viewed through the lenses of a learner model, an adaptive model and a domain model, from Imhof et al. (2020), and modified for the purpose of fostering metacognition and SDL through adaptive learning prompts. This framework therefore serves as a theoretical basis for this study and provides a practical application of the theoretical framework to focus on the learner for whom the adapted learning system is created and prompts are designed. In this adaptive system, the learner engages with a series of tasks, which could include scaffolds (i.e. prompts, hints and examples) and which serve as tools to elicit signs or indicators of their metacognitive regulation. The purpose of these tools and signs (the tasks and scaffolds) is set and aimed to facilitate metacognitive regulation behaviour, and this is the object of this activity system. In turn, it is believed that once metacognitive regulation is facilitated, the learner can be (more) self-directed as the outcome of the activity system.

Vagale and Niedrite (2012) explained the learner model as the user or student model which represents the learner or student. This model embodies



Source: Adapted from Imhof, Bergamin & McGarrity (2020).

FIGURE 5.2: Model of core components of adaptive learning prompts.

the qualities including attributes such as gender, prior knowledge and skills, particular learning styles or the affective state. These measured qualities are then conveyed to the adaptive model which combined the information gathered from the learner model with information in the course or curriculum design that is situated in the domain model.

According to Coertjens (2018), such an adaptive and personalised learning system that can facilitate metacognition in adaptive and personalised instructional designs consists of:

1. *a concept* of a particular task or goal to reach
2. *design* a user friendly online platform to generate learning experiences
3. *intelligent instruction* to provide hints for appropriate correction
4. a *workflow space* for learner creations in the form of written reflections
5. a mechanism to *oversee learner workflow*
6. an *instructional workflow* for the lecturer's administration
7. a *database* for online exercises categorised according to the learner's personal learning behaviour.

To apply the core components identified by Imhof et al.'s (2020) model of the core components of adaptive learning systems, the following questions can be phrased:

1. Why should the prompt(s) be adapted?
2. What prompt(s) should be adapted?
3. What should the prompt adapt to?
4. Where and when can this prompt be applied?
5. How does the prompt adapt?

These questions are revisited in the discussion section of this chapter as a response to each based on a sampled and analysed literature set as application of the model and exploring of the adaptations of prompts to facilitate metacognitive awareness.

Methodology

Setting up these prompts to facilitate metacognitive regulation in online learning tasks seldom personalises the learning experience, and this is perhaps because of a gap in the literature to report on such procedures. As metacognitive regulation is an important measure of SDL (source), prompts that facilitate metacognitive regulation could promote SDL skills. We adopted the conceptual analysis procedure by Avella et al. (2016). According to Avella et al. (2016), this procedure consists of (1) formulating the problem, (2) collecting the data, (3) evaluating the appropriateness of the data, and (4) analysing the data, interpreting and organising the results. To do so, we applied the results to compose a conceptual framework which can be applied to the development of a prototype set of prompts or for the development of an online learning platform. To determine what prompts can facilitate metacognitive regulation in technology-based learning platforms, we searched for studies relevant to metacognition in technology-based adaptive learning using Harzing's Publish or Perish software package (version 6.3.4.6288.6798). The programming nature of the Publish or Perish software allows the user to look up scholarly citations and calculate citation and impact metrics on a search query entered.

We assigned the following keywords as queries in the software platform: regulation and SDL, with plan, monitor, evaluate and prompt to search for and identify relevant sample sources. We also added the keyword 'mathematics' in the search to specify sources relevant to the context of the study. The purpose was to search for and find sources that self-identify as investigating or exploring the affordances and qualities of metacognition to promote SDL. The initial search produced 87 results of sources published between the years 2003 and 2018. Essentially the codes-to-theory model for qualitative inquiry by Saldaña (2015) allowed us to code, categorise and align sources with the themes: (1) Metacognitive regulation, (2) SDL and (3) Prompting. After the themes were identified, we assigned categories with codes such as MCR (metacognitive regulation), SDL, P (planning), M (monitoring), E (evaluation) and Pr (prompt) to the read text. A study of the words, phrases, sentences or sections related to the category determined if the source suggests any advice on the use and development of prompts applied in adaptive learning environments. In the sections that follow, we applied Avella et al.'s (2016) technique.

Formulating the problem

A systematic approach, such as that offered in this chapter, identifies prompts to aid in adaptive learning experiences. These prompts can be set up to facilitate metacognitive regulation skills of planning, monitoring and evaluating task performance online. As metacognitive regulation is an important measure of SDL (Neubrand & Harms 2017), prompts that facilitate metacognitive regulation could promote SDL skills. Based on this reasoning, the following research question guides the literature review: What prompts can facilitate metacognitive regulation in technology-based learning platforms?

Data collection and data evaluation

The purpose was to search for and find sources that self-identify as investigating or exploring the affordances and qualities of metacognition to promote SDL.

The initial search produced 87 results of sources published between the years 2003 and 2018. To cull the search results further, we identified only the most applicable ones after a proper evaluation by reading through them and then determining their alignment with the conceptual framework of the study. We then followed the inclusion criteria advice from Winters et al. (2008:432).

Firstly, studies had to refer to empirical evidence and be peer-reviewed. In the case of dissertation studies, these were not included. Further, a clear description of the participants of these studies, as well as the methods and results sections should be provided. Secondly, 'regulation' or 'self-directed learning' had to be a primary focus of the study, or advancing or promoting SDL, as determined by reading the abstract and introduction. Thirdly, online instructional systems must be the primary instructional modality and context of the study, while using prompts as learning scaffolds. After the evaluation, we identified 28 sources for the literature sample, considered to be suitable for the analysis towards answering the research question (Table 5.2).

TABLE 5.2: Identified sources for the literature sample set (a complete reference list of these sources can be found in the Addendum of this chapter).

No.	Source*	Title	Journal/Book
1	Crippen and Antonenko (2018)	Designing for Collaborative Problem Solving in STEM Cyberlearning	*Cognition, Metacognition, and Culture in STEM Education*
2	Yen et al. (2018)	Assessing Metacognitive Components in Self-Regulated Reading of Science Texts in E-Based Environments	*International Journal of Science and Mathematics Education*
3	Kim and Lim (2017)	Promoting socially shared metacognitive regulation in collaborative project-based learning: a framework for the design of structured guidance	*Teaching in Higher Education*
4	Kramarski and Kohen (2016)	Promoting pre-service teachers' dual self-regulation roles as learners and as teachers: effects of generic vs. specific prompts	*Metacognition and Learning*
5	Rum and Ismail (2017)	Metocognitive support accelerates computer assisted learning for novice programmers	*Educational Technology & Society*
6	Seel, Lehmann, Blumschein and Podolskiy (2017)	*Instructional design for learning*	*Instructional design for learning*
7	George, Michel and Ollagnier-Beldame (2016)	Favouring reflexivity in technology-enhanced learning systems: towards smart uses of traces	*Interactive Learning Environments*
8	Grant (2016)	Teaching Law Effectively with the Socratic Method: The Case for a Psychodynamic Metacognition	*Texas Law Review*
9	Stanton, Neider, Gallegos and Clark (2015)	Differences in metacognitive regulation in introductory biology students: when prompts are not enough	*CBE: Life Sciences Education*
10	Alleva and Gundlach (2016)	Learning Intentionally and the Metacognitive Task	*Journal of Legal Education*

*To ensure the review captures the most recent developments in the field and contribute to these developments, the sources were ranked according to the year of publication.
PBL, problem-based learning; STEM, science, technology, engineering and mathematics.

Table 5.2 continues on the next page→

TABLE 5.2 (Continues…): Identified sources for the literature sample set (a complete reference list of these sources can be found in the Addendum of this chapter).

No.	Source*	Title	Journal/Book
11	Chua, Liu and Tan (2015)	Pedagogical Interfaces in a Problem-Based Learning Environment: Cognitive Functioning at PBL Stages	*Authentic Problem Solving and Learning in the 21st Century*
12	Broadbent and Poon (2015)	Self-regulated learning strategies & academic achievement in online higher education learning environments: A systematic review	*The Internet and Higher Education*
13	Chang and Chang (2014)	Developing students' listening metacognitive strategies using online videotext self-dictation-generation learning activity	*The EuroCALL Review*
14	Michalsky (2014)	Developing the SRL-PV assessment scheme: Pre-service teachers' professional vision for teaching self-regulated learning	*Studies in Educational Evaluation*
15	Nguyen and Gu (2013)	Strategy-based instruction: A learner-focused approach to developing learner autonomy	*Language Teaching Research*
16	Schellings, Hout-Wolters, Veenman and Meijer (2012)	Assessing metacognitive activities: the in-depth comparison of a task-specific questionnaire with think-aloud protocols	*European Journal of Psychology of Education*
17	West, Hill and Song (2018)	Cognitive perspectives on online learning environments	*Handbook of distance education*
18	De Backer, Van Keer and Valcke (2012)	Exploring the potential impact of reciprocal peer tutoring on higher education students' metacognitive knowledge and regulation	*Instructional Science*
19	Meijer, Veenman and Van Hout-Wolters (2012)	Multi-Domain, Multi-Method Measures of Metacognitive Activity: What Is All the Fuss about Metacognition … Indeed?	*Research Papers in Education*
20	Shamir, Zion and Spector_ Levi (2008)	Peer Tutoring, Metacognitive Processes and Multimedia Problem-Based Learning: The Effect of Mediation Training on Critical Thinking	*Journal of Science Education and Technology*
21	Meijer, Veenman and Van Hout-Wolters (2006)	Metacognitive activities in text-studying and problem-solving: Development of a taxonomy	*Educational Research and Evaluation*
22	Bannert (2006)	Effects of reflection prompts when learning with hypermedia	*Journal of Educational Computing Research*
23	Smyth (2005)	Exploring the Usefulness of Broadband Videoconferencing for Student-Centred Distance Learning in Tertiary Science	*Teaching in the sciences: learner-centred approaches*
24	Hollingworth and McLoughlin (2005)	Developing the Metacognitive and Problem-Solving Skills of Science Students in Higher Education	*Teaching in the sciences: learner-centred approaches*
25	Quinn (2005)	Assessing for learning in the crucial first year of university study in the sciences	*Teaching in the sciences: learner-centred approaches*
26	Van den Boom, Paas, Van Merriënboer and Van Gog (2004)	Reflection prompts and tutor feedback in a web-based learning environment: effects on students' self-regulated learning competence	*Computers in Human Behavior*

*To ensure the review captures the most recent developments in the field and contribute to these developments, the sources were ranked according to the year of publication.
PBL, problem-based learning; STEM, science, technology, engineering and mathematics.

Analyses of the data

We analysed sources in the literature sample set through deductive content analysis by reading and rereading them. The purpose of the analysis was to search for and identify text or phrases in the content which represented or discussed the keywords ascribed to them, or associated with one or more of the other keywords in the initial online sample search.

Essentially the codes-to-theory model for qualitative inquiry by Saldaña (2015) allowed us to code, categorise and align sources with the themes of: (1) Metacognitive regulation, (2) SDL and (3) Prompting. After these themes were identified, we assigned categories with codes such as SDL, P (planning), M (monitoring), E (evaluation) and Pr (prompt) to the read text. We made use of ATLAS.ti as a qualitative data analysis package to show the frequency of text through both ATLAS.ti auto-coding and manual coding functions for reasons of consistency and validity of that particular code or category. A study of the words, phrases, sentences or sections related to the category determined if the source suggests any advice on the use and development of prompts applied in adaptive learning environments.

Presentation of results

Using ATALS.ti automated coding, Table 5.3's frequencies could be determined. These frequencies indicate the number of in-text corresponded to statements made in the text following the sampled phrases and extracts of text.

Table 5.3 (see also the Addendum for a complete list of the sampled references) summarises the results of the literature study and represents sampled phrases and extracts from the identified sources that elicit reflection on prompts when carrying out tasks. Table 5.3 shows sampled literature sets as sources reporting on metacognitive regulation components and SDL. In sample literature set 23 (by Bannert 2006), for example, the frequency of codes for the theme of SDL shows sources with a high frequency of indicators for prompting (12), reporting little on regulation (2) and SDL (0). In contrast to this, sources with a high frequency of indicators for regulation (e.g. 18) report vaguely on the use of prompts (2) and SDL (1), as the examples show. When these references were reread, they were significantly reduced to the numbers illustrated in Table 5.4. This also provided a more in-depth view on the sampled and analysed literature as the risk of repeated counting of indicators for each theme was reduced. Table 5.4 shows the manual coding where certain phrases in the text were omitted because of them not being related to prompts at all or could not be used as guidelines to formulate prompts.

Publication metrics of the initial search include publications between 2003 and 2018. Within 15 years, 87 papers were published with 1092 citations.

TABLE 5.3: Frequencies of reference to themes and subcategories, with automated coding as indicators.

Sample set*	E	M	P	Pr	SDL	Totals
01	151	83	183	44	81	**692**
10	21	23	10	5	14	**95**
12	10	13	6	3	5	**138**
13	17	10	8	7	5	**53**
14	33	9	22	6	121	**272**
15	38	37	43	1	10	**163**
16	42	29	60	3	15	**169**
17	6	2	4	9	4	**38**
19	75	68	57	4	1	**321**
02	20	35	22	3	5	**137**
20	18	21	32	3	12	**103**
21	11	5	20	1	11	**62**
22	37	47	45	1	5	**163**
23	7	12	11	67	12	**122**
24	20	7	6	8	5	**51**
25	5	0	14	0	6	**25**
27	0	0	0	0	0	**0**
28	16	6	11	90	11	**252**
03	17	19	23	6	3	**116**
04	44	35	52	303	14	**667**
05	15	24	5	43	28	**132**
07	17	9	4	4	6	**94**
08	7	6	8	1	7	**37**
09	33	42	100	13	6	**370**
Totals	**660**	**542**	**746**	**625**	**400**	**4272**

Source: Autocoded frequencies of reference to themes and subcategories obtained through analysis with ATLAS.ti.
*, Samples 6, 11, 18 and 26 were removed from the sample set as these sources were unavailable during the time of the online library search to download for analysis.
E, evaluation; M, monitoring; P, planning; Pr, prompts; SDL, self-directed learning.

Only 13 of these papers were available freely in a portable document format (pdf), and only 16 of these papers reported on research done in mathematics education contexts. For the purpose of the chapter, only the theme of prompting (Pr) will be considered using Figure 5.1's hierarchy of prompts as a classification system, reported on here in terms of the prompt's condition, the category and the type of prompt. The metacognitive themes of evaluation, monitoring, planning and metacognitive regulation in addition to the SDL can be used to assist in formulating prompts according to these conditions.

The results presented below as quotations offer guidelines for prompts based on the condition and type of prompting. These statements are borrowed from the sampled literature sets, particularly those which indicate high frequencies in Table 5.3 and Table 5.4's auto and manual coding of the theme of prompts.

TABLE 5.4: Coded outline of the themes.

No.	Title	E	M	P	Pr	SDL
1	Designing for collaborative problem solving in STEM cyberlearning	34	4	2	2	23
2	Assessing metacognitive components in self-regulated reading of science texts in e-based environments	14	2	0	5	1
3	Promoting socially shared metacognitive regulation in collaborative project-based learning: A framework for the design of structured guidance	16	1	1	2	1
4	Promoting pre-service teachers' dual self-regulation roles as learners and as teachers: Effects of generic versus specific prompts	11	4	2	2	1
5	Metocognitive support accelerates computer assisted learning for novice programmers	13	2	1	2	1
6	Favouring reflexivity in technology-enhanced learning systems: Towards smart uses of traces	26	3	1	3	2
7	Teaching law effectively with the Socratic method: The case for a psychodynamic metacognition	24	0	0	1	2
8	Differences in metacognitive regulation in introductory biology students: When prompts are not enough	5	16	4	4	3
9	Learning intentionally and the metacognitive task	31	2	1	2	3
10	Self-regulated learning strategies and academic achievement in online higher education learning environments: A systematic review	7	144	72	2	3
11	Developing students' listening metacognitive strategies using online videotext self-dictation-generation learning activity	10	6	3	2	4
12	Developing the SRL-PV assessment scheme: Pre-service teachers' professional vision for teaching self-regulated learning	27	6	6	1	4
13	Strategy-based instruction: A learner-focused approach to developing learner autonomy	6	63	32	2	5
14	Assessing metacognitive activities: the in-depth comparison of a task-specific questionnaire with think-aloud protocols	8	24	8	3	5
15	Cognitive perspectives on online learning environments	37	8	2	4	5
16	Exploring the potential impact of reciprocal peer tutoring on higher education students' metacognitive knowledge and regulation	4	101	34	3	6
17	Multi-domain, multi-method measures of metacognitive activity: what is all the fuss about metacognition … indeed?	19	14	5	3	6
18	Peer tutoring, metacognitive processes and multimedia problem-based learning: The effect of mediation training on critical thinking	12	40	13	3	10
19	Metacognitive activities in text-studying and problem-solving: Development of a taxonomy	3	164	55	3	12
20	Effects of reflection prompts when learning with hypermedia	2	112	112	1	12
21	And problem-solving skills of science students in higher education	9	16	8	2	13
22	Exploring the usefulness of broadband videoconferencing for student-centred	45	2	2	1	13
23	In the crucial first year of university study in the sciences	65	0	0	1	13
24	Reflection prompts and tutor feedback in a web-based learning environment: Effects on students' self-regulated learning competence	1	203	51	4	14

E, evaluation; M, monitoring; P, planning; Pr, prompts; SDL, self-directed learning.

Prompts for planning

The theme of planning seemed to have received the highest frequency of codes in the analysed sample set with 1299 autocoded codes and 414 manual codes. Even though the theme of planning does not explicitly appear in the model by Imhof et al. (2020), the model does emphasise core components of adaptive learning which imply prompts regarding planning when, where, what and how strategies can be applied. For instance, sample sets 2, 22 and 24 indicate that prompts should allow for learners to 'plan the learning strategies they use' (Hollingworth & McLoughlin 2005:277), 'set goals for their own planning, whereas teachers proactively guide students to plan a specific task' (Yen et al. 2018:158), 'systematically order [and] plan a solution strategy, deciding to execute it and subsequently monitoring progress' (Bannert 2006:211, 217). In addition, prompts for planning should encourage 'note taking, reading only a part of a text, and estimating a solution to a problem' (Bannert 2006:218), 'preparation of the sequential planning and execution of cognitive activities [and] ... the development of an action plan to attain learning goals' (Meijer, Veenman & Van Hout-Wolters 2012:561).

Prompts for monitoring

The high frequency of 542 autocoded and 937 manual codes from the literature reporting on monitoring is in line with Imhof et al.'s (2020:95) model, in that monitoring is 'crucial in this context'. Sample sets 10, 12, 17, 19 and 25 suggest that prompts should cater for (Alleva & Gundlach 2016):

> Making students aware of ... challenges can enhance their abilities to be more intentional in monitoring their learning about them. [...] [*S*]elf-question(ing) both to obtain knowledge and to monitor understanding of it [...], determin(ing) if the task is being completed correctly and make corrections as appropriate. (pp. 719, 722)

Furthermore, West, Hill and Song (2018:134, 207) (sample set 17) suggest that 'making cognition more visible, [...] demonstrating such practices', and Meijer, Veenman and Van Hout-Wolters (2012:566) (sample set 19) suggest that 'planning activities can be directed at the problem-solving approach and/or at a timeframe for task execution'.

Reference to the social-cognitive view of learning as well as applications to problem-solving was also found to relate to discussion on monitoring, with Broadbent and Poon (2015:2) suggesting that 'self-observation (is) seen as the most important of these processes'. Bannert (2006:211) also states that, 'monitoring of calculation errors during mathematics problem-solving may generate control processes at the metacognitive level, which may lead to correction of these errors'.

Prompts for evaluating

Across the literature sample, evaluation was the theme among metacognitive regulation domain that deemed necessary when coded with the frequency of 660 codes for the auto coding process and 585 codes for the manual coding process. This implies that evaluation is emphasised in adaptive learning process, as Imhof et al. (2020) also noted. Sample sets 1, 14, 17 and 25 indicated the most references to evaluation. It appears from these references that prompts should provide opportunities where (Crippen & Antonenko 2018):

> [*S*]pecial attention is given to explicating the differences between well-structured (textbook) and ill-structured (authentic) problems in order to enable educators to evaluate and compare the complexity, structuredness, and dynamicity of various types of problems. (p. 104)

These educators should then 'reflect on their actions and decisions in order to evaluate goals, processes, and efforts' (Michalsky 2014:214), 'directly and explicitly inform students about the significance of a strategy and about how to employ, monitor, and evaluate this strategy' (Michalsky 2014:217), 'analyse, synthesize, and evaluate information in ill-structured and well-structured asynchronous online learning environments' (West, Hill & Song 2018:139.

Although the literature review indicated that SDL can be fostered by self-regulation skills such as planning, monitoring and evaluation, there were also particular references in the sampled and analysed literature set that suggest specific prompts for SDL.

Prompts for self-directed learning

The theme of prompts for SDL showed the smallest number of autocoded (400) and manually coded (162) frequencies. This low frequency, especially when compared to the metacognitive regulation domain of monitoring, is not surprising as the introductory remarks of this chapter emphasised that there is a scarcity of literature reporting on how metacognitive regulation can be promoted as a state or ability of SDL in online learning environments. The few extracts that do offer guidance for prompting SDL behaviour include those found in sample sets 10 and 12: 'encouraging students to use high-quality learning activities [...] (advocating that teaching for intentional learning in experiential courses' (Alleva & Gundlach 2016:711, 715), 'the very nature of online settings promotes self-directed learning' (Broadbent and Poon 2015:2).

Discussion

The study followed a literature review approach with the intention to identify adaptive prompts to facilitate metacognitive regulation during online learning. The conceptual-theoretical framework served as a proposition regarding the condition of prompting and its application according to Imhof et al.'s (2020) model of the core components of adaptive learning systems and facets of the design process, as modified for the purpose of this study. Based on the analysis, distinct prompts can be organised according to the level of expertise (either novice, in transition or expert) and aligned with the particular sequence of the activity. These different categories of prompts can be aligned with the different conditions, as per the sequence of an activity. Following Imhof et al.'s (2020) framework as theoretical model for this study, three sets of conditions for prompting were confirmed by the analysis of a sampled literature set (see Table 5.2). In the discussion sections that follow, each of these conditions are explained with guidelines based on the theoretical framework followed by examples of metacognitive prompts.

There are, however, conditions where no prompting is required. In such cases, the analysed literature sample set indicates that no prompts are needed when prior knowledge, skills or affective states are tested (Imhof et al. 2020) as part of diagnosing an aspect of the learner's learning. No-prompting conditions can also serve well in situations where exploratory, convergent research designs are followed where the no-prompting groups often serve as validation or comparison group, to determine any effects the non-adaptive prompting and adaptive prompting conditions might have had on the learners' SDL.

The condition of adaptive prompting

Adaptive prompting requires as a prerequisite a framework with several prompting steps that adapt to the individual needs of the learner. Important in this context are the characteristics of the learner, which are modelled in the adaptive system. The literature review suggests that prompting provides guidance that benefits both novices and experienced students. Prompts can lose their effectiveness and stay counterproductive to experts. Adaptive learning prompts can support novice learners who need guidance by, for example, limiting the number of alternative response options or providing access to additional resources such as Wikipedia, online assessment tools or other relevant links (Imhof et al. 2020)

Prompts designed in a clear and guiding manner can assist novice learners and hinder expert learners because of too much instruction with negative effects at a motivational level (Imhof et al. 2020). If the learner receives too little assistance, it can also affect novice learners who do not have the expertise to determine what the task requires is and, in addition, receive too limited support to develop and apply the necessary problem-solving strategies. However, in the opposite case, if the guidance provided by the prompts is too extensive, cognitive overload may occur, so a step-by-step approach is appropriate to guide them through the task. The novice learner may receive supplementary clarifications, explanations, descriptions and hints to improve his or her understanding of the content and to support solving procedures of a task. Another way of adapting prompts in scaffolds can be by applying instructional techniques for novice learners (Avella et al. 2016) and differentiating them from those for experienced learners.

At the end of this section, let us give an explanatory example. One problem with good automated feedback concerns open-ended questions, for example. In order to evaluate corresponding text answers automatically and provide them with feedback, very sophisticated intelligent algorithms are needed, which usually have to be trained over several years and need deep knowledge of artificial intelligence. An alternative to this are metacognitive prompts, such as that we use in some cases at the Swiss Distance University of Applied Sciences. For example, after entering a text, a student can be asked to compare their answer with that of a peer or a standard solution and to rate the extent of the difference based on a Likert scale. Depending on the result, the students are asked to justify their answer. The question about the justification can then, for example, be unspecific in the case of a small difference and divided into several steps with different aspects (e.g. length of the justification, contain key terms and logical errors) in the case of a larger difference. The aim here is to optimise the cognitive load in the context of the prompts or to adapt them to the learner's knowledge. This example is only intended as an illustrative one. Basically, the possibilities of adaptation in such a context are inexhaustible, and there are no limits to the didactic imagination. However, we also do not want to conceal here that the construction and implementation of such metacognitive adaptive prompts require empirical testing with regard to the learning effects and the acceptance of the students. Based on our experience, there are always unexpected surprises in this context that allow for an improvement of the prompts.

Conclusion

The chapter presents a tangible pedagogical approach to identify adaptive prompts for facilitating metacognitive regulation in online learning environments which can easily be inserted into online learning systems. To do so, the prompts should be prepared (and therefore prototyped) in terms of the opportunities and experiences they provide to plan, monitor and evaluate the learning experiences. This prerequisite of the prompts serves as a guiding principle along with the questions posed in the conceptual-theoretical framework (see Figure 5.2) for the development and implementation of the adaptive prompts, particularly focusing on why, what, when, where and how the prompts should be adapted. The findings inform the defining of adaptive prompts needed within this system and motivate a pilot study of the prototype before the initial system is put in place. Several limitations could be considered to ensure the conditions of prompting are met, for instance, to determine the learners' prior knowledge and experience in terms of their knowledge and skills, as well as the familiarity with adaptive systems. Moreover, future research could develop adaptive learning systems that explore the applicability of the identified conditions of prompting and examine the role prompts play in facilitating metacognition towards promoting SDL during online learning experiences.

Chapter 6

Knowledge surveys: Supporting students along pathways to self-directed learning with self-assessment

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Abstract

Self-assessment is an essential skill for the development of self-directing learners. However, it is seldom an explicit learning objective in most university-level courses and programmes. This chapter describes how knowledge surveys support the development of self-assessment skills in courses and programmes. We use knowledge survey data from a national study of science literacy using the Science Literacy Concept Inventory to illustrate several graphical formats for analysing self-assessment results. The results confirm that greater self-assessment accuracy correlates with academic rank, commitment to science, and demonstrated science literacy. We also confirm differences in self-assessment that correlate with several socioeconomic variables, including gender, race and ethnicity, status as a first-generation college student, and English second language speakers. Additionally, we describe how different applications of knowledge surveys compare with other typologies of self-assessment. Because self-assessment is crucial in informing important educational and career decisions, we offer examples showing how to use knowledge surveys to integrate self-assessment into courses and programmes. We argue for deliberately teaching self-assessment in all curricula. Doing so supports more inclusive and equitable learning environments and societies.

Introduction

When one fully acquires the capacity for SDL, one knows how to learn and is prepared for lifelong learning. Research on lifelong learning has been variously described using the terms 'self-regulated learning' and 'self-directed learning', and a review of the extensive body of literature is beyond the scope of this chapter.

Central to most models of self-directed and self-regulated learning (SRL) (e.g. Cosnefroy & Carré 2014; Dinsmore, Alexander & Loughlin 2008; Loyens, Magda & Rikers 2008) is a quality termed *self-efficacy* – an informed confidence in self to achieve, over a reasonable amount of time, what one wants to learn through effort and, where needed, instruction from others (Bandura 1982). Ross (2006) argued further that practice in *self-assessment* offers a path to the development of self-efficacy. Self-assessments involve self-rated estimations of one's capability, at the present time, to engage with specific challenges. Every experience of engaging with a new challenge then provides prompt feedback about the accuracy of one's estimated present capabilities to perform.

Accuracy in the self-assessments of one's knowledge and abilities is central to metacognition (e.g. Dunlosky & Metcalfe 2009), for the development of

SRL (Zimmerman 1990) and SDL (Knowles 1975), and for succeeding with the challenging coursework inherent in pursuing careers in science (Nix, Perez-Felkner & Thomas 2015; Perez-Felkner, Nix & Thomas 2017). Thus, self-assessment is the essential building block for developing self-efficacy and SDL. Without mastering the ability to self-assess accurately, development of the latter qualities remains out of reach. Despite the importance of accurate self-assessment of one's abilities for lifelong learning (Boud & Falchikov 2006) and meaningful career and life decisions (Sheldrake, Mujtaba & Reiss 2015), self-assessment is seldom an explicit learning objective in college-level courses and programmes.

Until recently, the consensus established by prevalent self-assessment literature depicted most people as holding overly optimistic views of their knowledge. Some researchers even suggested that self-assessments of competence were unrelated to actual capabilities. The authors of this chapter include those who recently discovered that these dominant consensus views were untenable because they rested on flawed mathematical arguments (Nuhfer et al. 2016a, 2017; Watson et al. 2019).

A lack of readily available tools and methods poses an additional challenge for teachers who wish to investigate self-assessment in the classroom and the laboratory. In this chapter, we focus on knowledge surveys as tools uniquely suited for supporting learning, teaching and intellectual development. We also summarise current knowledge on how to analyse and present the results from self-assessment measures.

Measuring self-assessment and improving learners' capacities to self-assess are often seen as separate methods or activities, which further complicate incorporating self-assessment into teaching and research. We now know that different socioeconomic groups exhibit self-assessment characteristics that impact both academic success and life decisions. We believe that a commitment to develop the essential self-assessment skills needed by all students can remove barriers that privilege has constructed and that currently impede the achievement of particular learners. By acting on what we now know, we can change our institutions into more effective places in which to learn.

Our goals for this chapter are to:

1. examine several alternative graphical formats for presenting self-assessment results
2. document the distinct characteristics of self-assessments derived from different populations using different measures
3. describe explicit uses of knowledge surveys for supporting teaching and learning of self-assessment
4. situate knowledge surveys in the body of scholarship on self-assessment.

This chapter employs new knowledge about self-assessment to improve understanding about developing SDL. We confirm that people can learn to do accurate self-assessment and introduce ways for teaching and measuring it. We hope to communicate the value of accurate self-assessment for nourishing the development of SDL using examples of different kinds of lesson design that provide students with regular self-assessment practice and prompt feedback.

Promotion of learning and self-directed learning with improved self-assessment

In order to understand how SDL develops through self-assessment, it is necessary to first unpack the two concepts. The most widely quoted and accepted definition of SDL is that of Knowles (1975) who stated that SDL is:

> [*A*] process 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 for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. (p. 18)

Beckers et al. (2019:2) noted that although several definitions of SDL exist, all definitions include 'self-assessment of performance, identification of learning needs and subsequent formulation of points for improvement'.

Reviews of self-assessment research (e.g. Andrade 2019) consistently call for clearer definitions of self-assessment. Boud and Falchikov (1989:529) described self-assessment as 'the involvement of learners in making judgements about their own learning, particularly about their achievements and the outcomes of their learning'. Panadero, Jonsson and Strijbos (2016b) further defined self-assessment to include a spectrum of techniques that students use to assess and evaluate the qualities of their own learning process. According to Reddy et al. 2015 (as quoted in Lubbe & Mentz 2019), self-assessment encourages students to continually ask reflective questions about their learning and in this process enable themselves to diagnose their learning needs (an imperative for SDL). In championing the effects of self-assessment on intrinsic motivation, effort, goal orientation and learning, McMillan and Hearn (2008:40) asserted that 'student self-assessment stands alone in its promise of improved student motivation and engagement, and learning'.

Also embedded in the concept of SDL is SRL, which occurs when students 'self-generate thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals' (Zimmerman 2000:14). Feedback has traditionally been connected with SRL (e.g. Black & Wiliam 1998; Butler & Winne 1995), and most models of SRL include phases (e.g. forethought, performance and appraisal) that involve cyclically implemented reflection and self-assessment (Yan 2020; Zimmerman & Schunk 2001). When students engage in self-assessment, they become more active agents in their own learning (Schraw & Dennison 1994) and improve their SRL strategies (Panadero, Jonsson & Botella 2017). This also leads to students engaging in praxis where action and reflection are in constant interplay.

Brandt (2020:12) noted that several approaches may be utilised to promote SDL: 'experiential learning, PBL, project-based learning, inquiry-based learning, personalised learning, competency-based learning, self-assessment and online and distance learning'. All of these approaches specifically support SDL because of their focus on choice and personalisation and also agency (King & Siddiqui 2011; Nieminen & Tuohilampi 2020) and responsibility (Brandt 2020:12). Seifert and Feliks (2018) emphasised the use of self-assessment and peer-assessment to promote students' sense of responsibility for their own learning (i.e. SDL).

From the definitions above, one becomes acutely aware of the necessity for adequate self-assessment skills if the aim is to promote SDL. Beckers, Dolmans and Van Merriënboer (2016:37) specifically researched the use of e-portfolios (as a self-assessment tool) to promote SDL. Although they found five groups of factors that influence the promotion of SDL skills when using e-portfolios (e.g. the students' motivation [or lack thereof], their perceived time to complete self-assessments, low technological competence, their awareness of the need to self-improve and their multiple goal orientations), we focus on the 'personal factors' in this chapter. This group (personal factors) describes the influences the individual/student themselves have on their SDL development.

Apart from Beckers et al.'s (2016) notion about the influences of self-assessment on students, Ratminingsih, Marhaeni and Vigayanti (2018) also made a case for using self-assessment as a teaching strategy for prompting students' metacognitive awareness and awareness of their skills (aspects that strongly correlate with SDL). Further, Ratminingsih et al. (2018) found that self-assessment increases students' independence – also an important aspect in SDL. It becomes evident that using self-assessment holds positive results for SDL development.

Knowledge surveys

The initial application of knowledge surveys for enhancing teaching and learning across courses and curricula occurred over a decade ago (Nuhfer 1993, 1996; Nuhfer & Knipp 2003). Knowledge surveys consist of learning objectives framed as challenges to be addressed by a student. Individual survey items describe detailed learning objectives, which can be either knowledge or skill-based. Teachers craft the items to address specific levels of understanding (Bloom 1956). In completing a knowledge survey, respondents do not directly respond to the questions, but instead provide ratings of their self-assessed ability to do so at that time.

Several authors described the varied ways in which knowledge surveys promote teaching and learning in courses. Because students interact with the surveys at several critical points throughout a course, they support the development of metacognitive processes, including planning, monitoring and self-assessment (Bell & Volkmann 2011; Favazzo, Willford & Watson 2014; Goodson, Slater & Zubovic 2015; Nuhfer & Knipp 2003; Wirth & Perkins 2005). Stapleton (2018) also described the use of knowledge surveys for supporting 'non-traditional pedagogies' (e.g. simulations and games) in a political science course. Nuhfer and Knipp (2003), Wirth and Perkins (2005) and Wirth, Perkins and Nuhfer (2005) advocated the use of knowledge surveys for assessing learning at the departmental and programmatic levels, and Favazzo et al. (2014) reported the results of using knowledge surveys for assessing a microbiology programme.

In the South African context, the use of knowledge surveys has also gained interest. In a recent study of the use of technology-supported cooperative learning by one of the co-authors (R. Bailey), students were required to complete a knowledge survey based on the set outcomes of the study unit to be completed in that week. Anecdotally, the lecturer responsible for the module has commented on the advantages of using such surveys: It sets the learning stage for what is to come and promotes students' ability to delve into the zone of proximal development.

Nuhfer and Knipp (2003) initially offered knowledge surveys to teachers as an efficient method for organising teaching and promoting student learning. Other researchers soon explored knowledge surveys to quantitatively determine the validity of self-assessment. Early reports by Wirth and Perkins (2005), Wirth et al. (2005) and Clauss and Geedey (2010) described student self-estimates that correlated with objective measures and group-averaged self-assessments that aligned closely with average exam results. Some peer-reviewed research (e.g. Bell & Volkmann 2011; Lindsey & Nagel 2015; Price & Randall 2008; Ziegler & Montplaisir 2014) reported self-assessed learning measures that also aligned well with objective measures. However, other peer-reviewed research disagreed (Bowers, Brandon & Hill 2005; Luce & Kirnan 2016). All early investigators employed small databases of undocumented reliability, usually local data obtained from the authors' classes. Some even wrote opinions without collecting any data (Ebert-May & Weber 2006). Nuhfer and Knipp (2006) replied that the high reliability of knowledge survey data indicated their value. They observed that weak or negative correlations between knowledge surveys and objective measures that were being reported could be the result of poorly aligned instruments or objective measures with low reliability. Nuhfer (2015) used later findings to formulate guidelines for the effective use of paired measures (self-assessed ratings and competency scores) in research.

The above dispute ended when researchers employed validated instruments for the paired measures, large databases from students at diverse institutions and the reporting of results in peer-reviewed journals (Nuhfer et al. 2016b, 2017; Watson et al. 2019; Wirth et al. 2016). The results confirmed that self-assessed competency is significantly related to demonstrable competence. These findings also upset two decades of behavioural science research that began in 1999 (Kruger & Dunning 1999). Nuhfer et al. (2016b, 2017) revealed in great detail how the literature supporting the notion that many people are 'unskilled and unaware of it' (Dunning–Kruger Effect) rested on interpreting numerical artefacts as human behaviour. The research team later published to show the value of self-assessment when applied to teaching (Wirth et al. 2016) and to understanding the effects of socioeconomic privilege on student success (Watson et al. 2019).

We now know that most people are generally good self-assessors. Further, there are meaningful differences in self-assessment skills in different groups characterised by academic experience, domain expertise and socioeconomic variables.

Methodology

Four related papers employed data similar to that used for this chapter (Nuhfer et al. 2016b, 2017; Walter, Nuhfer & Suarez 2021; Watson et al. 2019). All employed quantified self-assessed competence ratings with scores from a validated test of demonstrated competence (the Science Literacy Concept Inventory [SLCI] – Nuhfer et al. 2016a). The Inventory measures the comprehension of science as a way of knowing by addressing 12 concepts with 25 items with the goal of understanding the level of understanding of science concepts among undergraduate college students in non-science majors. We employed the SLCI for this study because it is currently the only existing instrument, vetted for both validity and reliability, with a corresponding, well-aligned instrument for self-assessment measures with similarly documented psychometrics. This chapter differs from our previous published studies (Nuhfer et al. 2016b, 2017; Watson et al. 2019) in that it includes only students and professors from 4-year undergraduate programmes. This restriction enables a better focus on relationships between self-assessment and rank and other relevant variables.

Participants

We studied 1540 undergraduate students and professors – all involved in 4-year degree programmes. at >13 different institutions. The Institutional Review Boards at California State University – Channel Islands (IRB-105122) and Humboldt State University (IRB-13-019), whose purposes are to protect the rights and safety of persons participating in research, have granted ethical clearance and overseen this human subject research since its inception.

Instruments

Participants in this study completed a daisy-chain of instruments, including a *predicted global* measure, the Knowledge Survey of the Science Literacy Concept Inventory (KSSLCI), the SLCI and a *postdicted global* measure. After reading a description of the nature of the SLCI, participants responded to a single-item self-assessment (*predicted global self-assessment*) that prompted participants to impart a self-estimated rating (between 0% and 100%) of their understanding of science literacy. Next, participants completed the KSSLCI (Nuhfer et al. 2016b), which consists of 25 items (Cronbach's alpha = 0.93; Nuhfer et al. 2016b) that are worded identically to those in the SLCI. Participants addressed their self-assessed confidence to answer each item in the KSSLCI with the following response options (Nuhfer et al. 2016b):

1. I can fully address this item now for graded test purposes.
2. I have partial knowledge that permits me to address at least 50% of this item.
3. I am not yet able to address this item adequately for graded test purposes.

The SLCI offers 25 multiple choice items (Cronbach's alpha = 0.85; Nuhfer et al. 2016a) with four choices, only one of which is a correct answer. The Inventory addresses 12 concepts of science literacy articulated by nine researchers from four California State University campuses (Nuhfer et al. 2016a). The development of this instrument and the efforts to ensure its validity are described in Nuhfer et al. (2016a, 2016b). A second global self-assessment measure prompts participants to impart a single-item, self-estimated rating, again in percent, after completing the SLCI (*postdicted global self-assessment*). Participants complete the self-assessments and the Inventory in a single sitting, so no teaching is involved. This study draws mostly from the paired measures of the KSSLCI and the SLCI, but we occasionally refer to the *predicted* and *postdicted global measures* for comparison.

Design

Several critical aspects separate this research design on knowledge surveys and self-assessment measures from others' peer-reviewed reports. (1) We employ a validated instrument (SLCI) with known psychometric properties as our competence measure, rather than a faculty-made test without established psychometric properties. (2) We employ an extensive database of participants in diverse courses representing multiple institutions rather than small studies obtained in single institutions or only in our classes. (3) The KSSLCI is a knowledge survey in which the self-assessments align tightly with the competence that we are measuring. Because no teaching is involved, there are no factors other than the interaction between participants and the instruments to consider. (4) Participants take the Inventory and the self-assessments online in a single sitting under the same conditions in which they interact with science literature in real life, with no restrictions and not under timed in-class conditions. Ours is thus a field study done under actual conditions in which participants engage with learning challenges. From this design, we established a strong positive relationship between self-assessed competence and demonstrated competence (Nuhfer et al. 2016b, 2017), after which we explored applying the relationship to understand the role that privilege plays on demographic groups of ethnicity, gender and sexual orientation (Watson et al. 2019).

In this chapter, we report applying a research design from work that we began over four years ago (Wirth et al. 2016). We establish the value of knowledge surveys for (1) promoting student learning in courses and (2) for measuring self-assessment to better understand student learners and learning in our classes.

Demographic information

The online survey package also prompted participants to provide demographic information after responding to the science literacy items. This information included their educational background, intent to major in science, the number of science courses completed, gender, race and ethnicity, and status as a first-generation college student and as an English second language speaker. Responses to the educational background item were recoded into 'academic rank' as *novices* (1st- and 2nd-year students), *developing experts* (3rd- and 4th-year students) and *experts* (professors). We recoded participant-reported information about race and ethnicity to a binary 'ethnic minority' category (no or yes). Entries in this category include those in the U.S. National Science Foundation definition of historically underrepresented minorities in science, technology, engineering and mathematics (STEM) (Black or African American, Hispanic or Latino, American Indian or Alaska Native, and Native Hawaiian or Pacific Islander). This binary categorisation limits seeing some differences between these groups but allows supporting generalisable statements from our current data. As we grow our database, more granular categorisation is possible. This data set consists only of records with 'female' or 'male' responses to the gender item because few non-binary gender responses appeared in this database. Participants who indicated status as a 'first-generation' college student are generally understood to be the first in their family to seek a degree beyond traditional K-12 education. We recoded responses to questions about the number of college science courses that participants had fully completed into 'science courses completed' (none, 1–2, 3–4, ≥5). 'Science interest' indicates if a participant was majoring in or intended to major in a science field or not, as shown by 'yes' or 'no' participants' responses, respectively.

Analysis procedure

We use the differences obtained between self-assessed ratings of science literacy (*predicted global*, KSSLCI, *postdicted global*) minus the objective measure of science literacy (SLCI) score to characterise individual's and groups' self-assessment skills. If one's self-assessment rating correctly matches the test score obtained on the objective measure, the difference between the two measurements will be zero (perfect self-assessment). If imperfectly calibrated, the difference obtained by subtracting the objective measure from the self-assessed rating represents an error. The error can be positive (self-assessed overestimation) or negative (self-assessed underestimation).

We calculated quartile values between the minimum and maximum values of SLCI scores using SPSS. The four resulting populations between the bounding values (minimum, first quartile, median, third quartile and top) are unequal because of the large interval (between adjacent scores and skewed distribution of scores) resulting from the SLCI instrument. To avoid introducing artificial statistical relationships, we chose to leave the groups as defined by the quartile values rather than rebalance them.

The distributions of values in many of the variables (e.g. quartiles of science literacy) appear non-normal (i.e., skewed and with unequal variance) and yield significant Kolmogorov–Smirnov test values. Thus, we chose non-parametric methods (e.g. Mann-Whitney) for statistical tests. Correlations among scale variables were calculated using Spearman's correlation coefficients (r_s); biserial correlations (r_b) were used for dichotomous categorical variables. We use $r = Z/N^{0.5}$ (Rosenthal 1991) or Spearman's correlation coefficient (r_s) to estimate practical significance, or effect size, and we adopted the guidelines of Cohen (1988, 1992) for describing practical significance: small effect, $r = 0.1 – 0.3$; medium effect, $r = 0.3 – 0.5$; and large effect, $r = 0.5 – 1.0$. For data management, coding and statistical analysis, we used Microsoft Excel and IBM SPSS Statistics for Macintosh, version 26 (IBM Corp., Armonk, NY, USA).

Results

Our results focus on comparisons of data from self-assessed and objective measures of competence in science literacy. We explore graphical methods for interpreting self-assessment data, investigate the self-assessment characteristics of different demographic groups and articulate some of the pedagogical options made possible by the knowledge survey instrument. We also compare these results of our previous studies (Nuhfer et al. 2016a, 2016b, 2017; Walter et al. 2021; Watson et al. 2019) using different subsamples of the paired measures database.

Objective measures of science literacy

We begin with a brief comparison of objective measures of science literacy scores among different demographic groups (Table 6.1). SLCI scores as percentages increase with academic rank, from a median of 68% among novices (1st- and 2nd-year students), to 80% among developing experts (3rd- and 4th-year students) and to 92% among experts; statistical tests between all pairs of ranks are highly significant ($p < 0.001$ after adjusting with the Bonferroni correction). Those who indicated a greater interest in science scored higher on the SLCI (median = 80%) than those who did not (median = 68%; $p < 0.001$). The median SLCI scores of those who completed five or more science courses (median = 84%) are significantly different ($p < 0.001$ after adjusting with Bonferroni correction) from those with only 3–4 (median = 76%; $r = -0.41$), 1–2 (median = 72%; $r = -0.41$) and no (median = 68%; $r = -0.27$) science courses. However, differences among those with 3–4, 1–2 and no prior science courses are not statistically significant. These results confirm that objective measures of science literacy improve with academic rank and with

TABLE 6.1: Demographic information and descriptive statistics.

Category	Group	N	Category percent	SLCI score	Self-assessed error		
					Predicted global	KSSLCI	Postdicted global
				Median scores			
All participants	All	1 540	100.0	76	0	2	0
Academic rank	Novices	645	41.9	68	2	2	2
	Devel. Exp.	786	51.0	80	−1	2	0
	Experts	109	7.1	92	−10	0	−4
Science courses	None	305	19.8	68	1	2	0
	1-2	244	15.9	72	2	0	2
	3-4	224	14.6	76	3	2	2
	≥5	114	7.4	84	−3	2	−1
Science interest	No	551	35.9	68	4	0	0
	Yes	984	64.1	80	−2	2	0
Gender	Female	988	64.4	76	0	2	0
	Male	546	35.6	84	−1	4	0
Historically underrepresented minority in STEM	No	1006	65.6	80	−2	0	−1
	Yes	445	29.0	64	4	4	2
First-generation college student	No	924	60.3	80	−2	2	−1
	Yes	609	39.7	72	3	2	1
English second language speaker	No	254	16.6	64	6	1	1
	Yes	1280	83.4	80	−1	3	0
Quartile of SLCI scores	1	399	25.9	48	25	10	14
	2	388	25.2	72	4	3	3
	3	283	18.4	84	−4	0	0
	4	470	30.5	92	−10	−2	−6

KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory; STEM, science, technology, engineering and mathematics.

science interest, but that completing four or fewer science courses does not produce significant improvements in science literacy (SLCI scores). However, a few schools we studied did produce a significant difference with just four (Nuhfer et al. 2016a, 2016b, 2017).

On average, female participants in this paired data set earned a significantly lower SLCI score (median = 76%) compared with male participants (median = 84%; $p < 0.001$), but the effect size is small ($r = -0.16$). We do not observe difference in our current, much larger national data set (>28 809 participants) nor our previous studies, where the SLCI proved gender-neutral (see also Nuhfer et al. 2016b). Another of our team's studies revealed a small gender bias for female respondents not in the sciences (Walter et al. 2021). Elsewhere, Nuhfer et al. (2017) and Watson et al. (2019) found gender differences in science literacy scores explained by unequal distributions of other socioeconomic factors (e.g. first-generation college student status, English second-language speakers and interest in science) between the binary gender categories. Analysis of the binary historically underrepresented minority in STEM category indicates that the median SLCI scores of members of a racial or ethnic minority group (64%) are significantly lower than those from majority (Caucasian) groups (80%; $p < 0.001$, $r = -0.35$). Furthermore, first-generation college students have lower SLCI scores (median = 72) than those who are not the first generation in their family to seek a degree (median = 80; $p \leq 0.001$, $r = -0.22$).

The median scores of English first language speakers (median = 80%) are significantly higher than those who are English second language speakers (median = 64%; $p < 0.001$, $r = -0.24$). These results confirm earlier studies using the SLCI and likely reflect the penalties exacted on those with less-privileged backgrounds (Nuhfer et al. 2016a, 2016b, 2017; Watson et al. 2019).

Self-assessed science literacy and metrics of expertise

Next, we summarise the results of self-assessments of science literacy, starting with three different metrics of expertise (academic rank, interest in science and the number of completed science courses). We might expect all to contribute to increased competence and self-assessment skill in science literacy.

Our other paired-measures studies (Nuhfer et al. 2016b, 2017; Watson et al. 2019) also utilised three to four self-assessment measures to understand the nature of self-assessment. In the first measure (*predicted global*), we asked participants to self-assess their science literacy using a single, global query that described the nature of the SLCI. Self-assessed ratings using this measure are moderately correlated ($r_s = 0.320$; $p < 0.001$) with objective measures of

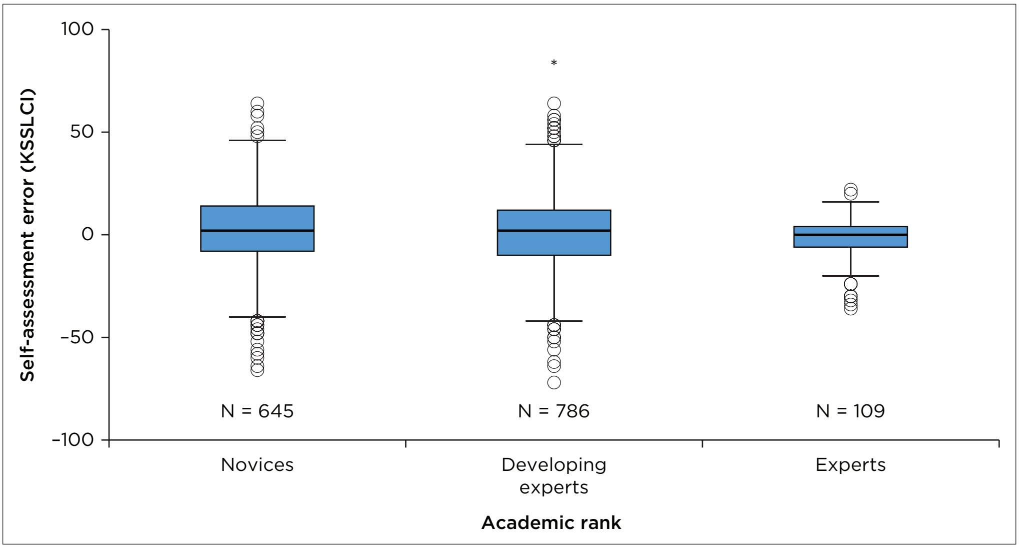
TABLE 6.2: Correlations among self-assessment measures and demographic variables.

Category	Predicted global	KSSLCI	SLCI	Postdicted global	Self-assess error
Predicted global					
KSSLCI	0.482*** (1,540)				
SLCI	0.320*** (1,540)	0.624*** (1,540)			
Postdicted global	0.604*** (1,540)	0.727*** (1,540)	0.623*** (1,540)		
Self-assessment error (KSSLCI)	0.185*** (1,540)	0.446*** (1,540)	-0.354** (1,540)	0.142*** (1,540)	
Science interest	0.216*** (1,535)	0.395*** (1,535)	0.341*** (1,535)	0.335*** (1,535)	0.089* (1,535)
Gender	0.199*** (1,534)	0.275*** (1,534)	0.206*** (1,534)	0.265*** (1,534)	0.105* (1,534)
Historically underrepresented minority in STEM	−0.195*** (1,534)	−0.312*** (1,534)	−0.410*** (1,534)	−0.344*** (1,534)	0.094* (1,534)
First-generation college student	−0.158*** (1,533)	−0.302*** (1,533)	−0.282*** (1,533)	−0.284*** (1,533)	−0.048 (1,533)
English second language speaker	−0.162*** (1,534)	−0.305*** (1,534)	−0.308*** (1,534)	−0.282*** (1,534)	−0.040 (1,534)

Cronbach's alpha reliability (*R*) for the KSSLCI and SLCI data are 0.93 and 0.86, respectively.
KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Spearman's rho (r_s) was used for variables in the first five rows of the table, and biserial correlations (r_b) were used for variables in the bottom five rows. Sample sizes are reported in parentheses.

science literacy resulting from the SLCI (Table 6.2). Participants next completed the closely aligned 25-item knowledge survey (KSSLCI), which provided a more granular definition of the meaning of science literacy. Self-assessed ratings using the KSSLCI are more highly correlated (r_s = 0.624; p < 0.001) with the SLCI than those from the *predicted global* measure (r_s = 0.320; p < 0.001). Participants again self-assessed their science literacy using a single, global measure after completing the 25-item SLCI. Ratings derived from this *postdicted global* self-assessment measure correlate highly with those from the SLCI (r_s = 0.623; p < 0.001), KSSLCI (r_s = 0.727; p < 0.001) and the *predicted global* self-assessment (r_s = 0.604; p < 0.001). These relationships confirm that self-estimates derived from instruments with more granular prompts (e.g. KSSLCI) correlate more highly with objective measures (SLCI) than those from single-item, global prompts (e.g. *predicted global* self-assessment).

For each academic rank, the self-assessment errors (rating from the self-assessment minus score from the objective measure) derived from the granular KSSLCI registered by each academic rank are similar and close to zero (Table 6.1; Figure 6.1). This result confirms that people tend to over- and under-estimate with about equal frequency and magnitude and suggests that self-assessed competence, in aggregate, is well calibrated to objective measures of competence in science literacy. This observation remains true across academic ranks (Nuhfer et al. 2016a, 2017). However, the distributions of the

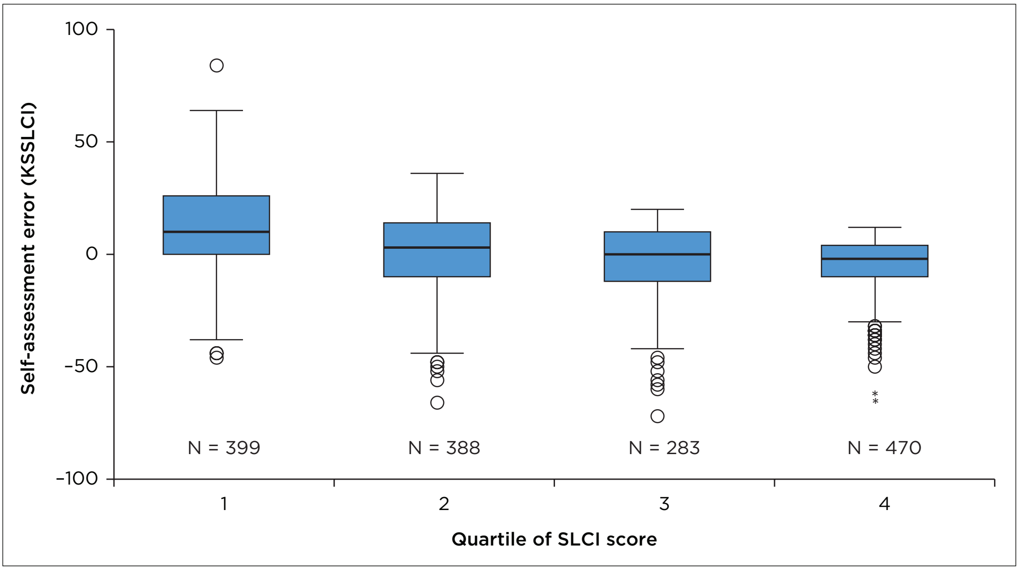


KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Note: Median self-assessment errors are near zero for all academic ranks, but that the range of errors decreases with increasing rank. Median values are indicated by thick horizontal lines, the enclosing shaded rectangle outlines the interquartile range, and the top and bottom quartiles are indicated by vertical whiskers; outliers are indicated with open circles.

FIGURE 6.1: Boxplot of self-assessment errors, calculated as the difference between the self-assessed competence and an objective measure of competence (KSSLCI minus SLCI), by academic rank.

self-assessment errors vary with academic rank (Figure 6.1), and the *range* of self-assessment errors recorded by professors is significantly different from those by novices (p = 0.003; r = −0.11); the difference between developing experts and professors is only marginally insignificant (p = 0.051). Of the two global measures, self-estimates of competence in science literacy from the *predicted global* measure generate the largest errors, and those generated after completing the 25-item SLCI (*postdicted global*) generally exhibit greater accuracy (Table 6.1).

The self-assessment errors derived from the three self-assessment measures (*predicted global*, KSSLCI and *postdicted global*) generally trend from positive to negative values with increasing academic rank (Table 6.1). Yet, this does not necessarily indicate a tendency towards self-assessed under-estimates with increasing academic rank. A boxplot of KSSLCI self-assessment errors by quartiles of SLCI scores suggests that the median self-assessed errors decrease with increasing objective measures of competence in science literacy (Figure 6.2). However, Nuhfer et al. (2016a, 2017) explained this apparent trend as a numerical artefact produced from the probabilities of obtaining different frequencies of values that come from calculating differences in paired scores and ratings (e.g. self-assessment errors) near the centres and



KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Note: That the direction of skewness (asymmetry of the shaded box relative to the median value shown with the heavy line) and range of self-assessment errors change with increasing quartile of SLCI score. See text for details.

FIGURE 6.2: Boxplot of self-assessment errors plotted by quartile of measured competence (SLCI score). The decreasing median self-assessment errors, from the bottom to the top quartile of SLCI scores, are a numeracy artefact.

margins (lowest and highest quartiles) of distributions bounded by the same values. This effect is visible in the asymmetric distributions of the interquartile ranges and minimum and maximum values in Figure 6.2. Because our sample comprises professors with relatively high levels of measured science literacy, their self-assessment errors tend towards more negative values because of the greater range available for under-estimates. Despite the inherent numeracy artefacts in plots such as in Figure 6.2, the presence of a self-assessment signal makes these graphs different from similar-looking graphs produced by modelling random noise with random numbers (Nuhfer et al. 2016b). From the lowest to highest science literacy quartiles, self-assessment errors derived from the global measures show similar patterns of error values and ranges.

Nuhfer et al. (2016b) observed that commitment to science (intent to major) had significant positive effects on the objective measures of science literacy (SLCI). This data set continues to show the significant differences between means of the two categories of both SLCI scores and KSSLCI ratings, as reported by Nuhfer et al. (2016b, 2017) and Watson et al. (2019). However, we investigated if these also had significant impacts on self-assessed competence in science literacy, given our different approach to doing these calculations. The median self-assessment errors derived from the paired KSSLCI and SLCI measures range from 0 to 2 across the four groups in the science course category (e.g. none, 1–2, 3–4, ≥5 science courses), and none of the differences are statistically significant (Table 6.1).

The self-assessment errors (derived from the KSSLCI) between those with (median = 2) and without science interest (median = 0) are significant (Table 6.1), but of little practical effect ($p = 0.007$; $r = -0.06$). Differences in the self-assessment errors between those with and without an intent to major in science are also insignificant for the pre-SLCI global and *postdicted global* measures. However, the more negative self-assessment error (median = –2) resulting from the *predicted global* measure for those with a science interest is significantly lower than those without a commitment to science (median = 4; $p < 0.001$; $r = –0.11$). In boxplots, the self-assessment errors resulting from all three self-assessment measures are narrower for those who indicated an interest in science compared with those who did not.

Self-assessed science literacy and socioeconomic variables

Other demographic variables that have been identified to impact science literacy and self-assessment include gender, race and ethnicity, and first-generation college student status (Nuhfer et al. 2016b; Watson et al. 2019). Notably, the self-assessment errors registered by female respondents are closer to unity than those of male respondents across all three self-assessment measures (Table 6.1), and except for those derived from the *predicted global* item, all differences are statistically significant ($p \leq 0.001$) but of little practical effect ($r < 0.01$). Comparing the results of the three self-assessment measures from those of our binary race and ethnicity category (i.e. majority and historically underrepresented minority groups in STEM), the mean self-assessment errors generated by those from minority groups (medians = 2–4) are consistently larger than those from majority groups (medians = –2–0), but these differences are only significant ($p \leq 0.001$; $r < 0.01$) for the *predicted global* item. First-generation college students consistently register similar or higher median self-assessment errors (Table 6.1), but except for those derived from the *predicted global* measure ($p \leq 0.001$; $r < 0.01$), all are insignificant.

Self-assessment errors derived from the *predicted global* measure often show the greatest magnitudes and differences between different groups (e.g. academic rank, ethnicity, first-generation, first language, completed science courses, science interest and domain expertise; see Table 6.1). The apparent 'magnification' of differential self-assessment error suggests that the *predicted global* measure presents a relatively unique challenge, especially for individuals from less-privileged demographic categories. Elsewhere, such 'feeling of knowing' judgements have been attributed to cue familiarity (Metcalfe, Schwartz & Joaquim 1993).

The correlations reported in Table 6.2 also support the previously described results. Most of the correlations of the SLCI scores with the self-assessment ratings derived from the three measures taken within the socioeconomic groups (e.g. gender, underrepresented minority, first-generation college student and English second language speakers) are modest ($r_b < 0.40$). The greatest of these *r*-values generally comes from the KSSLCI. Correlations between the socioeconomic variables and self-assessment error are considerably lower, and of those that are significant, gender, ethnicity and science interest are the most highly correlated. What emerges is a more complex understanding of self-assessment that underscores the importance of the nature of the self-assessment query, expertise in the domain and socioeconomic variables.

To summarise, our analysis of the paired measures data set (n = 1534) confirms that, in aggregate, most people are relatively accurate self-assessors. Further, there are significant differences in self-assessment accuracy made by different groups of individuals categorised by academic rank, commitment to science, gender and minority groups.

Discussion

In this section, we describe approaches for characterising self-assessment skills and improving teaching and learning through self-assessment. We further attempt to illuminate the effects of individual demographic variables on self-assessment; explore a range of pedagogical uses for knowledge surveys for teaching, learning and scholarship; and analyse knowledge surveys in the context of self-assessment typologies.

Insights from distributions of self-assessment errors

The numerical artefacts which underlie the graphical approaches used to establish the Dunning–Kruger effect (Kruger & Dunning 1999) have been extensively documented by Nuhfer et al. (2016b, 2017) and Watson et al. (2019). These studies provided several approaches that included categorical analyses. How else should we illustrate self-assessment skills for teaching, learning and research that are less susceptible to spurious numeracy effects?

Analyses of the paired measures in the SLCI database confirm that self-assessment errors are typically near zero, meaning that in aggregate, people are generally good self-assessors (Nuhfer et al. 2016a, 2017; Watson et al. 2019). Thus, difference scores (self-assessed competence minus objective measure of competence) are unlikely to provide a comprehensive picture of self-assessment when used alone. When generating graphs of self-assessment results, we regularly observe different groups with near-zero self-assessment errors. In the rare cases where we observe relatively large self-assessment errors, they are typically: (1) derived from a global measure or (2) registered by a group dominated by a single demographic. The median self-assessment errors in

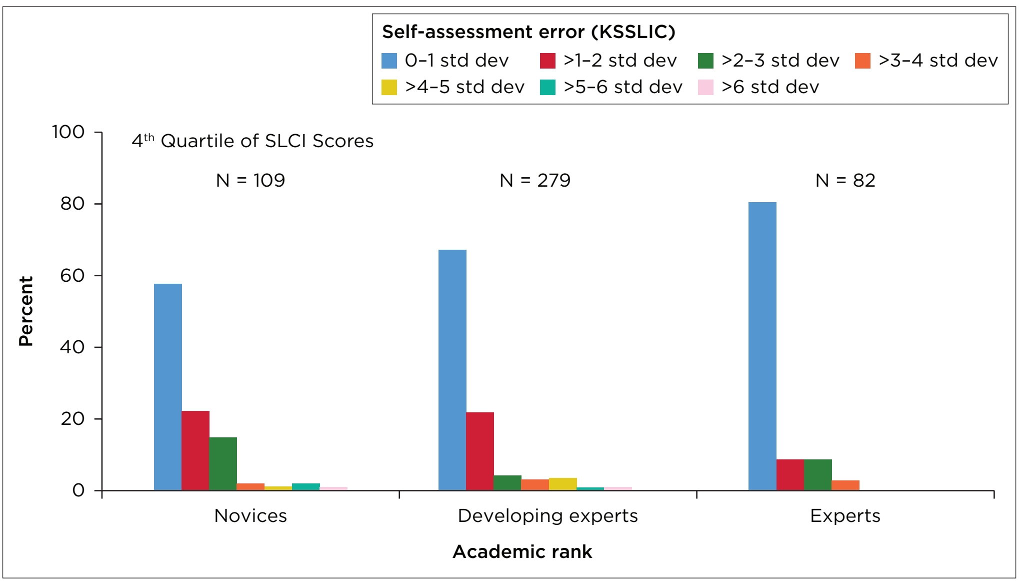
Table 6.1 are ≤ ±4 percentage points, except those derived from the *predicted global* measure. The only other large median self-assessment errors result from calculations involving the lowest and highest quartiles of SLCI scores, where ceiling and floor effects limit the range of available ratings for self-assessments.

Nuhfer (2019) compared self-assessments by individuals and aggregate self-assessments of groups. By drawing on 104 randomised groups of 50 individuals from the SLCI database, he showed that individuals are generally accurate at self-assessment, and group self-assessments are even more accurate. Group knowledge survey means are very accurate predictors of the group mean test scores of demonstrated competency. From this report emerges a classification scheme for the self-assessment accuracy of groups based on the standard deviation of the average group self-assessment errors. Applying that approach to this data set, we obtain estimates of good (±3 percentage points), adequate (±6 ppts) and poor (±9 ppts) self-assessment based on the mean standard deviation of randomly generated groups. This standard deviation for groups is less than half the standard deviation for the individuals (1s = 8.38) in this data set.

These results naturally raise the question about the level of self-assessment accuracy that we expect from our students with regular practice and feedback. Given that individual inaccuracy is caused by random inconsistence or ‘noise’, and averaging by groups tends to attenuate such noise, the group self-assessment values may offer a realistic goal. Students who register as good self-assessors, without focused training of the kind that we advocate for here, are accurate within ±10 ppts (Nuhfer et al. 2017). With training and practice, we can help individuals reduce their own inconsistence or ‘noise’ and possibly get them to achieve accuracy within ± 3 ppts. Work by one of the authors (K. Wirth) with students in his programmes. indicates that this goal is plausible; most (64%) students in a 2nd-year majors course consistently postdict their exam scores within ±5 ppts, and >40% do so within ±3 ppts. If such improvements prove generalisable, self-assessment training and practice should significantly boost the capacity of students to do SDL.

Here, we describe a new approach to interpreting paired measures by limiting our comparisons to groups with similar ranges of competence scores. This approach attenuates the ceiling and floor effects that prove troublesome when studying groups with a broader range of scores. By comparing the self-assessment errors of individuals in different academic ranks who are all in the top quartile of SLCI scores, we reduce the differential contributions from the ceiling effect. We also minimise the impact of individuals’ unequal distributions in the different academic ranks across all the SLCI quartiles. In this analysis, we are less interested in the direction of the self-assessment errors and more interested in their relative magnitudes. To facilitate comparison of the distributions of self-assessment errors, we normalised the absolute value of each individual's self-assessment error to the standard deviation of self-assessments by the expert group (i.e. professors). Figure 6.3 illustrates the distributions of self-assessment errors for each academic rank, normalised to the standard deviation of those in the expert group, and reveals more individuals in successive academic ranks with small self-assessment errors and fewer individuals with extreme self-assessment errors. Because each rank consists only of the individuals from the highest quartile, the ceiling effect is similar within each categorical group examined. Statistical tests confirm that the differences between novices and developing experts and novices and experts are highly significant (Mann-Whitney; $p < 0.001$), but the practical effects are small ($r = 0.19$ and 0.23, respectively). These observations support the notion that self-assessment improves with academic experience (Nuhfer et al. 2016b, 2017; Wirth et al. 2016), perhaps independent of knowledge in the domain.

Another metric of self-assessment also comes from analyses of the distributions of self-assessment ratings. Table 6.3 shows the cumulative percentages of individuals with assessment errors classified following the



KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Note: Increasing proportion of small errors and decreasing proportion of large errors with increasing rank. Percentages are calculated based on totals within each x-axis category.

FIGURE 6.3: Clustered bar graph of normalised self-assessment errors (KSSLCI rating minus SLCI score) by academic rank for those with SLCI scores in the highest quartile. Self-assessment errors are normalised to the standard deviation of the expert (professor) group of academic rank.

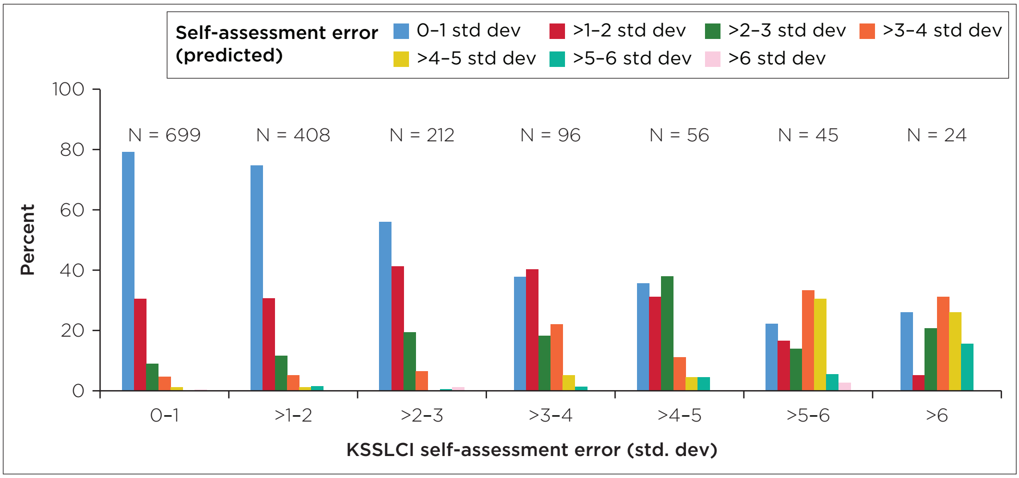
TABLE 6.3: Cumulative percentages of individuals in different academic ranks and quartiles of science literacy with better than good, adequate, marginal and inadequate self-assessment errors (KSSLCI rating – SLCI score).

Category	Group	Good	Adequate	Marginal	Inadequate
		≤1 Std dev	≤2 Std dev	≤3 Std dev	≤4 Std dev
Academic rank	Novices	41,2	68,5	85,4	91,9
	Devel. experts	45,0	73,1	85,5	92,4
	Experts	72,5	85,6	94,9	98,6
Quartile of SLCI scores	1	30,6	53,8	72,1	84,4
	2	35,6	67,1	86,9	95,1
	3	43,5	80,3	91,8	94,4
	4	67,2	86,8	94,2	96,8

KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory; SD, standard deviation.

method proposed by Nuhfer et al. (2017). Here, we normalised each individual's self-assessment error (KSSLCI rating-SLCI score) to the standard deviation of self-assessment errors recorded by professors in the sciences (SD = 8.4 ppts), our sample with the highest academic rank and domain expertise. These standard deviation categories (8.4 ppts, 16.8 ppts, 25.2 ppts and 33.6 ppts) approximate the classification cut-offs used by Nuhfer et al. (2017) to define good (≤10 ppts), adequate (≤15 ppts), marginal (≤20 ppts) and inadequate (≤30 ppts) self-assessment. These data clearly show that the cumulative percentage of individuals with the lowest self-assessment errors (±8 ppts) increases with academic rank. Furthermore, these data indicate that 85.6% of experts, 73.1% of developing experts and 68.5% of novices self-assess within 17 ppts of objective measures of their competence. Similar trends are apparent from the distribution of errors among the different quartiles of science literacy (SLCI scores). About 30.6% of people in the lowest quartile of SLCI scores self-assessed within ± 8 ppts, whereas more than 67% of those in the highest quartile did so. These increase to nearly 54% and 87%, respectively, when we consider errors of less than ±17 ppts. Clearly, most people are aware of their knowledge and skills, and relatively few individuals exist with extreme self-assessment errors of >30 ppts above or below their measured competence (Nuhfer et al. 2016b).

We also use the distributions of self-assessment errors to explore the consistency of self-assessments across different measures. Again, to avoid artefacts resulting from differences in scale and floor-ceiling effects, it is better to compare ranges rather than absolute values. In Figure 6.4, we plot the distributions of individual self-assessment errors (normalised to the standard deviation of self-assessment errors of the professor rank) derived from the *predicted global* measure by each individual's self-assessment error derived from the KSSLCI. More than 60% of those who registered the smallest

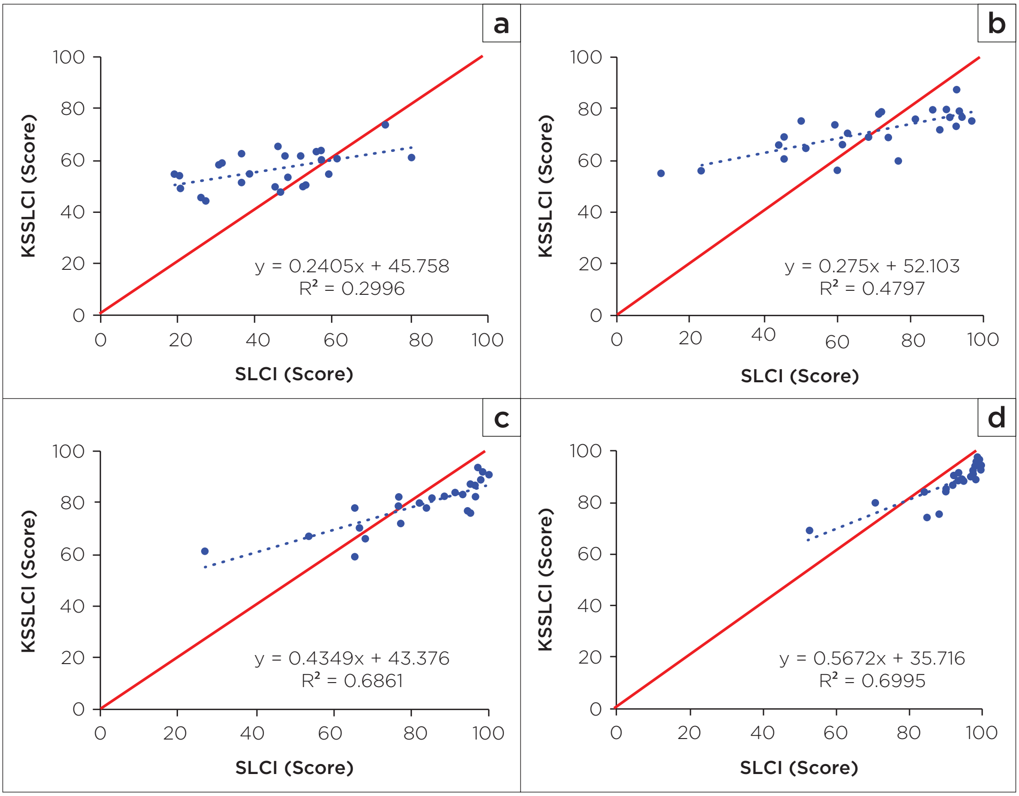


KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Note: Individuals who register the lowest self-assessment errors derived from the 25-item KSSLCI (0–1 standard deviations) also tend to register the lowest self-assessment errors using the single-item, predicted global measure. The reverse is true for those individuals who register a large self-assessment error with the KSSLCI.

FIGURE 6.4: Clustered bar graph of the distributions of normalised self-assessment errors derived from the predicted global measure plotted by the corresponding normalised self-assessment errors derived from the KSSLCI instrument. Self-assessment errors normalised as in Figure 6.3.

self-assessment errors (≤1 standard deviation) using the more informed and granular KSSLCI also had the smallest self-assessment errors using the *predicted global* measure (Figure 6.4). Because predicted self-assessments of competence are less informed, they rely more on affect (e.g. Sitzmann et al. 2010). The proportion of individuals with large self-assessment errors from the *predicted global* measure also increases among those with increasing self-assessment errors from the KSSLCI. All participants completed the single-item, *predicted global* self-estimate before encountering the 25 items on the KSSLCI, so this relationship strongly supports the notion that self-assessment, whether of global or granular nature, is a generally developed skill. Comparisons of self-assessment errors from the granular KSSLCI with the postdicted global measure yield similar results. People with more accurate self-assessment seem to demonstrate it more consistently (see also Nuhfer et al. 2017).

An approach for investigating self-assessment advocated by Nuhfer et al. (2016b, 2017) and Watson et al. (2019) was involved using correlation plots. These researchers correlated the mean scores of individual items from an objective measure with their corresponding mean self-assessed ratings from the same items. Doing so attenuated the random noise that abounds in individual human self-assessments. The grouping categories that facilitate



KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Note: The increasing correlation coefficient and decreasing y-intercept with plots of successive quartiles of SLCI score. Slopes defined by the data are at least partly the result of numeracy artefacts (floor-ceiling effects). See text for details.

FIGURE 6.5: Scatter plots of objective measures of science literacy (SLCI scores) versus self-assessed competence in science literacy (KSSLCI ratings) for the (a) first quartile, (b) second quartile, (c) third quartile, and (d) fourth quartile. Data points represent the average SLCI scores and KSSLCI ratings for each of the 25 items on the paired measures. Perfect self-assessments would plot along a slope of unity and intercept of zero (red reference line).

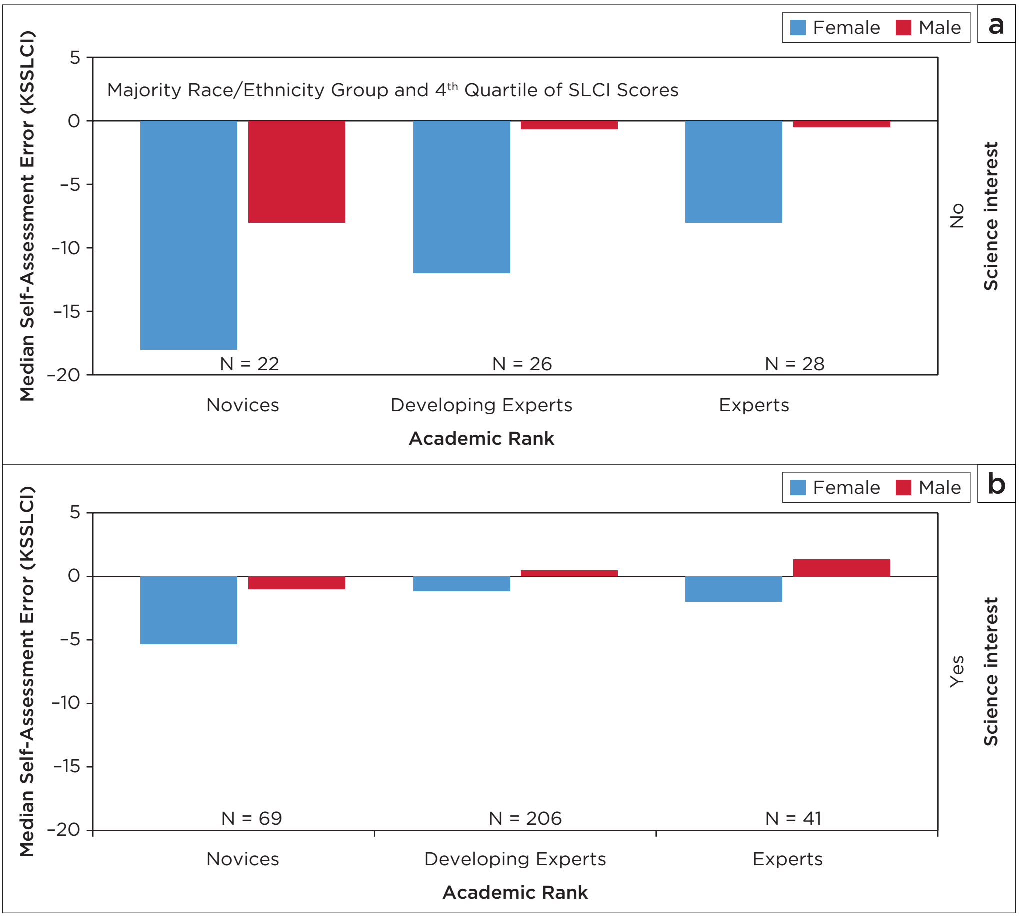
focused research are numerous, but examples include each of the 25 items in the SLCI, demographic groups, individual classes, class ranks or institutions. This graphical approach permits comparing groups with a wide range of scores and avoids employing graphs that produce numerical artefacts. Figure 6.5 reveals the SLCI scores and KSSLCI ratings for the 25 items for each quartile of measured competence, as determined by the SLCI score. The data points spread in each plot reflect the individual items' relative difficulty in the KSSLCI and SLCI. In these plots, perfect self-assessment would produce best-fit lines with slope = 1, and R^2 = 1. Note that for those in the first quartile, the objective and self-assessed measures of the 25 items in the SLCI have a slope of 0.24 and R^2 = 0.30. The slope and R^2 values increase in the successive quartiles of greater science literacy, reaching a maximum of 0.57 and 0.70, respectively, in the fourth quartile. Correlation plots by academic rank indicate similar increases in both slope (0.37 to 0.51) and R^2 (0.51 to 0.69) from novices to experts. These results suggest that greater domain knowledge (quartile of SLCI scores) and improved intellectual development (e.g. Perry 1999) contribute together to develop the capacity for self-assessment accuracy. These plots also confirm that people are generally aware of what their competence is, even when they have relative inexperience in a knowledge domain (Nuhfer et al. 2016b, 2017; Watson et al. 2019).

Self-assessments by historically underrepresented groups in STEM

The preceding discussions indicate that self-assessment skill correlates with educational background (academic rank), interest and experience in the domain (a major, or intent to major in science) and demonstrates knowledge in the domain (SLCI scores). However, realise that 'educational background' refers to the standard educational approach in which self-assessment skill is rarely taught as an explicit learning objective. In the present system, improved skill in self-assessment likely occurs as a collateral effect rather than the product of intentional efforts. Next, we address socioeconomic variables.

Several studies using knowledge survey data (Nuhfer et al. 2016b, 2017; Watson et al. 2019; Wirth et al. 2016) reported negative impacts on objective test scores and self-assessed ratings of science literacy resulting from the effects of lesser privilege. Reduced privilege disproportionately falls on underrepresented populations (e.g. female students, racial and ethnic minorities, first-generation students and English second language speakers). However, few studies have investigated these demographic variables independent of potential interactions by the other variables. Given the mounting evidence of significant differences in self-assessment with an increasing number of variables, the availability of larger paired-measures data sets permits us to extend the examination of the impacts of socioeconomic variables on self-assessment.

Several studies reported lower self-confidence among female populations and their tendency to underestimate their competence relative to objective measures of their competence in those domains (Herbst 2020; Perez-Felkner, Nix & Thomas 2017; Sakellariou 2020). However, if other demographic variables also affect self-assessment, and if the binary genders have unequal distributions across groups, then the correlations that consider only gender differences become tenuous. To isolate the effects of gender on self-assessment while controlling for floor-ceiling effects, we selected only those participants with SLCI scores in the highest quartile and majority group of our binary race and ethnicity variable. We then compared the self-assessment errors of male respondents and female respondents with and without an interest in science from each academic rank (Figure 6.6). Perhaps most notable is the observation that self-assessment errors are increasingly significant and negative for those without a science commitment. This observation held for both binary genders within all academic ranks. We interpret this relationship to confirm the importance of knowledge and experience in the STEM domain to making accurate self-assessments (e.g. Falchikov & Boud 1989; Nietfeld & Schraw 2002). The more negative self-assessment errors registered by non-science female respondents might result from that population's responding differently to certain items on the SLCI that exhibit bias or could also result from some gender bias in the overall SLCI instrument, as suggested by recent IRT analysis



KSSLCI, Knowledge Survey of the Science Literacy Concept Inventory; SLCI, Science Literacy Concept Inventory.
Note: The median self-assessment ratings of female respondents are consistently lower than those of men and that the median self-assessments by those with science interest are significantly more accurate.

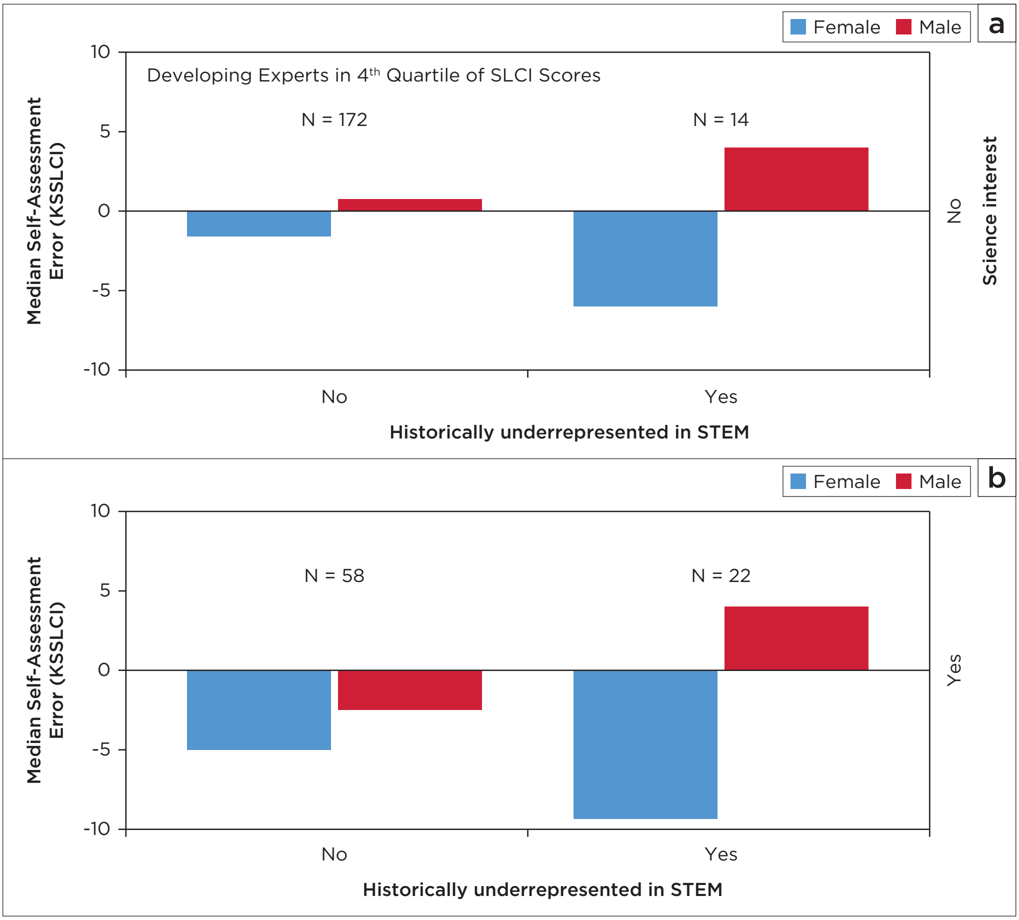
FIGURE 6.6: (a & b) Bar graphs of self-assessment errors (derived from the KSSLCI) for those in the majority category of the binary ethnicity variable and in the highest quartile of SLCI scores. The median self-assessment errors are shown for female (blue shading) and male (red shading) respondents in each category of academic rank (*x*-axis) and science interest (row panels).

(Walter et al. 2021). The magnitudes of the self-assessment errors decrease with increasing rank, for those both with and without an interest in science, suggesting that educational experience contributes to improved self-assessment independent of domain expertise.

In summary, female respondents consistently register more negative self-assessment errors compared with equivalent male populations (Figure 6.6). Most notably, significant negative self-assessment errors persist among female participants, even at the highest academic rank (professor) in the sciences (Figure 6.6). This approach allowed us to control for five out of the seven most significant demographic variables that we have identified thus far and strongly support the notion that female respondents tend to self-assess their competence at lower levels than they can demonstrate. Remarkably, in all combinations of variables that we have plotted, female respondents rarely have larger self-assessment errors than male respondents.

Using a similar approach, we also investigated the relationships between ethnic minorities and first-generation status on self-assessment. For this analysis, we selected participants from the rank of developing experts (3rd- and 4th-year students), the largest group in our database and from the highest quartile of SLCI scores to control for floor-ceiling effects. Comparing binary gender categories by underrepresented minority and first-generation status, we again observe that our sample of female students consistently under-estimates their demonstrable competence relative to male students (Figure 6.7). The relationships exhibited by this plot also suggest larger and more negative self-assessment errors for those in our binary racial/ethnic minority and first-generation college student categories. Because the number of students in our racial/ethnic minority and first-generation categories is relatively small (Table 6.1), further analyses controlling for other variables are not yet possible.

In our modest study sample, the results are remarkably consistent over a wide range of combinations of variables – those who are racial/ethnic minorities or first-generation college students consistently self-assess themselves below objective measures of their competence. Extended analyses of these and other variables await a larger database with a more diverse sample. Indeed, a more accurate and nuanced understanding of self-assessment has recently emerged. The findings contradict a large block of literature in the behavioural sciences that began with Kruger and Dunning (1999), which underestimates most people's self-awareness and ability to accurately self-assess their competence. Nuhfer et al. (2016a, 2017) explained how these underestimations became the accepted consensus and offer strong evidence that the inferred accuracies of self-assessments depend on the quality of the measures. High-quality measures reveal that self-assessment ratings also vary with privilege and intellectual development. Broad generalisations about self-assessment across diverse populations risk being oversimplified.



Note: The median self-assessment ratings of female students are consistently more underconfident than those of male students and that the median self-assessments by historically underrepresented minority groups in the categories of ethnicity and first-generation students have consistently lower median self-assessment ratings.

FIGURE 6.7: Bar graphs of group median self-assessment errors (derived from the KSSLCI) for developing experts (3rd- and 4th-year students) and in the highest quartile of SLCI scores. The median self-assessment errors are shown for female respondents (blue shading) and male respondents (red shading) in each category of academic rank (*x*-axis) and first-generation college student status (row panels).

Unjustified underconfidence and overconfidence

Another unique approach we employ here to characterise groups' self-assessments involves focusing on people's tendencies to under- or over-estimate their abilities. Paired measures that use knowledge surveys as a source of self-assessment ratings allow for estimating the degree of underconfidence or overconfidence. When participants complete the self-assessment of their science literacy (KSSLCI), they self-assess their understanding of each science literacy item by using three psychometrically sound, distinct and efficient response options. In contrast, participant responses to the aligned objective measures of science literacy (SLCI) generate a binary scoring system ('correct' or 'incorrect'). When participants answer an item correctly on the SLCI, their response option to that same item on the KSSLCI offers insights into participants' self-assessment accuracy and confidence. For correctly answered items on the SLCI, we should expect that accurate self-assessors would more frequently select response options indicating some level of knowledge (e.g. partial or full understanding of the item). When participants choose 'not yet able to address the item' but answer it correctly, this offers an opportunity for study. For each individual, we calculated the proportion of items with correct responses on the SLCI that received the least confident response option ('not yet able to address the item') on the KSSLCI, and we refer to the paired measures exhibiting this relationship as characterising 'unjustified underconfidence'. We first verified that more such responses occurred than should occur by random chance.

We proclaimed such paired responses as 'unjustified' because the magnitude of the under-estimates seemed unwarranted after comparisons with the correct answers registered by those same individuals on the SLCI. We can also use the complimentary relationship (i.e. the proportion of items with incorrect responses on the SLCI that received the most confident response option on the KSSLCI) to calculate a measure of 'unjustified overconfidence'.

In Figure 6.8, we consider unjustified underconfidence among those with a commitment to science by gender, academic rank and the binary ethnic minority category. This bar graph shows that female students consistently register greater median levels of unjustified underconfidence across all demographic groups. Thus, female respondents self-assessed at the lowest level of competence ('not yet able to address this item') more often than did men when they demonstrated that they knew the correct response option on the SLCI. The plot reveals that unjustified underconfidence decreases for both female and male students with increasing academic rank. Once again, this confirms that self-assessment accuracy improves with expertise (e.g. educational experience and domain knowledge). This plot reveals generally increased levels of unjustified underconfidence among those who are historically underrepresented in STEM, relative to those from majority ethnic groups. It also supports the genuine relationship between underconfidence and students of lesser privilege, as noted by Watson et al. (2019).

Comparing response options on self-assessment measures across correct or incorrect items from objective measures avoids the numerical artefacts (e.g. floor and ceiling effects) inherent to other commonly used approaches in self-assessment (e.g. use of quartiles and difference scores consisting of self-assessment and objective measures). Still, for those with the lowest and highest objective measures of science literacy, we recognise that one potential limitation of this approach lies in the limited number of correct and incorrect SLCI responses available to calculate measures.

Many researchers have emphasised the long-term impacts of beliefs about self on important career decisions (e.g. Correll 2001). Representative belief

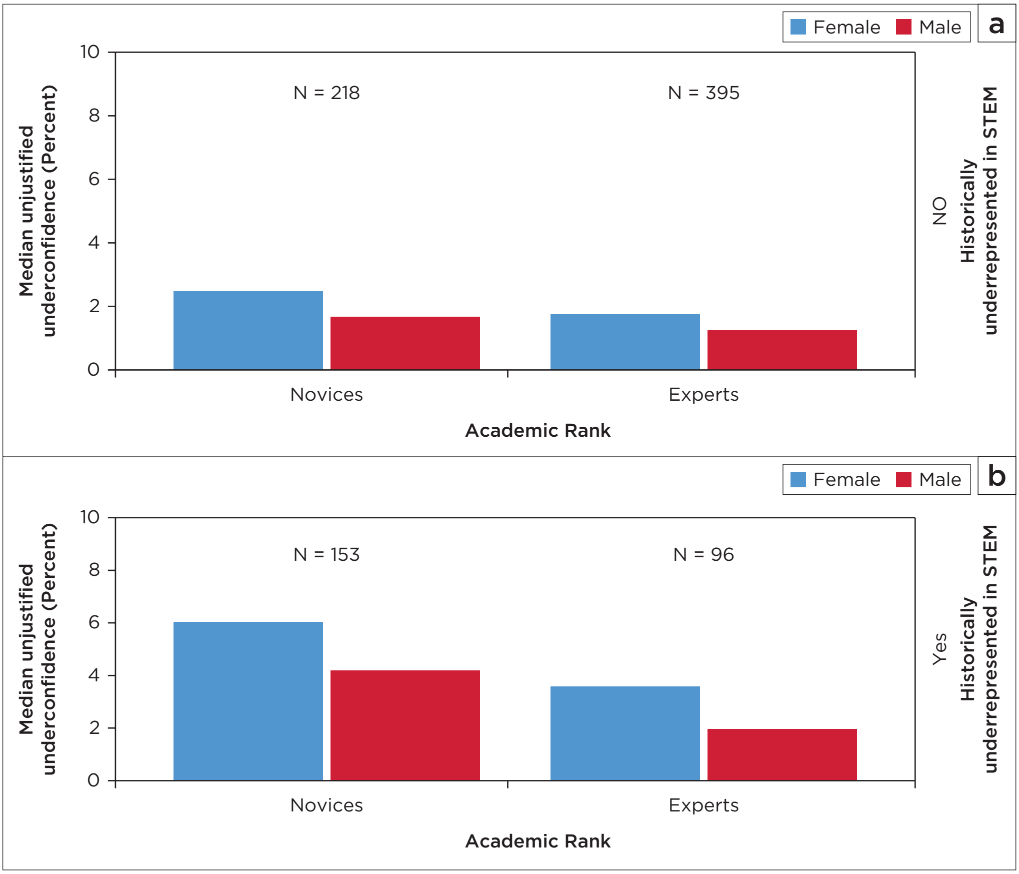


FIGURE 6.8: (a & b) Comparison of group medians of unjustified underconfidence by male and female students with science interests in the novice (1st- and 2nd-year students) and developing expert (3rd- and 4th-year students) categories for minority and majority groups in STEM. Female respondents consistently indicate greater underconfidence in all categories by rank and ethnic minority/majority. Participants in the higher developing expert category and majority binary ethnic category register lower unjustified underconfidence. See text for explanation.

systems include stereotype threats (Spencer, Steele & Quinn 1999; Steele 1997; Steele & Aronson 1995) and growth mindsets (Dweck 1999). Given the multitude of daily self-assessments and decisions required to become a scientist (e.g. 'Can I complete that homework problem?' 'Will I be successful in that course if I take it?' 'Am I good enough to declare a major in science, technology, engineering or mathematics?' 'Am I smart enough to get into a good graduate programme?' 'Will I be competitive enough to secure funding for my research career?'), it is no small wonder that even slight differences in tendencies to overestimate or underestimate competence can have enormous consequences on important life decisions (e.g. Ehrlinger & Dunning 2003; Schulz & Thöni 2016; Sheldrake et al. 2015). We agree with Nix et al. (2015) and Perez-Felkner et al. (2017), who emphasised the importance of gendered ability beliefs on making decisions to engage with advanced coursework and pursue degrees in STEM fields at several critical stages during late secondary school and early college. Moreover, this work suggests that the magnitudes and signs of errors in self-estimated competence change with other variables (e.g. academic rank, measured competence and socioeconomic variables). Our results reveal the complexity of determining whether the underconfident groups or the overconfident groups most merit intervention. By strengthening the capacity for accurate self-assessment and developing self-regulation in students, educators can mitigate damage caused by overconfidence and underconfidence across all demographic groups. Learning environments in which ALL students practice self-assessment and then discuss misalignments can create equitable and inclusive classrooms.

Promoting self-directed learning with knowledge surveys and self-assessment

The knowledge survey's design and format make it useful to a wide range of purposes and environments in teaching and learning. The process begins with the teacher writing knowledge survey items that are directly assessable and closely align with the learning objectives for a unit of learning or an experience. Individual knowledge survey items describe, at a granular level, the target knowledge or skill, the desired level of understanding and the context. They supply the blueprint to the scaffolding to using content – content in ANY discipline – to realise higher-order thinking. The knowledge survey prompts or the response options should contain some variant of the root 'I can…'. This reminds the respondent that affect and awareness of self are part of the response to any cognitive challenge. Responding to 'self' reveals whether the respondent can complete the described task at this time. Students can complete the surveys in the classroom using pencil and paper or outside the traditional classroom using a wide range of digital platforms (e.g. Google Forms and learning management systems). We prefer that students do the completions outside, where constraints do not distract attention from self-reflection to 'covering the survey' by attending to a clock rather than to the queries. The knowledge survey design also facilitates efficient administration before and after a short unit of learning such as in a workshop or at multiple points throughout an extended programme of study. Because respondents only respond with their perceived ability to address a task at that time, knowledge survey prompts are appropriate for learning objectives that address both knowledge and skills. programme leaders can administer knowledge surveys efficiently and effectively in settings where more traditional tests are inappropriate or logistically difficult (e.g. co-curricular activities, internships, leadership programmes and research experiences).

Many teachers utilise knowledge surveys for pre-post learning assessments for courses or smaller learning units in other contexts (e.g. workshops, conferences, research experiences and internships). In this mode of use, learners interact with the survey items at the beginning and/or end of a unit of learning, and the primary goal of student self-assessment is to guide teaching. Student responses to a pre-course knowledge survey provide information about students' background knowledge that can inform course and instructional design. A teacher can also use pre-course survey data to establish a baseline for evaluating learning gains at the end of a learning unit. When administered over multiple iterations of a course, knowledge surveys also provide an efficient way for teachers to evaluate the impacts of course organisation or instructional design changes. Some teachers who realise the awareness they are achieving in constructing a knowledge survey soon recognise that teaching students how to construct knowledge survey items imparts the same benefits. Constructing knowledge surveys helps teachers be more metacognitive about their teaching to carefully consider the goals for learning, the targeted levels of mastery and the alignment of assessments with learning goals (Cohen 1987). Instructors can guide students to own these same benefits too. Students can start by replacing the teacher's knowledge survey items with their own and then progress to designing their own battery of items that scaffold their learning to the desired goal.

In addition to serving as a pre-post learning survey, some teachers also use knowledge surveys to support student learning of the content and skill objectives in a course (e.g. Harris & Watson 2021). Instructors share knowledge survey items with students to communicate course goals and expectations for learning more clearly and in greater detail. Students can also refer to the relevant items in a knowledge survey before beginning a reading assignment. In this practice, the knowledge survey serves as a guide to focus on student learning while reading or conducting an activity. Using self-assessments to clarify expectations, especially for 1st-year and underserved students, improves the learning experience, helps students develop as self-directing learners and improves student success and retention (Mahlberg 2015; Nicol 2009; Yorke 2005).

Students can informally use the survey items to self-assess their mastery of the learning objectives at the end of a reading assignment or teaching activity. Alternatively, teachers can direct students to use the survey items to guide their study before an exam. In a more formal version of this approach, teachers can offer students the opportunity to complete a pencil-and-paper or online self-assessment of their learning using a knowledge survey to gauge their readiness to complete a summative assessment (e.g. quizzes or exams) in a course. Typically, teachers do not grade knowledge survey responses, but to encourage participation, teachers can treat knowledge surveys as assignments and award credit for their completion. At this level of usage, knowledge survey data inform teaching practices, but students also use them to facilitate their learning of course content and skills.

In addition to supporting student learning of a course's content and skill objectives, some teachers also use knowledge surveys to foster student learning about metacognition, self-regulation and SDL. When teachers include similar items on both knowledge surveys and summative assessments (e.g. quizzes or tests), students and teachers can compare student self-assessments with those from direct measures of competence. Another approach is for the teacher to encourage students to compare the formative self-assessment results with those of the summative assessment. Alternatively, students can complete a structured reflection (e.g. post-exam reflection or exam wrapper; Achacoso 2004) that guides them to reflect on their self-assessed readiness to meet a summative assessment. This reflection informs study strategies, time management and analyses of exam performance. The analysis can include careful evaluation of their performance at different Bloom levels of understanding, an essential design element of knowledge surveys (e.g. Favazzo et al. 2014). Instructors can also encourage students to outline plans for improvement, including how they can better plan for the next summative assessment. These self-assessment activities promote students' affect and metacognitive knowledge (e.g. McMillan & Hearn 2008; Ross 2006), which in turn supports their development as self-regulating (Black & Wiliam 1998; Panadero, Andrade & Brookhart 2018) and self-directing learners (e.g. eds. Mentz, De Beer & Bailey 2019).

Students can also be directly involved in generating knowledge survey items. Instructors can guide students in identifying learning objectives (both knowledge and skill) from readings and other course materials. Following an introduction to Bloom's taxonomy (Anderson & Krathwohl 2001) and Perry's stages of intellectual development (Perry 1999), students can begin to comprehend the differences in thinking characteristics demanded for different learning objectives. Working in small groups, they can develop knowledge survey items addressing the material at varying Bloom levels aligned with the course level. This activity fosters engagement and an improved understanding of the relationship between self-assessment and learning. Later, teachers can guide students through reviews of the survey results leading to improved student interest and engagement. Students seem to develop curiosity about understanding how differences in self-assessment relate to socioeconomic variables and privilege. They appreciate discussing how these findings inform the experiences many students have in college (Fleisher 2019). Instructors can combine the topic of self-assessment with discussions of standards, criteria, the design of rubrics and self-evaluation. These approaches bring the goals of learning into sharper focus. They help develop a common language understood by both teachers and students and encourage students to assume greater responsibility and agency in the learning process.

Finally, we note that the pedagogical shifts produced from varied applications of knowledge surveys and purposeful self-assessment occur best through close teacher involvement (e.g. Brown & Harris 2013). Instructors providing learning activities about self-assessment, self-regulation and SDL help students understand how to scaffold their learning and development.

Self-assessment measures and instruments

The self-assessed measures of competence derived from three self-assessment measures correlate well with our objective measure of competence (*predicted global* self-assessment, r_s = 0.32; KSSLCI, r_s = 0.62; *postdicted global* self-assessment, r_s = 0.62; Table 6.2), consistent with our earlier findings (Nuhfer et al. 2016b). This pattern reveals the importance of communication in self-assessment, especially the requirement that students must understand what they are being asked to self-assess. A broad, general description of the challenge (e.g. a *predicted global* self-assessment) is almost always insufficient, and there is evidence that feeling of knowing and confidence judgements may have different psychological bases (e.g. beliefs vs. retrieval cues, respectively; Costermans, Lories & Ansay 1992; Perfect & Hollins 1996). Additional opportunities for retrieval practice (e.g. Miller & Geraci 2014) might also contribute to the apparent improved metacognitive accuracies of self-estimates from our postdicted global measure.

The participants studied in this chapter took the survey in one sitting and experienced no teaching of the content. The disclosure provided by merely interacting with the knowledge survey produced learning by clarifying the nature of the coming challenge. After engaging with the knowledge survey, the participants' self-assessment accuracy improved significantly. This increased understanding persisted through confronting the actual challenge. This indicates that engaging with a course knowledge survey better prepares students for learning course content by clarifying the nature of the challenges ahead. When teaching follows this understanding, it will almost certainly be more successful than the teaching that falls on no such heightened awareness. People adjust their self-assessments as their understanding of the domain increases (Nuhfer et al. 2017; Watson et al. 2019).

After completing several published studies with these different kinds of self-assessments, we realised that the *postdicted global* self-assessment following taking the SLCI is almost as revealing as that obtained by taking the full granular knowledge survey. Inclusion of the 25-item KSSLCI adds 20 to 30 min to completing the daisy-chained instrument; the final *postdicted global* self-assessment adds about 10 to 20 s. So, the version of the SLCI in use for routine assessments since 2018 now carries a *predicted global* self-assessed competence rating at the beginning and a *postdicted global* self-assessed competence rating at the end (post-SLCI). The full KSSLCI served its purpose by revealing that knowledge surveys capture self-assessments that relate strongly to the mastery of the content addressed by the instrument. It is no longer necessary to run it together with the SLCI to obtain useful assessment information.

A lesson emerges from all of this research: if adding a *predicted* and *postdicted global* self-assessment query adds only seconds of test-taking time for participants, why not incorporate these global self-assessments on every scored faculty-made test, quiz and assignment? Doing so provides students with practice in doing self-assessment and enables later feedback to polish their accuracy. Further, it gives faculty the benefit of receiving self-assessment information together with test scores of cognitive content mastery. These paired measures give us much more valuable insights about students and learning than can test scores alone.

Knowledge surveys and typologies of self-assessment

The knowledge survey examples described above reveal formative and summative applications for improving teaching, content learning and SDL in teacher- and learner-centred environments. In many respects, the design of knowledge surveys makes them ideally suited as both a measure of self-assessment and as an intervention for improving it. In other words, an accurate characterisation of the role of knowledge surveys in supporting learning depends less on the measure (it remains unchanged) and more on the intended use. This approach ('measurement + intervention'), described as the 'third wave' in the history of self-assessment by Panadero, Klug and Järvelä (2016c), serves for improving student monitoring and SRL.

Most existing typologies do not fully capture the nuances of self-assessment practices offered by knowledge surveys. We suggest that a typology of self-assessment could include elements of the agents, contexts and goals of self-assessment. Table 6.4 summarises the examples of knowledge survey uses (e.g. classroom pre- and post-assessment, learner reading/study guides, learner pre-test self-assessments, learner post-test analysis and learner-generated surveys) described in the preceding section. The examples listed from left to right in Table 6.4 define a continuum from teaching-centred to learning-centred. In this continuum, a pedagogical shift occurs from a focus purely on disciplinary learning towards an emphasis on developing the knowledge and skills required for self-regulated and SDL. The table also represents several self-assessment typologies summarised by Panadero, Brown and Strijbos (2016a) and the classifications articulated by each typology as applied to the different uses of knowledge surveys.

When employed to develop the 'knowledge interests' of Boud and Brew (1995), knowledge surveys can address the full range of interests from *technical* to *communicative* and *emancipatory* (Table 6.4). In the teaching-centred uses, which include research conducted with a general goal of improving teaching and learning, knowledge survey creation and administration are under full control of the teacher, and the primary goal of self-assessment is improving teaching (and indirectly learning). At the learning-centred levels of knowledge survey use, the teacher and students use knowledge surveys to support the learning of disciplinary content to serve both *technical* and

TABLE 6.4: Summary of different uses of knowledge surveys in higher education and their alignment with published typologies of self-assessment (see text for discussion).

Typology	**Examples of Knowledge Survey Uses for Supporting Teaching, Learning, and Scholarship**				
	Classroom pre-/post-assessment	**Learner reading/study guide**	**Learner pre-test self-assessment**	**Learner post-test analysis**	**Learner-generated surveys and rubrics**
Knowledge interest (Boud & Brew 1995)	Technical interest	Technical and communicative interests	Technical and communicative interests	Communicative and emancipatory interests	Communicative and emancipatory interests
Involvement (Tan 2001)	Self-awareness	Self-appraisal	Self-appraisal	Self-assessment practice	Self-determined and self-assessment practice
Power and transparency (Taras 2010)	Standard model	Standard model	Standard model	Standard model	Self-assessment with integrated feedback
Assessment criteria (Alonso-Tapia & Panadero 2010; Panadero et al. 2013)	Standard self-assessment	Standard self-assessment	Standard self-assessment	Standard self-assessment	Rubrics
Response format (Brown & Harris 2013)	Self-ratings	Self-ratings/self-estimates	Self-ratings/self-estimates	Self-estimates	Criteria- based assessments
What, why, and how (Andrade 2019)	Formative, task-specific ratings and summative post-task judgements	Formative and process-oriented with standards	Formative and process-oriented with standards	Summative, process-oriented with standards	Summative, process-oriented with standards
Agents, contexts and purposes of self-assessment (this study)	**Teaching-centred** *Self-assessments employed by teacher for course or instructional design and improvement*	**Learning-centred** *Informal use by students for improving learning of course objectives*	**Learning-centred** *Increasingly formal student self-assessment and focus on metacognitive skills*	**SDL-centred** *Formal student self-assessment and scaffolded instruction on SRL*	**SDL-centred** *Increasing emphasis on developing agency as students assume greater roles*

SDL, self-directed learning; SRL, self-regulated learning.

communicative interests. Finally, when used for improving SDL, students assume greater responsibility in using knowledge surveys. The focus of self-assessment shifts towards promoting the development of metacognition, SRL and agency (Boud and Brew's 'emancipatory interests').

The typology of self-assessment proposed by Tan (2001) emphasises teacher involvement. In the example of teaching-centred knowledge survey use, students assess their thinking processes (*self-awareness* category), but they do so without consistent criteria or comparison with external standards (Table 6.4). At the middle levels of learning-centred self-assessment, students engage in self-assessments (*self-appraisals)* with increasing awareness of teacher expectations without formal comparison to external standards. At the SDL-centred levels of knowledge survey uses, classified as *self-assessment practice* and *self-determined assessment*, students compare self- and teachers' assessments and assume greater responsibility for determining what and how to self-assess. The example knowledge survey applications described in Table 6.4 address two intermediate to high level categories (*standard model* and *self-assessment with integrated feedback)* of the power balance and transparency typology of Taras (2010).

According to the typology of Alonso-Tapia and Panadero (2010) and Panadero, Alonso-Tapia and Reche (2013), all example uses of knowledge surveys would be classified as *standard self-assessment*. However, components of *rubrics* (e.g. criteria and standards) are involved in the highest level of SDL-centred knowledge surveys (Table 6.4). Under the classification of self-assessment formats by Brown and Harris (2013), the different knowledge survey applications span the range from *self-ratings* to *self-estimates* and *criteria-* or *rubric-based assessments*. Andrade (2019), who responded to Panadero et al.'s (2016c) call for a more comprehensive typology of self-assessment, proposed a typology based on the *what*, *why* and *how* of self-assessment. By this typology, knowledge surveys function across a range of categories from *formative*, *task-specific ratings* to *summative, post-task judgements* and *process-oriented formats with standards* (Table 6.4).

In summary, it is informative to examine knowledge survey uses in the context of several recent typologies of self-assessment. Given the singular design and form of knowledge surveys, it is somewhat remarkable that they function across such a wide range of categories that represent such different criteria and approaches. The comparison with existing typologies highlights additional dimensions for consideration in the classification of self-assessment practices. Essential elements in the use of knowledge surveys include the agent (teacher, student), the context (e.g. self-assessment measure and learning intervention) and the purposes (e.g. improving teaching and learning, content learning, or SRL and SDL).

For us, the most critical differences in the self-assessment approach accompany shifts from teacher-directed uses for improving teaching to student-guided uses for deeper content learning and after that to student-managed uses for the more holistic development of SRL and agency. We also recognise that the different uses of knowledge surveys reflected in this continuum could serve as microcosms for the courses that employ the instrument. In summary, the effective implementation of knowledge surveys to support deeper forms of student self-assessment and development also requires a developing pedagogical awareness of needed transformations at the scales of teaching, courses and curricula.

Limitations

The results of this study, as with most studies, prove to have some limitations. Although our results suggest that self-assessment accuracy correlates with academic rank, commitment to science and demonstrated science literacy, we have not undertaken studies of causation. The SLCI-KSSLCI national database includes some pre- and post-course survey data, but our analyses are cross-sectional. That is, the data from each survey respondent are considered a snapshot of unique individual's self-assessment in the context of a single course. As such, our study design does not track individual changes in self-assessment skill or dispositions through a curriculum or degree programme. Apparent improvements in self-assessment skill with increasing educational background and disciplinary knowledge could result, at least in part, from biases in our sample.

Our ability to more rigorously evaluate the impacts of several demographic variables on self-assessment is also limited by our sample. The national SLCI-KSSLCI database contains relatively small numbers of respondents from underrepresented minorities (e.g. ethnic, racial, gender and sexual identity, and first generation), so our conclusions about differences in self-assessment skill should be regarded as exploratory. Furthermore, the way in which instructors volunteer to have their courses participate in the study, and the ways in which students in those courses respond to the surveys are completely voluntary. This means that we cannot ensure a sample that is representative of the HE population. However, we do not attempt to make generalisations that are not bound by the sample and demography of this investigation. Further studies that mitigate these limitations and include a larger sample in terms of demography will be considered.

The design of the study, with an emphasis on citizen-level understanding of science concepts, also means that surveys are completed under a wide range of conditions and settings. As such, we have little control over the conditions and effort of the respondents. In some cases, course instructors award students with extra credit and feedback (not a letter grade) for completing the surveys, so some students may not have been sufficiently motivated to employ their best self-assessment skills when completing the surveys. We have tried to mitigate this limitation by culling patterned responses (i.e. random guesses) that likely do not reflect intentional self-assessment.

Statistical analyses of self-assessment have previously been fraught with challenges, and we have attempted to address some of those challenges in this chapter. Certain comparisons of individuals with widely differing self-assessment skills, calculated as the difference between demonstrated and self-assessed knowledge, yield numerical artefacts interpreted as a Dunning–Kruger effect. To minimise these artefacts, we focus our comparisons on data from individuals with similarly demonstrated competencies. Of course, this has the unintended consequence of greatly reducing our sample size and introduces noise into our comparisons of different demographic groups.

Finally, the generalisability of the results of this study is limited by biases in the study population and by the limits of the knowledge domain. Respondents to the SLCI and KSSLCI surveys are mostly from university settings, so strictly speaking, our results are relevant to students and faculty in HE. Although we are quite confident that our conclusions about the fallacies inherent in the methods of analyses of some prior studies of self-assessment, we are less certain about the generalisability of our conclusions to other knowledge domains. Because the SLCI and KSSLCI surveys specifically target knowledge in the science domain, we have not studied how self-assessment accuracy or dispositions might differ in other content domains. Finally, our analysis of knowledge survey data thus far has been largely limited to the United States, so generalisability of the results to different cultures and educational systems in other countries awaits broader implementation. With the use of self-assessment (e.g. knowledge surveys) taking rise in countries such as South Africa, further investigations which include these contexts are considered.

■ Conclusion

We began this chapter with four goals:

1. Use a database obtained from 4-year institutions and demonstrate previously unreported ways to extract information from the paired measures of self-assessed competence ratings obtained from knowledge surveys and actual competence scores from a validated concept inventory.
2. Explore the results obtained by applying these methods to diverse demographic groups.
3. Describe current applications of knowledge surveys for supporting learning, teaching and research.
4. Summarise how knowledge surveys exemplify the spectrum of teaching and learning expressed in recent typologies of self-assessment.

For this study, we collected a unique database of paired measures collected with high-quality instruments, and we used it to illustrate different ways of analysing and presenting self-assessment data, including comparisons of the distributions of self-assessment errors, item-by-item correlations of self-estimated and objective measures, detailed comparisons of subgroups and analyses of the degree of mis-estimated competence for correct or incorrect items on objective measures. Using these analytical approaches, we observed consistent patterns of self-assessment suggesting that meaningful differences in self-assessment exist within different socioeconomic groups. We describe how teachers proficient in using knowledge surveys employ them to promote active learning of content and to mentor students towards self-regulation, higher-order thinking and SDL. We also brought together two previously separate tracks of research and mapped established uses of knowledge surveys across several distinct typologies of self-assessment.

Extensive data now establish knowledge surveys as ideally suited as both an intervention for improving learning and as an instrument for measuring learning and self-assessment. Knowledge surveys are readily adapted to offer efficient and reliable support for a wide range of self-assessment purposes (e.g. learning, teaching and research) across varied learning environments (e.g. classrooms, online, programs, workshops, internships and research experiences). Finally, to ensure that ALL students develop as self-directing learners, self-assessment should be an explicit learning objective in our courses and curricula. Knowledge surveys are ideally suited for supporting students as they progress along the pathways to SDL.

For this chapter, we employed extensive data generated from validated and aligned instruments to confirm that developing students' capacity for self-assessment accuracy is essential to their becoming truly educated and self-directing learners. We argue that knowledge surveys are perhaps the most versatile instrument for developing such capacity. In constructing this chapter, we met four goals: (1) demonstrated ways to extract information from comparisons of self-assessed and demonstrated competence from aligned instruments, (2) showed the value of applying these methods to understand diverse demographic groups, (3) presented the utility of knowledge surveys for supporting learning, teaching and research, and (4) summarised how knowledge surveys promote the outcomes articulated in typologies of self-assessment.

We can no longer ignore the vital role of self-assessment in innumerable decisions that students confront about learning, problem-solving, educational plans and career paths. The knowledge we present obligates educators to equip all students with the self-assessment skills needed for lifelong learning, careers and successful engagement with a rapidly changing world.

Chapter 7

Self-directed learning: A *sine qua non* in in-service teacher education

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Abstract

This chapter provides empirical research findings on an in-service professional development programme in which 10 natural sciences teachers from Ikageng and Promosa schools in the Potchefstroom district, North West province, South Africa, participated. The leitmotif underpinning this research was that teachers should take ownership of their learning (as

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intended by the professional development programme) as self-directed learners. Based on teachers' needs, a professional development programme was developed to assist teachers in their learning and professional growth. The 2-year-long intervention was guided by SDL principles, and the researchers (who were also the facilitators) wanted to see teachers being active agents in the planning of the learning activities. Teachers had to formulate their personal learning goals, in terms of four dimensions or domains, namely (1) classroom pedagogy and interaction (which included subject knowledge), (2) practical work and inquiry approaches in the science laboratory, (3) science-and-society perspectives (which included indigenous knowledge to contextualise curriculum themes) and (4) assessment practices. Based on these learning goals, the teachers and facilitators worked in tandem to design a teacher professional development programme that would facilitate the teachers' learning. This mixed-methods research utilised the Self-Directed Learning Instrument (SDLI) of Cheng et al. (2010) to determine whether the intervention influenced the teachers' SDL. Third-generation Cultural-Historical Activity Theory was used as a research lens, in analysing the quantitative and qualitative data. A five-domain (dimensions) heuristic, that includes SDL as a fifth domain (dimension), is proposed, as this would ensure teacher agency in teacher professional development programmes. These teachers engaged in diverse learning activities, for example, a short learning programme on indigenous knowledge, a two-day immersion laboratory work opportunity at the African Centre for DNA Barcoding (to develop a better understanding of the tenets of science); workshops on frugal science (science-on-a-shoestring), where teachers explored how low-cost materials could be used to foster inquiry learning in an under-resourced science classroom; a workshop on utilising information and communications technologies (ICTs) (such as the PhET simulations) in the science classroom; and general workshops on pedagogies and learning strategies, for example, problem-based and cooperative learning. To illustrate the learning of the teachers across the five domains, a profile of implementation was constructed for each of the 10 teachers. For this chapter, only one profile of implementation was analysed, to indicate how teacher professional development can be mapped using the revised Rogan and Grayson (2003) profile of implementation.

■ Introduction

For many years, countries in Africa have been performing dismally on global development indices (De Beer 2019; Oyelekan 2016). Amongst these countries is South Africa. South Africa is plagued by poor learner performance in science subjects (Sebotsa, De Beer & Kriek 2018:268). This poor learner performance is also shown in the Southern and East African Consortium for Monitoring Educational Quality (SACMEQ) (Spaull 2013). As an indication of the seriousness of this problem, the South African educational system was ranked fourth last in the world by the Programme for International Student Assessment of 2011 (Monyooe 2017). Major issues concerning science education are teachers with a paucity of subject knowledge (Centre for Development and Enterprise [CDE] 2011), poor pedagogical content knowledge (PCK) (Kriek & Grayson 2009; Mothwa 2011) and teachers 'trading' learner-centred inquiry learning for transmission-mode teaching because of systemic pressures, despite their pedagogical orientations (Petersen, Golightly & Dudu 2019; Ramnarain & Schuster 2014). A big problem highlighted by Voskamp, Kuiper and Volman (2020:3) is that 'teachers often take over a large part of the learning process, so that students do not learn how to direct their own learning'. Consequently, a specific aim of this research was to sensitise teachers to foster SDL in their classrooms.

An exigent strategy to address this formidable challenge remains teacher professional development (Sebotsa, De Beer & Kriek 2019). However, many in-service teacher professional development programmes (TPDP) remain characterised by 'top-down' approaches (Cronje et al. 2015; Hoban 2002; Sebotsa et al. 2018). The programme designers and facilitators often decide on the learning content, pedagogies and assessment that would constitute the fabric of the programme (Sebotsa et al. 2018). Schlager and Fusco (2003) are of the view that this approach is tantamount to putting the 'cart before the horse'. As a case in point, the training of many teachers in South Africa during the introduction of the National Curriculum Statement consisted of 'one-shot' workshops (Hoban 2002) that failed to recognise teachers' real professional development needs and grassroots challenges. Most of the interventions presented to the teachers did not adhere to the desired objectives and outcomes of the curriculum (Kriek & Basson 2008) and took a linear top-down approach (Kriek & Basson 2008).

The top-down approach often occurs in three stages, namely, innovation arrival, teacher usage and teacher change. In the innovation arrival stage, the policymakers develop material and workshops, followed by presentations by facilitators; and it is assumed the teachers will arrive at the correct teacher use. The new content and skills presented are assumed to make sense to the teachers and enable application in the classroom. Further, it is assumed that the 'piecemeal' approach will result in transformed teaching and teacher change. According to Hoban (2002), Cronje (2015), Sebotsa et al. (2018), a top-down approach is a simplistic approach that assumes that brief workshops and little backup support will provide classroom change. This simplistic approach often fails to lead to transformed teaching.

The CDE report of 2011 avers that traditional 'one-shot' approaches to professional development could be seen as 'piecemeal, workshop-type development programmes which are not effective and are inadequate in the context of current educational reform efforts' (p. 22). To address this challenge in teacher education, Louws et al. (2017) stated that in-service TPDPs should be built around the real needs of teachers and that teachers should be active participants in such professional development. These authors, therefore, advocate for SDL as the foundation for TPDP. Personal autonomy should characterise such programmes, and teachers should assume ownership of their learning (Garrison 1997).

In this chapter, the authors provide an overview of a TPDP for natural sciences teachers in Potchefstroom, North West province, South Africa, that used SDL as its point of departure. Self-directed learning can be defined as a process whereby the learner sets individual learning goals, identifies learning resources, adopts suitable methods and evaluates the learning process through critical reflection (Cazan & Schiopca 2014; Knowles 1975).

The focus on SDL during the intervention served a dual purpose. Firstly, it served as a vehicle for teachers' individual learning. Secondly, it sensitised teachers to the affordances of SDL in their own classrooms. The researchers had to find a suitable heuristic to map teacher professional development, based on SDL principles, and decided on a profile of implementation, adapted from Rogan and Grayson (2003). The latter authors identified four sub-constructs in their profile of implementation, which they called dimensions. In the context of the revised heuristic, we chose to speak of domains.

Problem statement: Recurrent trepidations in South African science education amid COVID-19

Teachers as 'front liners' hold the responsibility to scaffold learning across the zone of proximal development (Vygotsky 1978) in the classroom setting. Research literature shows that – even prior to the COVID-19 pandemic, which brought about a stronger blended learning approach – inquiry learning and laboratory work were often marginalised (De Beer 2019). Thus, we argue that, in a post-COVID-19 world, teacher professional development is even more important. How can the true nature of science be communicated on an online platform? In addition to the new problems brought about by the COVID-19 pandemic, for example, unequal access to online resources, science education in South Africa is also plagued with problems rooted in historical events. Some of these problems are:

1. Under-qualified teachers (CDE 2011), which impose dire constraints on classroom interaction (Sebotsa 2020; Sebotsa et al. 2019).

2. Lack of resources, which obfuscate science practical work, and which prevent students' engagement with the nature of science.
3. A western and decontextualised curriculum that marginalises many students, disallowing them from making sense of science-and-society imperatives, and further perpetuates failures to address the affective domain in the science classroom.
4. Lack of assessment methods that support student learning (Sebotsa et al. 2019).

Czerniewicz et al. (2020:7) reflected on education in the context of COVID-19 by stating that 'the impact of the pandemic has served as a painful reminder of all the inequalities that the system has managed to mask'. Blended learning can be incorporated with ease in some (more privileged) contexts, whereas it is much more difficult in historically disadvantaged contexts. The authors of this chapter are of the view that SDL will become increasingly important in a post-COVID-19 era, thus emphasising the importance of building TPDPs on SDL principles.

Teacher professional development

In this section, we argue for the use of SDL as the *sine qua non* in TPDPs.

Winds of change in teacher professional development programmes

The National Department of Education promotes teacher development programmes as a foundation stone for improving schooling and learner performance (Carrim 2013). A similar view is posed by the South African Council for Educators (SACE 2018:8) which stress that educators should 'keep abreast of educational trends and developments'. It remains an international imperative to professionally assist the teachers to develop the necessary skills and knowledge, such as PCK and content knowledge (CK), for the 21st-century educational context (Hardy 2012). Van Wyk (2017:1) claimed that 'the emancipation and transformation of teacher education programmes for a quality education system needs creative and innovative strategies to empower teachers for the classroom of the future'.

Sebotsa et al. (2019:1) identified TPDP within a well-functioning community of practice metaphorically as the 'phoenix that will rise from ashes' and improve the state of science education in the country. The authors of this chapter acknowledge that many TPDPs fall short of assisting teachers with their real professional development needs (Sebotsa et al. 2018). Notwithstanding the significance of TPDPs in South Africa, challenges have been acknowledged in this system. Looking into the insights of Singh (2011), many TPDPs remain erratic, failing to address the inability of teachers to provide quality education. A factor that is under-researched in the field of TPDP is that of systemic programmes that are driven by the teachers and based on teachers own development needs.

Rogan and Grayson (2003) and Rogan and Aldous (2004) developed a profile of implementation that is useful in studying teachers' learning during a TPDP. These authors caution that implementation should consist of a series of small and manageable steps and that the context of the teachers' schools should be taken into consideration. However, their work did not give much prominence to SDL. Louws et al. (2017) made it clear that:

> [*T*]eachers show great ownership when directing their own learning in the workplace, it is of interest to explore what teachers themselves choose as their learning goals, what kind of learning activities they choose to engage in, and what reasons teachers have for professional learning. (p. 172)

Other researchers, such as Kyndt et al. (2016) and Thomson and Turner (2013), agree with these sentiments, and the TPDP programme reported on in this chapter was built on these insights.

Self-directed learning as the nuts and bolts of teacher professional development

Self-directed learning is a complex construct, and researchers highlight various aspects of importance, for example, that it is a process of autonomy of the learner (Harrison 1978); a personal attribute (Guglielmino 1977); and a moral, emotional and intellectual autonomy (Candy 1991). Self-directed learning speaks to all four of the domains (dimensions) in the Rogan and Grayson (2003) construct. For teachers to optimally develop knowledge and skills related to (1) classroom pedagogies, (2) practical work and the tenets of science, (3) science-and-society approaches that foreground the affective domain, and (4) innovative assessment practices, we argue that SDL should underpin professional development programmes.

Sebotsa et al. (2019) stated that:

> [*I*]n order to improve classroom interaction, develop practical work opportunities embedded in inquiry learning (clearly showing the science-and-society link) or engaging in innovative assessment, all require the teacher as a self-directed learner to: (1) set personal learning goals for themselves; (2) identify resources to achieve these learning goals (that could include other people, e.g., the more knowledgeable other); (3) decide upon relevant learning strategies; and (4) monitor and evaluate their own learning (Knowles 1975). (p. 358)

Critical reflection plays a big role in SDL (Thornton 2010), and this was the hallmark of the TPDP reported on in this chapter.

Methodology and research question

The research question guiding this research was: How did Senior Phase natural sciences teachers' views of their own SDL change during a longitudinal and systemic professional development intervention? In this chapter, we present the research findings by mapping teachers' learning on the adapted profile of implementation.

Developing a five-domain (dimension) profile of implementation

This research was underpinned by pragmatism, which Merriam and Tisdell (2016:46) describe as an approach where 'multiple paradigms can be used to address research problems'. It was a mixed-methods research, which included qualitative research methods (personal and focus group interviews with teachers; open-ended questionnaires such as the views-of-the-nature-of-science [Abd-El-Khalick, Bell & Lederman 1998] and views-of-the-nature-of-indigenous-knowledge questionnaires [Cronje, De Beer & Ankiewicz 2015]; classroom observations, using the Reformed Teaching Observation Protocol [RTOP] [Sawada et al. 2000]) and quantitative research, using the SDLI (Cheng et al. 2010), in a pre- and post- intervention context.

It is imperative to provide context for the reader. During the mentioned intervention, the teachers engaged in diverse learning activities, for example, a 2-day short learning programme on indigenous knowledge, and teachers thereafter submitted portfolios which were analysed. The teachers also attended a 2-day immersion laboratory work opportunity at the African Centre for DNA Barcoding at the University of Johannesburg, and teachers completed a DNA Barcoding Questionnaire which aimed to assess the teachers' understanding of the tenets of science. The DNA Barcoding Questionnaire was developed by the researchers and was evaluated by experts in the field, to ensure validity and credibility of the instrument. Similarly, experts were asked to critique the visible light test that teachers completed in a pre- and post-intervention fashion. (One of the problematic areas in the curriculum is visible light, and an intervention was arranged to scaffold teachers' learning in this regard). The intervention also included workshops on frugal science (science-on-a-shoestring), where teachers explored how low-cost materials could be used to foster inquiry learning in an under-resourced science classroom, and a workshop on utilising ICTs, such as the PhET simulations, in the science classroom. There were also a few general workshops on pedagogies and learning strategies, for example, problem-based and cooperative learning. Ten natural sciences teachers from Ikageng and Promosa, suburbs of Potchefstroom, were selected through convenience sampling to participate in this research, which took place over a period of two years. At the start of the programme, a needs analysis was done, and the teachers were active participants in the design of the TPDP. They were requested to show a high level of ownership over their own learning. Based on their identified needs, the facilitators assisted them in locating knowledgeable people to help them in their professional development. For example, a registered psychologist was contracted to facilitate a workshop on stress management, on the teachers' request. The researchers used a heuristic to map teacher professional development over the course of the two years and adopted the profile of implementation of Rogan and Grayson (2003) and Rogan and Aldous (2004), which focuses on four domains (dimensions), as can be seen in Table 7.1, namely:

TABLE 7.1: Profile of implementation of science teacher professional development that guided this research.

Level 1	Classroom interaction	Science practical work	Science in society	Assessment	Teachers' SDL**	
					Qualitative analysis	**Quantitative analysis using SDLI instrument (Cheng et al. 2010)**
0*	Teacher presents transmission-mode lessons in an unstructured way and reads mostly from the textbook; limited and ineffective media usage; learners passive and not engaged.	Practical work is seldom done; teacher uses limited and poorly planned demonstrations to assist in the explanation of concepts.	Teacher seldom uses examples from the learners' daily lives and, if used, these are not coherent.	Written tests on lower cognitive levels; Tests marked and handed out to learners.	There is no evidence of SDL; The teacher does not show interest in ongoing professional development activities.	0–24 score in the SDLI
1	Teacher presents organised lessons; uses textbook effectively; learners are engaged and respond to questions.	Teacher uses classroom demonstrations to help develop concepts.	Teacher uses examples from everyday life to illustrate scientific concepts.	Written tests are given; most questions are recall questions (lower cognitive level); most tests marked and returned promptly.	There is minimal evidence of SDL; the teacher indicates that he/she has professional development needs, but there are no concrete learning goals identified.	25–49 score on SDLI

Sources: Based on Rogan and Aldous (2004:868), Petersen and De Beer (2012:4), Sebotsa et al. (2019:357), and Sebotsa (2020:181–183).

Acknowledgement: This table has been published in an adapted form in Sebotsa et al. (2019:356–357).

* Level 0 was introduced by Petersen and De Beer 2012.

** The SDL domain (dimension) is a contribution of this research.

SDL: self-directed learning; SDLI: self-directed learning instrument

Table 7.1 continues on the next page→

TABLE 7.1 (Continues...): Profile of implementation of science teacher professional development that guided this research.

Level 1	Classroom interaction	Science practical work	Science in society	Assessment	Teachers' SDL**	
					Qualitative analysis	**Quantitative analysis using SDLI instrument (Cheng et al. 2010)**
2	Textbook used along with other resources; engages learners with questions that encourage deeper thinking and meaningful group work.	Teacher uses demonstrations to promote a limited form of inquiry; learners participate in 'cookery book' practical work.	Teacher bases lesson on specific problems faced by the community; clear effort to contextualise science.	Written tests include 50% of higher cognitive level questions.	The teacher formulates learning goals, but there is limited evidence that learning resources or learning strategies were identified in pursuing these goals.	50–74 score on SDLI
3	Teacher structures learning along 'best practice' lines; learners engage in minds-on learning activities. Clear evidence of inquiry learning.	Practical work to encourage learner discovery of information. Evidence that the tenets of science are addressed.	Learners actively investigate the application of science and technology in their own environment. Authentic problems in society are investigated.	Written tests include 'guided discovery'-type activities; assessment includes other forms such as reports; Teacher shows creativity in terms of assessment practices.	There is clear evidence of SDL: learning goals, resources and applicable strategies identified by the teacher. However, there is no evidence of evaluating the learning actions, or critical reflection.	75–89 score on SDLI
4	Learners take major responsibility for own learning and undertake long-term investigations and projects; teacher facilitates learning.	Learners design and do open investigations.	Learners actively undertake a project in their local community and explore long-term effects of community projects.	Open investigations and community-based projects included in final assessment; learners create portfolios. Teacher shows high creativity in designing authentic assessments.	Strong evidence that the teacher is a self-directed learner, that is, the teacher can design own learning goals, goals related to a central need, able to set a path to achieve the goal, the goal is realistic (not too high or too low), but enough to be challenging, and the teacher evaluates whether the learning goals were achieved. The teacher promotes SDL in his/her classroom.	90–100 score on SDLI

Sources: Based on Rogan and Aldous (2004:868), Petersen and De Beer (2012:4), Sebotsa et al. (2019:357), and Sebotsa (2020:181–183).
Acknowledgement: This table has been published in an adapted form in Sebotsa et al. (2019:356–357).
* Level 0 was introduced by Petersen and De Beer 2012.
** The SDL domain (dimension) is a contribution of this research.
SDL: self-directed learning; SDLI: self-directed learning instrument

1. classroom interaction (pedagogies used and how learning is facilitated)
2. science practical work (encompassing how the tenets of science are encapsulated in learning activities)
3. science in society (whether learners will be able to appreciate the value of science in their daily lives and addressing affective outcomes)
4. assessment practices.

The researchers' stance was that SDL should form the foundation of teacher professional development across these domains and, for this reason, a fifth domain was added, namely, SDL. For the SDL domain, both qualitative (interviews and observations) and quantitative descriptors (the SDLI of Cheng et al. 2010) were provided for each of the five levels (0–4) in the heuristic (Table 7.1).

Mapping teachers' progress on the five-dimension (domain) heuristic

A description of the pre- and post-intervention data and findings, indicating professional development, for one of the 10 teachers is described in the following section. Only one teacher profile was shared because of extent limitations. The rubric descriptors (Table 7.1) were used to map teachers' competence. The three researchers did this mapping individually and then reached consensus.

Data, data analysis and findings

In this section, Teacher A's data are presented to illustrate how the data were mapped using the profile of implementation.

Personal profile of Teacher A

Teacher A holds a BEd degree in natural sciences from the North-West University. Using the platforms provided during the professional development programme, she successfully applied for a BEd Honours degree in natural sciences Education for the 2020 academic year and is currently busy with postgraduate studies. In the pre-intervention personal interview, Teacher A mentioned that she had 2 years' experience of teaching natural sciences Grade 7–9. Teacher A was a novice teacher under the age of 30 years. Her teaching philosophy was to be a lifelong learner who inspires other South African learners. Teacher A had a teaching and learning philosophy prior to the intervention that is shared by so many teachers, namely, that the best way of preparing learners for the examination is by using a lecture-style approach. (This was determined in a personal interview and through classroom observations.)

She taught at a school resembling a typical township school in terms of demographics, consisting of 100% black learners, mostly from low-income families. The classes taught had 40 to 60 learners. The lessons observed were of a class consisting of 58 learners, where the ratio of boys to girls was approximately 2:1. Teacher A mentioned that she teaches in an under-resourced township school without resources such as data projector, laboratory consumables and microscopes, and with no access to library services.

According to Teacher A, the existing school laboratory was only utilised by the Grade 12 learners. She reported that the classroom did not inspire inquiry, and none of the many posters or equipment that the teacher received from this professional development intervention had been previously available to her (thanks to generous funding from the Fuchs Foundation, teachers were provided with resources; and it was disconcerting to see that these resources were not used by Teacher A). The teacher failed to create an inviting learning space for the learners. Nothing reminded the learners that, when they entered the natural sciences classroom, they were entering an 'epistemological space' of scientific investigation and problem-solving.

Pre-intervention data: Teacher A

The researchers utilised questionnaires, classroom observations, personal interviews and visible light test to capture pre-intervention data related to the five dimensions (domains), namely, classroom interaction, practical work, science and society, assessment and SDL.

Classroom interaction

Lesson observation using the reformed teaching observation protocol instrument

Teacher A was very dependent on the prescribed textbook during all observations, and learner engagement in these teacher-centred lessons was restricted to answering questions in chorus or doing homework assignments on a low cognitive level (according to Bloom's taxonomy). The teacher's pedagogical orientation (of transmission-mode teaching and learning) was further demonstrated by the predominant culture of writing the notes on the chalkboard followed by question and answers.

The teacher used transmission mode as a dominant teaching strategy, treating learners as *tabula rasa*. The teacher asked questions and only about 15 learners were superficially involved in responding to the lower-order questions. Other learners seemed tired, disengaged or did not seem to understand the work. No inquiry activities occurred during the lesson observation.

☐ *Pre-intervention interview with Teacher A, related to classroom interaction*

During the pre-intervention interview, Teacher A mentioned:

> 'Science is boring to the learners, and it is also boring to the teachers because it is only theory and we are repeating the same thing day in day out. It is never exciting because the learners are not excited.' (Teacher A, female, date unknown)

According to this view and the classroom observations, it can be concluded that the teacher finds it difficult to contextualise the content prescribed in the curriculum and apply it to the everyday life of learners. There is a lack of agency displayed by Teacher A, and to a large extent the teacher portrays science as being static and Eurocentric in nature, and she does not seem to realise that she can 'decolonise' the curriculum, through contextualisation for diverse learners.

☐ Analysis of lesson plan, in terms of classroom interaction

No formal lesson plan was presented during the lesson observation. The teacher had notes on a sheet of paper and a textbook to guide the lesson. Despite the lack of a formal lesson plan, the lesson was semi-structured. The teacher did not start the lesson by providing the objectives for the learners or sensitising the learners to the goals of the lesson. During the invitation stage of the lesson, the teacher introduced the lesson by asking the learners where animals receive their food. The learners' prior knowledge was activated during a short discussion, and the teacher explained how energy is converted from one form to another. The body of the lesson consisted of transmission-mode approaches (no learner-centred pedagogies were used). In terms of assessment, only a class activity was provided, and no homework was given to the learners. In the closing stage of the lesson, learners were not required to reflect on or summarise the lesson.

☐ *Content knowledge of optics (pre-intervention)*

Teacher A, before the intervention on the optics section of the Curriculum and Assessment Policy statement (CAPS) curriculum, scored 2/35 (5.7%) in a visible light test, which indicates that she had underdeveloped CK. This resonates with the concerns of Venkat and Spaull (2015) that many South African science teachers have CK below the Grade taught. In the authors' view, this is one of the main reasons why South African learners perform below standard in international tests such as TIMSS.

Teacher A's views on practical (laboratory) work, inquiry learning and the nature of science

Inquiry learning in Teacher A's classroom

During the observed lessons (utilising the RTOP instrument), the teacher did not engage learners in inquiry. Learners were mostly passive during the teacher-centred classroom activities. They were not afforded an opportunity to engage in the nature (tenets) of science and to develop their science process skills such as interpreting data, making careful observations, constructing an argument, measuring, problem-solving and critical thinking, recording and communicating information.

Teacher A's responses to the UJ-DNA Barcoding Questionnaire and focus group interview, prior to the DNA barcoding intervention

To improve teachers' understanding of the tenets of science, they were afforded the opportunity to work (with scientists) for two days at the UJ-based African Centre for DNA Barcoding. Prior to the intervention, teachers were asked to complete a questionnaire.

In the questionnaire, Teacher A reflected that she was 2 out of 5 confident in handling laboratory equipment. She also indicated the following sentiments, 'I do not have a laboratory to use at school. The last time I was in a laboratory, it was when I was at university' (Teacher A, female, date unknown). When the teacher was asked how often she does practical work in terms of laboratory investigations with her learners, her response was as follows: 'I hardly do practical work with my learners because I do not have a laboratory to use'. This indicates that most of her learners do not benefit from the affordances of practical work and that they do not optimally develop skills that enable them to investigate phenomena or develop basic science process skills such as observation, classification, inference of information from data, making predictions, or communicate findings. This practice could explain why most of the students do not develop work-related skills for the 21st-century world, for instance, critical thinking and analysing. Teacher A highlighted in the pre-questionnaire that she wants to learn more about DNA barcoding and how to use laboratory equipment. When she was asked what her understanding of DNA barcoding is, her response was 'I do not know much, but I think it is the sequence of genes (how genes are arranged)'. Again (as with her knowledge of optics), Teacher A showed underdeveloped CK.

When the teacher was asked what she understands by the term 'polymerase chain reaction' (PCR), her response was 'I have no idea'. When the teacher was further asked how she as a teacher could make the study of DNA relevant and interesting to learners, the teacher's response was 'conduct investigations with the learners'. The responses of Teacher A indicated that she was not confident in doing investigations with the learners because of the lack of resources in her school and her lack of agency to improvise. However, in her answers she provided the discourse used in policy documents ('learner investigations') – paying lip-service to inquiry learning.

What was promising was that Teacher A identified her own learning needs – to learn more about DNA and to improve her investigation skills to provide her learners with more nuanced understandings of the nature of science.

Teacher A's views of the nature of science

Teacher A had a partly informed view of the nature of science (VNOS). For instance, in the VNOS Questionnaire, the teacher was asked about the structure of the atom, and how scientists developed a model of the atom. Teacher A's responses indicated an underdeveloped understanding of atom modelling. However, she used popular jargon, such as 'uses models to explain how atoms look like', to camouflage her lack of insight. Her responses failed to provide a timeline on the development of an atom.

Teacher A could not provide any answers which demonstrated an understanding of the tenets (nature) of science, such as the tentative, inferential or creative nature of science.

Teacher A's views on science and society

Portraying the role of science in society during lessons: evidence from the lesson observations using reformed teaching observation protocol, lesson plans and interviews

During the pre-intervention class observations, the authors noticed that the teacher did not contextualise her lessons and did not address the affective domain. The lessons were typically structured around textbook activities, and no effort was made to contextualise curriculum content for the learners. During the interview, the researchers probed to understand why Teacher A said that science is boring. The response from the teacher was that science 'is boring to the learners and it is also boring to the teachers because it is only theory and we are repeating the same thing day in day out. It is never exciting because the learners are not excited'. This narrative is alarming, and we realised that the teacher did not emphasise the importance of science in the society in her lessons. Science was portrayed as being contained in a silo far removed from the learners' everyday experiences.

Teacher A's view on the nature of indigenous knowledge

Teacher A's understanding of indigenous knowledge was that:

> 'It is the deep knowledge and skills unique to a particular indigenous culture. This knowledge is passed on from one generation to another. It includes medical practices, production of food, etc.' (Teacher A, female, date unknown)

This view demonstrates that the teacher had some understanding of indigenous knowledge. When Teacher A was asked if practitioners of indigenous knowledge do engage in experiments and tests to verify or validate indigenous knowledge (IK), her response showed an informed understanding of indigenous knowledge. Her response was:

> 'Yes, indigenous knowledge is based on human experiences. The practitioners of indigenous knowledge tried different methods which were replaced with other methods if they were unsuccessful. This was continued till success. If a method was not working, they tried a different method.' (Teacher A, female, date unknown)

She also knew that the Khoisan used *Hoodia gordonii* as an appetite suppressant. The only aspect in which Teacher A showed a uniformed view in the VNOIK Questionnaire was that she believed that IK stays the same, not recognising that it is a dynamic knowledge base that evolves. The data obtained from the pre-intervention VNOIK Questionnaire suggest that Teacher A had a partially informed understanding of the tenets of IK. During classroom observations, there was no evidence of the integration of aspects of IK into lessons. Even though the teacher had a partially informed view of IK, she struggled to include IK in the natural sciences curriculum. One of the many reasons for this is that Teacher A in her undergraduate qualification was not taught and assisted with the integration of IK into the science curriculum (as inferred from the interview data). Our interpretation is that Teacher A understood the role of IK in science but struggled with the epistemological border crossing between the two knowledge systems in practice.

Teacher A's views on assessment/assessment practices

The pre-intervention data showed that Teacher A 'teaches to the test' and that she did not engage in innovative assessment practices. Furthermore, her assessment only covered lower levels in Bloom's taxonomy, such as 'knowledge' (based on data obtained from interviews and observations). During the classroom observations, of lessons on ecology, her assessment, for example, provided learners with one multiple choice question on what the purpose of the food chain is. This was followed with a question on matching column A with B (matching descriptions of omnivores, insectivores, consumers and producers). In question 3, the learners were provided with a case study involving a zebra, grass and lions, and they were required to write the information as a food chain, and this was followed with a question that required the learners to label the producer and consumers. In question 4, a follow-up question required the learners to answer what would happen when the zebra (in the context of question 3) died.

Lower-order cognitive questions are insufficient in providing learners with problem-solving and critical thinking skills, which are abilities required for the 21st century. According to CAPS, assessment must be structured to cover CK as well as science process skills (De Beer 2019). From classroom observation and analysis of assessment provided to the learners, science process skills were not included. The teacher asked questions and wrote the solutions on the board as the learners answered. Very little attention was given to assessing learner ability to solve real-life problems.

Teacher A's self-directed learning

Qualitative analysis of self-directed learning

In terms of the revised Rogan and Grayson (2003) profile of implementation, Teacher A was mapped at level 1 based on qualitative data (the mapping was done based on the rubric provided in Table 7.1; it was done independently by the three researchers, after which consensus was reached). From the pre-intervention data, Teacher A did not demonstrate the agency to improve her teaching strategy or to learn more about fostering inquiry-based learning. From the observed lessons, the teacher did not inspire learners to be self-directed in their learning, and this could be because the teacher, at this stage, had a naive understanding of SDL (Bailey 2016; Bosch 2017).

That Teacher A voluntarily became a member of the professional development programme can be regarded as an indication of interest in her own professional development. The decision required the teacher to, as a self-directed learner, be able to identify her own professional development need(s). There was minimal evidence of SDL; the teacher indicated that she had professional development needs, but she did not identify any concrete learning goals.

Quantitative analysis of Teacher A's self-directed learning, utilising the self-directed learning instrument

Teacher A completed the SDLI Questionnaire (Cheng et al. 2010) to determine her views on her own SDL skills. Teacher A scored 77 out of 100 in terms of the SDL instrument. Her SDL is indicated in terms of the four sub-domains in the SDLI (Table 7.2). Her score in the SDLI was relatively high, yet the qualitative data did not provide much evidence of SDL.

This places her on level 3 (in contrast to the qualitative analysis, which suggests a level 1). Mentz and De Beer (2019) show that such a discrepancy often occurs between quantitative and qualitative SDL data. Very often,

TABLE 7.2: Self-directed learning of Teacher A, based on her responses in the self-directed learning instrument.

Sub-domain in the profile of implementation	Questions	Score of Teacher A	Score of Teacher A reported as a percentage (%)
Learning motivation	Q 1–6	26/30	86.66
Planning and implementing	Q 7–12	20/30	66.67
Self-monitoring	Q 13–16	14/20	70.00
Interpersonal communication	Q 17–20	17/20	85.00
Total		**77/100**	

participants have naive understandings of SDL when they start to engage in the intervention – as reflected by the relatively high score of Teacher A in the SDLI.

As shown in Table 7.2, she scored 26/30 in terms of learning motivation, which is reported as 87%. She appeared, therefore, motivated to learn. Teacher A's responses to the questionnaire showed a strong desire to constantly improve and excel in her learning. Teacher A furthermore indicated that she knew which learning strategies were appropriate for her to reach her learning goals. This indicates that the teacher feels strongly about being a lifelong learner. In addition, she believes her interaction with others helps her plan for further learning. Her aspirations were further evidenced by her efforts to attend almost all the interventions. She also applied for postgraduate studies, as mentioned earlier.

It should also be emphasised that, even though Teacher A was motivated to learn, she scored the lowest score in planning and implementation in terms of the four sub-domains in the SDLI, namely, 20/30 (66%).

Teacher A's holistic well-being

Although this aspect does not correlate with the five dimensions or domains in the profile of implementation, our research also focused on the well-being of teachers.

Well-being of Teacher A

Teacher A indicated that she had to cope with tight deadlines (curriculum pacesetters) that caused stress, and she needed to learn techniques for dealing with stress. When Teacher A was interviewed, she mentioned that her job is stressful and that she sometimes struggled to cope with all the demands facing her.

Professional development needs of Teacher A

Teacher A indicated that she needed to be assisted with the following curriculum topics: electricity, chemistry and strategies to teach overcrowded classrooms.

Post-intervention data – Teacher A

Teacher A actively participated in most of the intervention activities. The only intervention she did not participate in was the short learning programme on IK organised by the North-West University. In the section that follows, we analyse the post-intervention data, based on the five domains (dimensions) in the profile of implementation.

Classroom interaction and the pedagogical orientation of Teacher A after the intervention

Teacher A had a definite 'active direct' teaching pedagogical orientation (Ramnarain & Schuster 2014). The teacher's pedagogical orientation did not change after the intervention. She still used transmission mode as a dominant teaching strategy, with very little engagement with the tenets of science. The DNA barcoding work did not seem to have much of an impact in terms of centre-staging the scientific method in the classroom. Despite being exposed to cooperative learning methodologies, such as the Jigsaw method, during the intervention Teacher A continued with transmission-mode approaches, for example, writing notes and solutions on the board, and expecting a 'chorus-like' response from learners.

Lesson observations using the reformed teaching observation protocol instrument

Teacher A started the observed lesson by determining background knowledge on visible light and asked learners, 'Why do we see a rainbow?'. The lesson was unfortunately still teacher-centred, despite her participation in the intervention on optics. Learners remained seated in lecture-style seating arrangement, making it difficult for cooperative learning. There was no evidence of either problem-based or project-based learning, despite the topic lending itself to such approaches.

What was observed with Teacher A was the 'wash-out' effect (Zeichner & Tabachnick 1981), whereby teachers return to their predominant (prior) strategies when they return to the 'coalface of the classroom'. Even though Teacher A was provided with a 'cognitive apprenticeship during the intervention' (Ramsaroop & Gravett 2018), she continued with the transmission-mode teaching. What is puzzling is why Teacher A defaulted to transmission-mode teaching after being provided with the teaching skills, techniques and equipment to teach this exact topic in a problem-based manner.

Lortie's (1975) theory of the 'apprenticeship of observation' provides a possible reason for why Teacher A did not use the optics kit, PhET simulations, tablets and shoestring approaches that were provided during the intervention, to engage learners in inquiry-based learning. Lortie is of the opinion that teachers teach as they were taught (Lortie 1975). None of the newly acquired skills and approaches obtained during the intervention were evident during the post-intervention classroom observation. Learners still answered questions in chorus style.

☐ *Analysis of post-intervention lesson plan*

No lesson plan was prepared for the lesson observed. Only the textbook was used during the observed post-intervention lesson to engage the learners on the rainbow colours and one activity consisting of lower-order questions. For instance, the learners were required to define the terms luminous, wavelength and frequency. Questions such as where does the light come from, how does light travel, how do you see the light, name all colours in the visible spectrum and name all the colours in order of increasing wavelength were posed. The teacher did not provide learners with a lesson that encouraged inquiry. As in the pre-intervention lesson observed, transmission-mode teaching took place, with very little learner engagement. The lesson lacked structured objectives, and the teacher did not reflect on the lesson. From the lesson observation and exit interview, it became clear that no reflection in, for and on practice was done.

☐ *Exit interview and discussion of recorded lesson using stimulated video recall*

During the exit interview, the teacher mentioned that systemic pressures coming from her seniors lead her to teach the way she does (using transmission mode). For instance, when the teacher was asked, do you feel that there is a lot of pressure from parents and principals, or school management, to 'teach to the test' to 'ensure good results?', her response was:

> 'Yes, they tell you that you to need to be done with this topic on this date then you start with this one at least the principal would be on my case if I do not produce results, they will be on my case, so you just need to teach to the test, and the kids give us the results that they need so there is no time to have fun in the classroom.' (Teacher A, female, 26 November 2019)

The response was disheartening on two levels: firstly, that the teacher's seniors accept transmission-mode teaching as the preferred way to capacitate learners. Secondly, that the teacher's actions did not prepare learners with the SDL skills needed in our complex society. The teacher's response indicates that she is aware that she uses transmission-mode teaching, not addressing the nature of science. For instance, she mentioned that she is forced to 'teach to the test'. Hence, her pedagogical orientation did not change. She also referred to the curriculum schedules ('pacesetters') (DoE) as a hindrance to addressing the skills and techniques taught in the intervention. Teacher A felt frustrated by the work schedule's inflexibility and prescribed time frames. Her teaching was based only on the content provided in the work schedule. However, she also indicated that the intervention inspired her and that she feels more empowered for the challenging profession.

When the teacher was asked if the school setup enables her to engage learners in PBL, inquiry learning or cooperative learning, which were the focus of the intervention, her response was as follows:

> 'This school makes it impossible. We have fifty kids in the classroom so we cannot do group work we cannot arrange the tables, it asks for space, then we get over and done, and then we move on even when we have to do practical investigations of the classroom it becomes difficult because you cannot keep the learners at all the apparatus, there's a shortage of apparatus ….' (Teacher A, female, 26 November 2019)

Teacher A's content knowledge on optics post-intervention

After the intervention (an optics workshop), Teacher A saw a percentage increase of 48% in her post-test. In her pre-test, she scored 2/35 (5.7%), and in the post-test, she scored 19/35 (54.3%). This could be an indication that the intervention was able to develop her CK on visible light. This was also evidenced by the greater confidence she showed when teaching visible light during the classroom observation. Overall, this teacher benefited from the intervention in terms of increased subject knowledge and confidence in teaching the content. It is disconcerting, however, that the activities and strategies presented in the intervention (e.g. the PhET simulations) were not transferred to her classroom teaching.

Teacher A's views on practical (laboratory) work, inquiry learning and the nature of science after the intervention

Inquiry learning in Teacher A's classroom – Evidence from classroom observations

No evidence of practical work or inquiry learning was provided or observed. What is disappointing is that there was no evidence that any of the resources provided to her (e.g. the optics kit, sponsored by the Fuchs Foundation) were used. Despite not having a laboratory, she was trained during the intervention to use shoestring approaches. A spectroscope has the affordances of facilitating inquiry-based activities on visible light and the dispersion of colours into their different wavelengths providing the colours of the rainbow. Despite the teacher being capacitated with skills to build and use spectroscopes during the intervention, no evidence of inquiry-based activity was observed. What is to be highlighted is that Teacher A, in the questionnaire, highlighted that the intervention addressed her professional development in terms of using science-on-a-shoestring approaches in under-resourced classrooms.

Based on the teacher's feedback from the questionnaire, the researchers conclude that Teacher A did not use inquiry-based activities despite having been equipped with the knowledge and skills to do so.

Teacher A's responses regarding the value of shoestring approaches in fostering inquiry learning in the questionnaire were not congruent with the evidence obtained during the classroom observation. Another concern is that Teacher A did not engage learners in doing problem-based activities. When the teacher was asked to provide an example of how PBL could be used to teach optics in the questionnaire, her response was as follows, 'Give learners problems to solve using PhET simulations', but this was not evident in the classroom observation. The teacher could have used PhET simulations to engage learners in an inquiry activity. According to Ledward and Hirata (2011), PhET simulations could assist in promoting 21st-century skills in place-based, project-based or PBL contexts. Teacher A was also provided with optic kits for her classroom. Regardless of resourcing the teacher with the methodological skills and equipment to facilitate inquiry activities, there was no evidence of transfer to the classroom.

☐ *Teacher A's responses in the UJ-DNA Barcoding Questionnaire (and subsequent focus group interview)*

In the post-questionnaire, Teacher A reflected that she is now (4 out of 5) confident in handling laboratory equipment after the intervention. She also indicated the following sentiments during the interview:

> 'I was feeling happy, I was excited to work with all the apparatus, and for me it was an experience. Once you like something, you are more interested in it. If we take it to the NS classroom, learners would be interested more in the subject because now they go to the classroom, we talk theory, and they do not know how to apply it in real life.' (Teacher A, female, date unknown).

She further emphasised the following in the post-questionnaire: 'after the experience of using laboratory equipment at the African Centre for DNA Barcoding (ACDB) I think I have gained a lot of lab skills'.

In the focus group interview, Teacher A made the following remark 'it was fun, we learned new things. I cannot wait to go back to the classroom and share the information which I have learned'.

An important remark made by Teacher A during the interview was:

> 'I see that there is much more to be done in classroom. I've been robbing my learners, now I realise why I was not getting those good marks because my kids were not motivated enough. With the knowledge I gained in two days, if I can take that knowledge and pass it all to my kids, pass on the skills, my learners will be much more interested in the subject.' (Teacher A, female, date unknown).

Despite this encouraging data, there was little evidence of transformed teaching after the intervention.

The data, therefore, point to the 'wash-out effect' of newly acquired knowledge and skills in the classroom after the intervention. Regardless of the well-planned intervention, the teacher resorted back to the same old ways of teaching, and no learner practical skills were enhanced.

Teacher A's views on the nature of science

Teacher A did not attend the short learning programme (SLP) on 18–19 March 2019. Amongst many activities that the teacher engaged in, a strong emphasis was based on activities that demonstrate the nature of science (NOS).

However, Teacher A did attend the DNA barcoding intervention, which aimed to achieve the same understanding of the processes of science. After the intervention, in the VNOS Questionnaire, Teacher A showed a more informed view on the NOS. She developed a better understanding of the inferential and empirical NOS. However, her views were not in sync with the classroom observations, as during the lesson, not a single element of the NOS (tenets of science) was evident.

Teacher A's views on science and society after the intervention

Portraying the role of science in society during lessons: evidence from the lesson observations using reformed teaching observation protocol, lesson plan and interviews

In the exit interview, Teacher A mentioned how IK could be integrated into a lesson and how this knowledge can make the lesson more interesting to learners. However, no attempt to infuse IK into the lesson, or an attempt to contextualise the lesson using some of the IK applicable to the topic of optics, was evident. For instance, when one teaches visible light, it is possible to make a connection to rainbow colours. The rainbow is a very familiar natural phenomenon, and colours play a pivotal role in most IK systems. For instance, the Ndebele relate colours to the status or power of the homeowner, and paintings on the house could indicate a period of prayer or the announcement of marriage (Sebotsa 2020). The authors are of the view that, if Teacher A addressed colour from an IK perspective, it would have centralised the affective domain.

During the classroom observations, Teacher A did not attempt to show the relevance of science in society and continued to marginalise the affective domain.

The data show that Teacher A found it challenging to facilitate the epistemological border crossing between science and IK (and society).

Despite an awareness of her learners experiencing science as uninspiring, there were minimal attempts by her to address the promotion of affective outcomes.

Teacher A's view on the nature of indigenous knowledge

Teacher A still held a partially informed view of the nature of IK after the intervention, probably because she could not participate in the SLP on IK and this knowledge was also not centre-staged during her BEd degree.

Teacher's views on assessment practices: Reformed teaching observation protocol and lesson plan

From the last lesson observed, it was clear that the teacher still 'teaches to the test', and lower-order questions in Bloom's taxonomy were still favoured. Teacher A did not attend the SLP and did not submit a portfolio for that reason. From the lesson observations, we could conclude that the teacher asks lower-order cognitive questions and does not engage in innovative assessment practices, for example, peer assessment. She utilised ineffective assessment techniques. For example, after a teacher-centred lesson, the assessment involved learners using their textbooks to answer lower-level cognitive questions. The teacher then called upon individual learners to write the answers on a whiteboard in front of the class. The researchers realised that much time is spent on very ineffective assessment procedures. While learners were writing answers on the whiteboard, other learners were talking to each other or did homework for other subjects. A significant limitation observed was the lack of assessment of affective and psychomotor outcomes.

Teacher A's self-directed learning

Qualitative analysis of self-directed learning

To map Teacher A's development on the profile of implementation rubric, interviews and post-intervention data were used to determine if the teacher facilitated self-directed skills among her learners. Evidence of enhanced SDL was that, motivated by the intervention, Teacher A successfully registered for BEd (Honours) studies in the natural sciences for 2020. When prompted about this in the exit interview, she responded that this intervention made her realise she needs to invest in her professional development.

She identified several aspects that she needed training on and identified personal learning goals such as becoming more competent in teaching electricity topics. Teacher A displayed several of the qualities of a self-directed learner, for example, her enthusiasm in terms of the intervention offerings. She could use resources during the intervention and use strategies to simulate inquiry-based activities. However, at the coal face of teaching in the classroom, no transformative teaching was observed, critical reflection was not evident and the teacher did not demonstrate agency to use science-on-a-shoestring in her under-resourced classroom. According to the profile of implementation rubric, Teacher A was mapped on level 2.

☐ *Quantitative analysis of Teacher A's self-directed learning, utilising the self-directed learning instrument*

To map Teacher A's development, the SDLI instrument was used. Teacher A's views in the pre- and post-intervention were compared (Table 7.3).

Even though Teacher A still valued learning motivation in the four sub-domains of SDL, her scores dropped from 26/30 to 25/30. This remained a domain Teacher A felt strongly about. The same patterns can be seen in terms of planning and implementation (a drop from 20 in the pre-test to 18 in the post-test). Research indicates that when participants complete the pre-SDL instrument, most of the participants have naive understandings of SDL (Bailey 2016; Bosch 2017). After the intervention, the teachers were generally more sensitised in terms of what SDL entails. In the post-intervention data, Teacher A scored 71 out of 100 (6 points lower than in the pre-test). In terms of the revised Rogan and Grayson's heuristic, both the qualitative and quantitative data indicate that Teacher A was at level 2 in terms of her SDL professional development after the intervention.

The drop in the score in the SDLI (from 77 to 71) seems to indicate that Teacher A became less self-directed as the intervention unfolded. In all

TABLE 7.3: Pre- and post-self-directed learning views of Teacher A.

Pre-SDL views			**Post-SDL views**				
Sub-domain in the profile of implementation	**Questions**	**Score of Teacher A**	**Score of Teacher A reported in percentage (%).**	**Score of Teacher A**	**Score of Teacher A reported in percentage (%)**	**Change in SDL scores**	**Change in SDL reported in percentage (%)**
Learning motivation	Q 1–6	26 / 30	86.67	25 / 30	83.33	−1	−3.3
Planning and implementing	Q 7–12	20 / 30	66.67	18 / 30	60.00	−2	−6.7
Self-monitoring	Q 13–16	14 / 20	70.00	13/ 20	65.00	−1	−5
Interpersonal communication	Q 17–20	17/ 20	85.00	15/ 20	75.00	−2	−10
Total		**77/100**		**71/100**		**−6**	**−6.25**

SDL, self-directed learning.

likeliness, she now has a more realistic view of her own SDL and what SDL entails. However, qualitative data provide a different picture. We concur with Mentz and De Beer (n.d.:25) that 'the utilisation of quantitative and qualitative methods could result in dichotomous data' and that Cultural-Historical Activity Theory (CHAT) holds many affordances for opening this 'black box'.

Professional development needs

After the visit to the African Centre for DNA Barcoding, Teacher A identified a number of goals for her own professional development (e.g. learning more about PCR and laboratory protocols) (Sebotsa et al. 2019:355). She successfully applied for registration for an Honours degree, fuelled by the realisation that she needs to invest in her own professional development and to become a more self-directed learner.

Synthesis: Using the revised Rogan and Grayson's heuristic to assess teacher professional growth and plotting learning/development during a longitudinal and systemic teacher development programme

Below we show how the revised Rogan and Grayson's profile of implementation, with the addition of SDL as fifth dimension, can be used to monitor Teacher A's learning. This heuristic assisted the authors to evaluate if Teacher A showed evidence of transformed teaching during the post-intervention. Below we provide Teacher A's progress during the longitudinal teacher development programme.

As can be seen in Box 7.1, a slight improvement was shown after the intervention in three of the domains: classroom interaction, assessment and SDL.

BOX 7.1: Teacher A's progress, mapped on the profile of implementation.

Teacher A's progress during teacher professional development that spanned from 2017 to 2019																									
A heuristic to map teachers' skills according to the Rogan and Greyson profile of implementation																									
Pre- (X) and post- (0) intervention profiling heuristic																									
	Classroom interaction					**Practical work**					**Science and society**					**Assessment**					**Self-directed learning**				
Levels	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Teacher A	X	0				X0						X0				X	0					X	0		

Second stage data analysis: Using cultural-historical activity theory to investigate the themes

Mentz and De Beer (2019) described CHAT as a meta-theoretical framework that can assist the researcher in analysing data from complex environments. Cultural-Historical Activity Theory is used to provide insight into the qualitative and quantitative data.

We conclude this chapter by shedding more light on the above data and findings, by using third-generation CHAT (Figure 7.1).

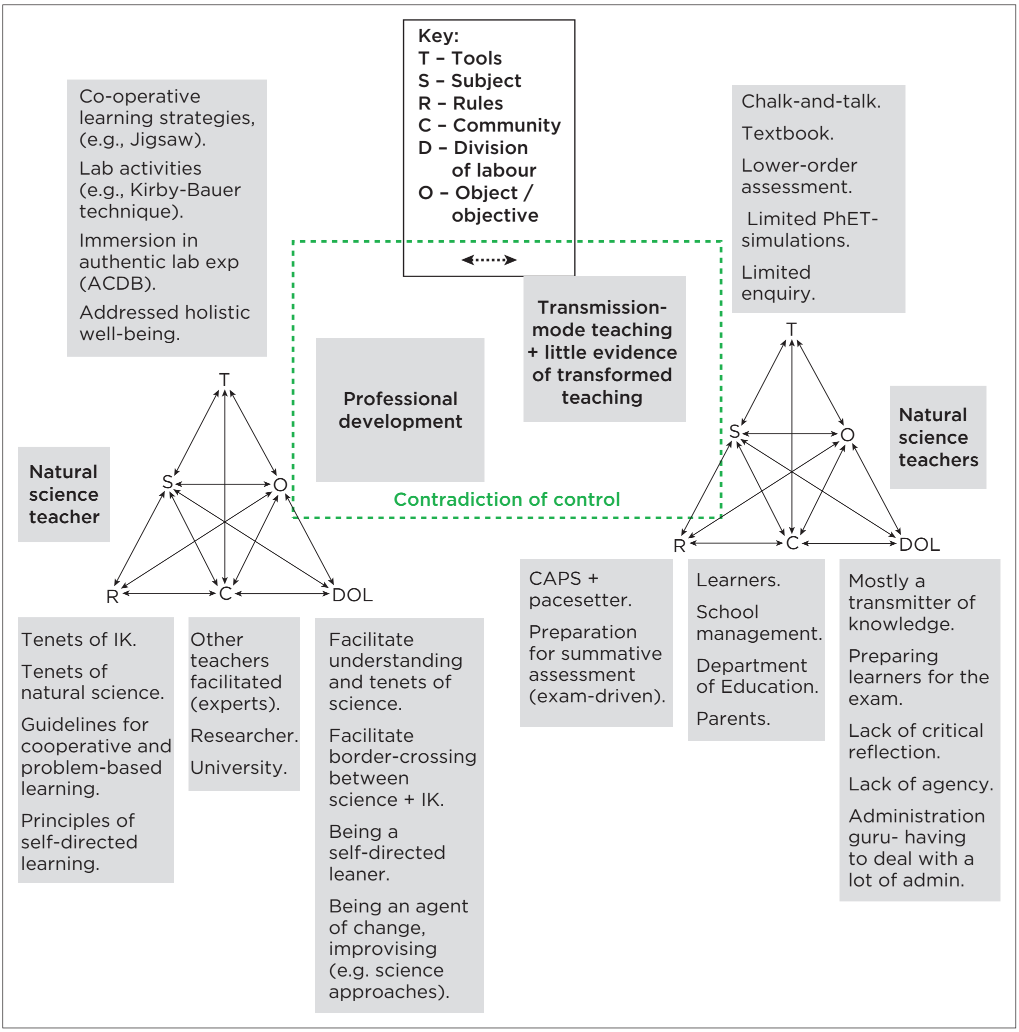

FIGURE 7.1: A cultural-historical activity theory analysis of the findings. The two juxtaposed activity systems are (1) the intervention on the left and (2) the post-intervention classroom on the right.

Evidence of self-directed learning, yet no agency to transform teaching practices

Teacher A showed a slight improvement in terms of SDL, as shown in Box 7.1. In terms of the revised Rogan and Grayson heuristic, Teacher A moved from level 1 to level 2 in the domain of SDL. This indicates that the intervention capacitated the teacher in terms of the SDL domain. According to Knowles, this indicates that Teacher A could formulate her learning goals, but there is limited evidence that learning resources or learning strategies were identified. It was disconcerting in the post-intervention classroom to find little evidence of Teacher A showing agency in the other four domains, namely, classroom interaction, practical work, science and society, and assessment. What was observed in the post-intervention classroom was that the teacher did not change, did not inspire learners to be self-directed learners and mostly reverted to 'chalk-and-talk' approaches. There was very little evidence of SDL.

Tensions in the activity system that prevent transformed teaching practices

Cultural-Historical Activity Theory provides a unique gaze on factors that negatively impact transformed teaching and learning. In terms of the CHAT analysis (Figure 7.1), there exists a tension between the division of labour and the object. The teacher did not show the agency to transform her teaching in the post-intervention classroom, and there was also very little evidence of critical reflection. The tools utilised in the classroom (predominantly transmission-mode approaches, e.g., a dependency on lectures and the textbook) did not foster SDL. Very limited data exist that show that the intervention pedagogies were transferred to the classroom. The community (principal and parents) are not always supportive in terms of promoting PBL and SDL. Pressure is experienced by the subject (teacher) to prepare learners for the examination. Evidence exists of nascent SDL in Teacher A, but this does not lead to transformed teaching practices or the development of teacher agency.

Conclusion

Based on this research, there are several design principles that should be kept in mind when planning and implementing TPDPs. The most important one is that SDL should underpin all teacher professional development interventions. Teachers should be involved in deciding upon the content of TPDPs, and they should take ownership of their own learning.

There is a big need to engage in-service teachers in authentic laboratory work to enhance their understanding of the tenets of science. An international example of this is the Target Inquiry project of Miami University in Ohio,[22]

22. See www.targetinquirymu.org.

spearheaded by Yezierski and Herrington (2011). Teacher A was one of the participants who engaged in laboratory work at the African Centre for DNA Barcoding at the University of Johannesburg. However, this short-lived experience was not enough, and longer interventions are needed. This intervention does not lead to transformed teaching and learning. Furthermore, teachers also need support in developing knowledge and skills in engaging pedagogies and in IK systems, to contextualise science curriculum themes for culturally diverse South African students.

As could be seen in Figure 7.1, there was a 'contradiction of control' (McNeil 2013) in terms of the 'object' in the activity systems. The intervention does not lead to transformed teaching and learning. Mentz and De Beer (2019) suggested that all stakeholders should be involved from the beginning when such professional development is planned. Mentz and De Beer (2019) and De Beer (2019) referred to the value of 'change laboratories', where all the stakeholders engage in negotiating a shared 'object'. Engeström (2011:612) portrayed a change laboratory as 'a microcosm in which potential new ways of working can be experienced and experimented with'. Stakeholders come together during such Change Laboratories, to discuss the intended object (in this context, the intended outcomes of professional development) and to reach consensus on a shared object. An overarching theme in this chapter is that teachers often fall back on transmission-mode approaches, despite interventions that emphasise inquiry learning, because of expectations of, and pressure from, principals and parents. By involving teachers, principals, subject advisors, the Department of Education, teacher unions, parents and the broader community in the conceptualisation of the PD intervention, one could avoid the 'contradiction of control' between the intended and realised objects.

Based on the above suggestion of engaging in 'change laboratories', the fourth-generation CHAT, as proposed by Engeström (2011) and Mentz and De Beer (2019), can provide an ideal lens. This is a nascent approach to research on teacher professional development, which has enormous potential for providing greater insights into this complex area of research.

The revised profile of implementation could aid as a heuristic for teacher educators to include SDL as a design principle in TPDPs. Self-directed learning is needed for a natural sciences teacher to develop in each of the other four dimensions or domains as suggested by Rogan and Grayson (2003), namely, classroom interaction, science practical work or inquiry learning, science-in-society perspectives and assessment practices. The revised heuristic (provided in Table 7.1) provides a vehicle to map teacher professional development during TPDP. Mapping teachers' professional development in this way provides insights into the effectiveness of professional development interventions.

Chapter 8

Exploring collaboration as a 21st-century skill to enhance self-directed learning while teaching particulate nature of matter through problem-based learning

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Abstract

In this qualitative study, we explored collaboration as a 21st-century skill to enhance SDL while teaching Grade 10 Chemistry through PBL. Social interdependence theory (SIT) was used as theoretical framework. The implementation of PBL to enhance collaboration skills for the benefit of learners could help promote SDL, which, in turn, could improve educational results and create better chances for learners to find work. This was a case study of one beginner teacher from one high school in the North West province, South Africa. Data were collected by means of an open-ended questionnaire, a reflective portfolio and a semi-structured interview. The data were analysed manually using Saldaña's model and Golightly's assessment rubric. The results show that it is possible for teachers without any prior knowledge of PBL to implement it successfully. Furthermore, the results indicate that, during PBL implementation, learners rely more on themselves as a group than on the teacher. However, the results also revealed that using such an unusual approach might make teachers uncomfortable. Therefore, it is recommended that intervention programmes be presented to enable teachers to improve their skills in implementing PBL in the Physical Sciences classroom.

Introduction

The aim of this research was to explore a 21st-century skill (i.e. collaboration) to enhance SDL while teaching the topic Particulate Nature of Matter (PNM) through PBL after a teacher professional development (TPD) programme. According to Rovers et al. (2018:416), '[PBL] is a comprehensive educational approach that is based on cognitive theories of learning and has continued to be important in education curricula across the world'. According to Overton and Randles (2015:251), PBL is 'the learning that results from the process of working toward the understanding or resolution of a problem'. The implementation of PBL as educational approach could help promote SDL among the learners and teachers in a classroom (Golightly 2019:143). Self-directed learning is a process whereby learners analyse their own learning needs, express purpose and select accurate approaches (Zainuddin & Perera 2018:282). According to Knowles (1975), SDL comprises three critical parts: the learner, the teacher and the learning resources (the learning resources in this regard being PBL and the content of the topic PNM).

According to Yasmin, Naseem and Masso (2019:35), SDL is associated with desirable educational results and better chances of finding employment. Twenty-first-century skills, such as collaboration, are core competencies for learning that can help learners in today's ever changing, globally interconnected world (Howlett & Waemusa 2019:74). Learners should be exposed to real-life problems, should be encouraged to communicate in and outside teaching–

learning situations, should collaborate with friends and should think critically (Wyness & Dalton 2018:3).

Problem statement

Afandi, Akhyar and Suryani (2019:90) claimed that teachers have a vital responsibility to support the development of their learners' 21st-century skills. According to Ceylan and Yiğital (2016:57), teachers fail to encourage, guide and promote 21st-century skills in their learners. The current teaching approaches implemented by teachers do not match the needs of the 21st-century world (Häkkinen et al. 2017:35). Also, there is a growing global need for 21st-century science teaching, as was also observed by Bustamante, White and Greenfield (2018:34) in the United States.

Research questions

The following research questions guided this research:

- How does a beginner physical sciences teacher's implementation of PBL enhance the development of collaboration as a 21st-century skill in learners for SDL while teaching PNM?
- What are the beginner physical sciences teacher's challenges, if any, when implementing PBL to enhance the development of collaboration as a 21st-century skill in learners for SDL while teaching PNM?

Theoretical framework and literature review

Theoretical framework

Social interdependence theory was used as theoretical framework. Formally coined by Deutsch (1949a, 1949b) for the effect of cooperation and competitiveness on small group functioning, SIT was defined by Johnson and Johnson (1999, 2005, 2009) as the shared influence between individuals in a small group. Social interdependence theory is primarily associated with collaboration, small group learning and cooperative learning. Previously, SIT was successfully implemented in education (Johnson & Johnson 1974, 2009; Slavin 1988). Problem-based learning is one of the learning approaches with a theoretical foundation premised on SIT (Torre, Van der Vleuten & Dolmans 2016:190). As the tenets of PBL are aligned to the broader philosophy of SIT (Torre et al. 2016), the researchers saw it fit to incorporate PBL as a conceptual construct of SIT.

In this research, a small group learning approach was used during a PBL TPD programme and the implementation of PBL in the classroom, taking a leaf from Johnson and Johnson (2009). They reported the success of SIT when implemented in the field of education. According to Johnson, Johnson and Smith (1995), when applying SIT:

> [*T*]he teacher ought to see a teaching–learning situation in terms of six principles: (1) Knowledge is constructed and extended by learners; (2) The learners are actively involved in constructing their own knowledge; (3) The teacher's effort must be aimed at developing and enhancing learners' skills; (4) Education is a personal transaction among the learners, between the learners and the teacher and work given; (5) Creating a conducive and cooperative atmosphere facilitates active mastery of concepts; (6) Considerable teacher training and continuous refinement of skills and procedures. (pp. 8–10)

An exploration of the schools of thought on the core model of SIT yielded a two-dimensional realisation: on the one hand, positive interdependence (cooperative) and, on the other hand, negative (competitive) interdependence (Deutsch 1949b, 1962; Johnson & Johnson 2003; Jongman 2017). Positive interdependence entails when one member's actions foster another member's goals to reach common goals in a small group (Johnson & Johnson 2019:45). Each group member assumes a key role so that the success of the group work is based on whether everyone succeeds in their role (Johnson & Johnson 2019; Li 2017). Social interdependence theory gives a broad concept of SDL that results from collaboration. In contrast, negative interdependence occurs when one group member's actions impede the attainment of joint goals of a small group. Negative interdependence recognises that learners working in a small group do not always approach a given task collaboratively and may view it as competition instead (Hartmann 2017:633). This research was significantly influenced by positive interdependence. Problem-based learning implementation requires that every group member contributes towards a common goal. This is achieved by requiring that each learner in the group assumes a key role – such as the leader, scriber and researcher – which ultimately contributes to group work.

◻ Problem-based learning and self-directed learning

Ansarian and Teoh (2018:1) argued that 'PBL was practised long before it was even known as a "scientific" approach'. The McMaster Faculty of Health Sciences (McMaster University, Canada) is widely known to have championed the PBL educational approach in their curriculum in the late 1960s (Lee & Kwan 1997; Savery 2019; Servant-Miklos, Norman & Schmidt 2019; Servant-Miklos, Woods & Dolmans 2019b). Problem-based learning features SDL (Ansarian & Teoh 2018; Barrows 1996:7). Knowles (1975) described SDL as follows:

> [*A*] process in which individuals take the initiative, with or without the help of others in, 1) diagnosing their learning needs; 2) formulating learning goals; 3) identifying

> human and material resources for learning; 4) choosing and implementing appropriate learning strategies; and 5) evaluating learning outcomes. (p. 18)

According to Achilles and Hoover (1996:19) and Koh and Chapman (2019:75), PBL as an educational approach effectively promotes SDL in learners from the school level (kindergarten to Grade 12) to the tertiary level.

Problem-based learning entails the use of an ill-structured problem, such that learning starts from a problem and moves to theory where there are multiple solutions (Abdullah, Mohd-Isa & Samsudin 2019; Akçay 2009; Golightly 2020; Hüttel & Gnaur 2017; Seleke, Havenga & De Beer 2019). Hung (2019:249) stated that such an ill-structured problem must 'contextualise abstract content knowledge to practical meaningful working knowledge'. During PBL, learners working in groups of four to six members are presented with an ill-structured problem of which the 'solutions require certain information and skills that they do not yet possess' (Poë 2015:280). Once presented with an ill-structured problem, the learners in the PBL process: (1) identify facts, (2) formulate learning objectives, (3) identify and select learning material, (4) apply new knowledge, and (5) evaluate learning objectives (Hmelo-Silver 2004:236). This PBL process happens through SDL (Hmelo-Silver 2004; Hung, Moallem & Dabbagh 2019). The SDL and PBL processes discussed here are more similar than contrary to each other.

Problem-based learning assessment focuses mainly on the learning process (Lee 2013) and entails learner-based assessment (self-assessment and peer-assessment) and teacher-based assessment (facilitator assessment), promoting SDL in the learners (Ansari et al. 2015:263). This research, however, focused on teacher-based assessment. In West Nusa Tenggara, Indonesia, Nursa'ban, Masykuri and Yamtinah (2019) implemented PBL in a Grade 11 Natural Sciences classroom. They found that the implementation of PBL conducted consistently could enhance science learners' SDL. In a qualitative study with 35 chemistry learners in Malaysia, Peen and Arshad (2017) investigated collaboration and SDL in a PBL lesson. Their findings showed that both collaboration and SDL were enhanced in groups of learners during the implementation of PBL. Although their findings showed comparatively high occurrences of collaboration and lower SDL, the implementation of PBL in a chemistry classroom overall enhanced learners' collaboration and SDL.

Havenga (2018b:318) believed that learners working in PBL groups for the first time may experience challenges such as time constraints, problems with communication and staying focused. In the Philippines, Valdez and Bungihan (2019:282) implemented PBL in a Grade 9 Chemistry classroom aimed at enhancing their problem-solving skills. Their findings showed that implementing PBL might be challenging in a larger classroom and may have undesired outcomes.

Collaboration as a 21st-century skill and self-directed learning

The acquisition of 21st-century skills, including collaboration, is associated with SDL (Turiman, Wook & Osman 2019:46–47), which is recognised 'as a crucial aspect of learning for the 21st century' (Van Zyl & Mentz 2019:70). Collaboration is defined as 'working together in small groups to achieve a common goal' (Chen & Kuo 2019:95). By acquiring collaboration as a 21st-century skill, learners might be ready to face complex real-life situations such as work experiences and day-to-day survival (Al Kandari & Al Qattan 2020:554). Moreover, according to Stehle and Peters-Burton (2019:4), 'collaboration is an important skill to enhance SDL'. Collaboration can focus on the quality of the group outcomes, and its process measures group success (Collazos et al. 2007:258). Havenga (2018a:255) emphasised that collaboration is a necessary skill in groups when solving real-world problems, as it is one of the ways to instil professional practice. Golightly and Raath (2015:64) argued that PBL enhances collaboration skills.

According to Sebotsa, De Beer and Kriek (2019), teachers are not familiar with the concept of SDL. Individuals with SDL skills in this ever changing world, where workplaces and professions often change because of economic instability, are most likely to adapt by learning more for their job security and personal development (Aoki 2020:42). Cheng et al. (2010:1157) mentioned several ways in which learners can exhibit SDL: 'knowing what to learn; enjoying to find answers to questions; establishing own learning goals; arranging and controlling own learning time; and knowing how to find resources for own learning'. In a study conducted by Thakur, Dutt and Chauhan (2018), PBL was implemented in a Grade 9 Biology class in New Delhi, India. These authors concluded that PBL is one of the best strategies to motivate, interest and encourage learners; it promotes scope for social interaction; and it promotes discussion, sharing of ideas and collaboration. Furthermore, Sekarini, Wiyanto and Ellianawati (2020) suggested that PBL is an effective learning model that could be implemented to develop the 21st-century skill of collaboration.

Traits of beginner physical sciences teachers and particulate nature of matter

Scholars have different definitions for the concept of *beginner teachers*. The term *beginner teachers* refers to teachers who have recently qualified from HE institutions and entered the education system to practise teaching. In addition, a beginner teacher may have spent many years (more than five years) in the education system but have recently (less than five years) begun teaching a particular subject. According to Mahmoudi and Özkan (2015:58), beginner teachers are those with little or no experience, who often have less than two years of teaching experience. In the case of this research, the term *beginner teachers* refers to teachers who have recently started teaching physical sciences, have five years or less practical experience, and hold relevant teaching qualifications, such as a Bachelor of Education (BEd), BEd Honours or the Postgraduate Certificate in Education. Beginner teachers are new to the teaching profession and classroom practice, and therefore, their teaching approaches, or rather their PCK, are at the 'novice' level (Van Heerden 2019:29). Beginner teachers often face complex and dynamic challenges, such as personnel, organisations and environments (Robson & Mtika 2017:243).

Chaves (2018:98–100) outlined some traits of beginner teachers: struggling to make their subject fun, under-preparedness in terms of teaching techniques and approaches, and struggling with some CK. Surprisingly, more than a decade later, Chaves corroborated the suggestion of Davis, Petish and Smithey (2006:610) that science content, science discipline, learners' approach, learning environment and professionalism are the five key aspects relating to the challenges that most beginner science teachers encounter. From the above literature, it can be inferred that most beginner teachers, among other challenges, struggle with delivering content effectively.

In the South African curriculum, physical sciences is a combination of two fields: Physics and chemistry (Ogegbo, Gaigher & Salagaram 2019; Samuel & Dudu 2018). Particulate Nature of Matter is one of the fundamental concepts in physical sciences for one to understand subsequent topics in chemistry. This is a chemistry component of physical sciences in the South African curriculum that is abstract and presents multiple teaching challenges (Harrison & Treagust 2002; Pitjeng 2015). Yakmaci-Guzel and Adadan (2013) supported this by saying that PNM is:

> [*P*]art of basic concepts in school science curricula worldwide from Grades 6 to 12, where learners are exposed to the structure of matter and three physical states, classification of matter, and different representational levels. (p. 110)

According to Merritt and Krajcik (2013:16), learners learn about PNM through daily experiences and classroom instruction. Therefore, we suggest that PBL, which allows the integration of real-life and class-taught content, be used.

Teacher professional development

Teacher professional development is a structured professional learning activity that aims to bring about changes or improvements in teachers' practices so that learners' learning can improve (Bates & Morgan 2018; Darling-Hammond, Hyler & Gardner 2017). Teacher professional development for in-service teachers is considered 'an important factor in improving South African education and teachers' confidence' (Christiansen & Bertram 2019:79).

Darling-Hammond et al. (2017:7) further stated that TPD should be linked with teachers' experiences and teaching standards. Dudu (2014) reported that South African Physical Sciences teachers acknowledge that TPD improved their teaching approaches and CK, as it was directly linked with their daily experiences. A South African study by De Villiers, De Beer and Golightly (2016) with 75 Life Sciences teachers from two provinces is an example of a study that administered TPD on PBL and SDL. These researchers reported that only a few of the teachers admitted to knowing about the PBL approach; however, they did not know how to use it because of a lack of confidence in their skills to manage it. The findings of the latter study further showed that, while other teachers were knowledgeable about PBL, most of the teachers admitted to being clueless in this regard. This is alarming, hence underscoring the need for a PBL TPD programme.

Lee and Blanchard (2019) reported that a TPD programme on PBL increases teachers' intention to implement PBL in their classrooms. Teacher professional development is an important factor in maintaining a strong workforce and keeping up with the 21st century (Wozniak 2020:195). People need some skills to either get or secure jobs and, as stated by Hunter and Molapo (2014:317), 'when the departments of education or educational systems adopt a new curriculum or teaching approach, teachers in the field will require training'.

Methodology

Purpose of the research

The aim of this research was (after presenting a TPD programme) to explore collaboration as a 21st-century skill to enhance SDL while a beginner physical sciences teacher taught Grade 10 Chemistry (PNM) through PBL.

Research design

In order to determine the effectiveness of a PBL approach to promote the 21st-century skill of collaboration, a qualitative research method was applied. For this research, it was ideal to adopt an exploratory qualitative case study approach (Thanh & Thanh 2015:26).

Data collection instrument

Data were collected by means of a self-developed open-ended questionnaire, a participant portfolio (after implementing PBL following a TPD programme) and a semi-structured interview. The data collected by means of the open-ended questionnaire were used (November–December 2019) to organise an effective TPD programme to meet the participant's needs. After the TPD programme, the portfolio by the participant was used to document the implementation of PBL (February 2020) in a Grade 10 Chemistry classroom. The portfolio contained the following data: the PBL lesson plan, the PBL problem used during implementation, the teacher's and the learners' roles during the PBL implementation, learners' worksheets, 21st-century skills observed, teacher-based and learner-based assessment rubrics, and details on what happened during the PBL lesson. Some of the interview questions were adapted from the Cheng et al.'s (2010:1157) SDLI, while others were self-developed by researchers (post-PBL implementation, March 2020) to explore the participant's views, perceptions and experiences. Examples of items from the SDLI are 'can your learners connect new knowledge with their own personal experiences? Explain' and 'explain how your learners evaluate their own learning outcomes'.

Teacher professional development programme

It is worth noting that this research is part of a larger project, but the focus of this research was a case of one teacher. A pseudonym ('Keobiditse') was used to protect the identity of the teacher participant (Mukungu 2017). A one-day-day PBL TPD programme was presented (January 2020) for those teachers who participated in the larger project. The purpose of this programme was to enhance the use of PBL by beginner physical sciences teachers to promote 21st-century skills while teaching PNM. The teacher participants were given a problem (Box 8.1) to work on which they had to use during the implementation of PBL to enhance collaboration as a 21st-century skill.

The physical sciences (chemistry) content for this problem was aligned with the CAPS. It was further properly planned and aligned with the Annual Teaching Plan (ATP) 2020 (DBE 2011): the content of the problem was for term 1 (January to March) when the PBL was implemented. Finally, for the PBL activity, the participant was shown how to assess learners' work using Golightly's (2013) assessment rubric.

BOX 8.1: A PBL problem.

Problem: Chemistry of Matter and Materials (Particulate Nature of Matter)

The central heating in your home during the winter season is the cooking stove. You realised that you could warm your kitchen by turning on the stove and keeping the oven door open. During summer evenings, it is hot and you cannot open windows because of mosquitos flying into the house. Some of your classmates are of the opinion that you could cool your kitchen by leaving the refrigerator door open. However, your parents disagree with your classmates' views. You discussed this with your chemistry teacher, after which he or she decided that you had to solve this problem in your PBL groups. You had to do research and inform the rest of the class of your findings regarding the above-mentioned problem.

PBL, problem-based learning.
Source: Adapted from Poë (2015:287).

Site selection, sampling technique and sample

The research was conducted in one of the four districts of the North West province in South Africa, namely, the Ngaka Modiri Molema district, because of the geographical proximity and accessibility to the researchers. The Ngaka Modiri Molema district consists of various area offices. However, Keobiditse was purposively selected from one area office in the said district. Keobiditse (23) had been teaching physical science for a year and was therefore considered a beginner teacher. Keobiditse completed a BEd degree the previous year (2018), majoring in physical sciences and mathematics. At the time of the research, he was teaching in a township secondary school and had two Grade 10 classes, from which one class of 26 learners was randomly selected to implement PBL in the teaching of PNM. He divided the learners into four groups: six members in two groups, respectively, and seven members in the other two groups, respectively. Moreover, he focused more on one group for close observation.

Data analysis

Saldaña's (2009) model was adopted as tool for the data analysis. The transcribed data from open-ended questionnaires, some of the contents of the portfolio and interview were coded. Additionally, the physical sciences assessment rubric for the PBL activity (chemistry – PNM) was adapted from Golightly (2013) and was used to assess learners' PBL process as described by Hmelo-Silver (2004) (see Appendix). It is worth mentioning that the PBL rubric was aligned with the SDL process described by Knowles (1975:18) where learners are 'formulating learning goals, identifying their resources, choosing and implementing appropriate learning strategies, and evaluating learning outcomes'. During adaptation, the sections, recent literature, resources, data and references were removed, as learners' primary sources are prescribed textbooks approved by the provincial departments of education. For this research, Golightly's (2013) assessment rubric was adapted as follows: demarcation of the problem (4), formulation of learning objectives (12), the scope and quality of the provisional research (20), identification and recommendation of possible solutions to the problem (20) and writing skills (4) (with a total mark of 60). Therefore, the highest score (maximum = 60) and the lowest score (minimum = 5) indicated the overall performance of the learner during the PBL activity. The continuum on which the scores fell is as follows: Inefficient – unsatisfactory (5–18.75), efficient – fairly acceptable (18.75–32.5), good – moderately satisfactory (32.5–46.25) and excellent – highly satisfactory (46.25–60.0). Golightly's teacher-based assessment rubric was part of the portfolio. While coding and categorising the beginner teacher's responses, emerging themes – which are outlined and discussed in 'Results and discussion' – were identified.

The assessment rubric for the PBL activity criteria scores was defined by four quality levels, namely, excellent, good, efficient and inefficient. For instance, the criteria 'Demarcation of the problem' and 'Writing skills' each had a total score of 4 on the continuum, where 4 was excellent, 3 was good, 2 was efficient and 1 was inefficient. The criterion 'Formulation of learning objectives' had a total weighting score of 12, which was spread on the continuum as follows: 10–12 was excellent, 6–9 was good, 3–5 was efficient and 1–2 was inefficient. The criteria 'The scope and quality of provisional research' and 'Identification and recommendation of possible solutions for the problem' both had a total weighting score of 20. The two criteria had an excellent score (12–20) and a good score (11–15). For the criterion 'Scope and quality of provisional research', 6–10 weighting was efficient, while 1–5 was inefficient. For the criterion 'Identification and recommendation of possible solutions for the problem', efficient was defined by the score of 5–10, whereas an inefficient score range was 1–4.

In this research, trustworthiness of the data was ensured through an audit trail, which is a strategy for confirmability and credibility (Korstjens & Moser 2018; Lincoln & Guba 1985). The audit trail entailed providing a complete set of notes on decisions made during the research process, research team meetings, reflective thoughts, sampling, research materials adopted, emergence of the findings and information concerning the data management. *Credibility* refers to research participants' involvement in the research findings to ensure the results of the research are true or credible (Yilmaz 2013:320). In this research, the authors were involved in the field for a prolonged period, checked their interpretations with their participants and showed a process of learning. *Confirmability* means that the findings and the interpretations made from findings do not derive from the imagination or emotions of the researchers but are clearly linked to the generated data (Liamputtong 2013). In this research, this was achieved by applying SIT – themes were created from theory which guided the analysis and discussion, thereby validating the interpretations made from the findings. Also, verbatim quotations were used to support the data.

■ Results and discussion

This section presents the results of the research and provides a discussion that addresses the research questions. Firstly, the pre-TPD results and interpretations are provided. Secondly, the results are presented in the order in which the research questions were posed.

BOX 8.2: Beginner teacher's knowledge of the four concepts prior to the teacher professional development programme.

Teaching approaches in teaching PNM	
Used approaches	*Other approaches, but not used*
Keobiditse responded as follows: 'Learner-Centred approach; Inductive approach; Participatory approach; Constructivist Learning approach.'	Keobiditse's response was: 'Teacher-centred approach; deductive approach.'
Knowledge of PBL	
Understanding of PBL	*Prior use of PBL*
Keobiditse's own understanding of PBL was: 'Problem-Based Learning is a learner-centred approach in which learners attempt to learn a particular content through experience of solving a particular open-ended problem.'	With regard to prior knowledge of using PBL, Keobiditse's response was: 'The knowledge I have is to request learners to state all material they consider to be matter and thereafter classify it in either liquid, solid or gas.'
Researchers' interpretation: Keobiditse's own definition of PBL was correct according the researchers' accepted definition of PBL based on PBL literature.	This response showed that Keobiditse had no prior use of PBL.
Knowledge of 21st-century skills	
21st-century skill(s) mentioned by the beginner teacher	*21st-century skill(s) not mentioned by the beginner teacher*
Communication, critical thinking, creativity, technology literacy and problem-solving.	Collaboration
Knowledge of SDL	
Ways in which Keobiditse's learners exhibited SDL	
Keobiditse's view: 'Positive thinking, commitment and punctuality, eagerness to learn and [solving] scientific problem(s) they were presented or confronted with'.	

PNM, particulate nature of matter; TPD, teacher professional development; SDL, self-directed learning.

Pre-teacher professional development results and interpretations

The aim of the open-ended questionnaire was to collect data that would answer the research questions. The open-ended questionnaire results – based on four concepts, that is, teaching of PNM, knowledge of PBL, promotion of collaboration as a 21st-century skill and Keobiditse's enhancement of SDL – were analysed before the TPD programme was presented. The researchers anticipated that, although Keobiditse might have had an understanding of science CK, including PNM, his knowledge of teaching approach(es), including PBL, might have been limited. Consequently, data generation was based on the teaching of PNM.

Table 8.1 presents the four concepts that emerged from the open-ended questionnaire regarding the teaching approach(es) used and others known but not used by the beginner teacher to teach PNM in his Grade 10 Chemistry classroom. The beginner teacher's responses are presented verbatim.

TABLE 8.1: The themes associated with collaboration as a 21st-century skill.

21st-century skill	Themes
Collaboration	• Quality of the group process and outcome as a measure of success. • Enhances SDL: Responsibility and evidence of interdependence.

SDL, self-directed learning.

Keobiditse's responses regarding this concept are, however, reported as no responses in this research, because they were not related to the information solicited. His responses were relatively broad. Regarding the concept of PBL in the open-ended questionnaire, Table 8.1 presents Keobiditse's own (verbatim) definition and indicates that he had no prior knowledge of using PBL in teaching PNM. Concerning Keobiditse's knowledge of 21st-century skills, he mentioned five 21st-century skills (see Table 8.1) which were not the focus of this research. As shown in Table 8.1, he did not mention collaboration as a skill. Finally, as regards the last concept of SDL, Keobiditse mentioned ways in which his learners exhibited SDL (see Table 8.1).

Keobiditse mentioned what could not be identified as teaching approaches. He mentioned broad teaching philosophy, frameworks and concepts such as the *constructivist learning approach* and the *inductive approach*. When asked to name other known teaching approaches that were introduced to them during their teacher training but were not utilised, none were mentioned, including PBL. It is difficult to explain this result. However, it was anticipated that the TPD programme would enhance and/or increase Keobiditse's knowledge of teaching approaches, especially PBL. The researchers anticipated that, although Keobiditse might have had relatively high science CK, including knowledge of PNM, he might have had limited knowledge of teaching approach(es), including PBL. The open-ended questionnaire was rendered to establish how much he knew about PBL, informing the aspects that should be focused on by the facilitator during the intervention programme.

In the literature, no studies could be found on beginner physical sciences teachers' knowledge of PBL. As shown in Table 8.1, Keobiditse's own understanding of PBL was correct according to the definition of PBL accepted in this research. Furthermore, Keobiditse's understanding of PBL as an open-ended, real-life problem that learners must solve using their own method and knowledge (see Table 8.1) was consistent with the views of many scholars, such as Abdullah et al. (2019) (Malaysia), Akçay (2009) (Turkey), Golightly (2020) (South Africa), Hüttel and Gnaur (2017) (Denmark) and Seleke et al. (2019) (South Africa). The definition adopted in this research is that PBL is a process whereby a group starts with a real-life or content-based ill-structured problem to achieve learning objectives. Furthermore, for the group to achieve the learning outcomes, group members must work cooperatively (Johnson et al. 1995). The authors contend that, to solve a real-life problem cooperatively, learners should achieve the learning objectives rather than simply solving the problem. This PBL definition comprises three components (i.e. problem-solving, cooperative learning and real-life problem), as was mentioned by Keobiditse (see Table 8.1).

As was anticipated, Keobiditse did not mention PBL under the teaching approaches and had never used PBL to teach. His lack of prior utilisation of PBL corroborates results from other studies, for example, De Villiers et al. (2016) found that most of the 75 Life Sciences teachers who participated in their study had no prior knowledge of PBL and also did not use PBL in the past. Therefore, this analysis urged that emphasis be put on the PBL implementation during the TPD programme, as Keobiditse was to implement PBL in his physical sciences classroom. Keobiditse did not mention collaboration as a 21st-century skill. It is difficult to explain this result, but it might be related to the fact that, as there are many 21st-century skills, Keobiditse only mentioned the first few that came to mind. Nonetheless, this finding showed a need to emphasise collaboration as a 21st-century skill during the TPD programme.

As was mentioned in the literature review, the importance of collaboration as a skill (Al Kandari & Al Qattan 2020; Collazos et al. 2007; Havenga 2018a; Stehle & Peters-Burton 2019) was emphasised during the TPD programme. One of the questionnaire sections aimed to capture data on how Keobiditse promoted SDL and how his learners consequently exhibited SDL. In this regard, the results of this research showed that Keobiditse's learners exhibited SDL through 'positive thinking, commitment and punctuality, eagerness to learn and solve scientific problem(s) they were presented or confronted with' (Table 8.1). This finding is not in line with that of Knowles (1975); however, Keobiditse's learners' eagerness to learn and solve scientific problem(s) is supported by Cheng et al. (2010). Nevertheless, this finding corroborates Sebotsa et al.'s (2019) argument that teachers are not familiar with the concept of SDL. It was therefore necessary to introduce the concept of SDL during the TPD programme and to show corroboration between Knowles' SDL process and teacher-based assessment rubric adapted from Golightly (2013).

During the TPD intervention, the importance of collaboration as a 21st-century skill for SDL (Turiman et al. 2019) was discussed. As was mentioned earlier, there are various ways for learners to exhibit SDL. The focus of the intervention workshop was on the utilisation of PBL. However, 21st-century skills, SDL and PNM content were emphasised. The PBL TPD programme was aligned with the needs of the teacher as per the open-ended questionnaire responses of the participant and the South African Physical Sciences curriculum.

How does a beginner physical sciences teacher's problem-based learning implementation enhance the development of collaboration as a 21st-century skill in learners for self-directed learning while teaching Particulate Nature of Matter?

The participant's portfolio and interview responses were analysed and grouped into a few themes relating to collaboration as a 21st-century skill. The researchers drew aspects from the SIT theoretical framework that underpinned this research and rephrased them as themes. During the interview, Keobiditse was asked to state PBL benefits for his learners. He said the following:

> 'PBL developed my learners' critical thinking and teamwork skills. Teamwork is an important skill to develop because, as science learners, they must know that ... they will not work as individuals; many science careers require teamwork. Therefore, it is important for my learners to develop these skills while in school. Learners were able to show critical thinking, which is a good skill, which boosted their performance. These are skills that will be beneficial for the real world.' (Keobiditse, beginner physical sciences teacher, 11 March 2020)

During the interview, Keobiditse was asked, 'How could you tell that 21st-century skills were enhanced in your learners while utilising PBL?' He replied:

> 'Because they could communicate ideas, thinking critically to come up with solutions. And they were creative coming up with solutions. They also managed to work together cooperatively and complete the work successfully.' (Keobiditse, beginner physical sciences teacher, 11 March 2020)

Table 8.1 outlines two themes for collaboration as a 21st-century skill. The data are presented under these two themes.

One of the themes that emerged regarding collaboration as a 21st-century skill – enhancement brought about by SDL – was an indication of responsibility and evidence of interdependence among the learners to complete the task. Keobiditse's responses during the interview reflected that learners were responsible for their own learning and to work cooperatively as a group. The present findings seem to be consistent with those of Peen and Arshad (2017), who reported a relatively high occurrence of collaboration among learners, as they managed to complete their task. The results further showed that learners knew and encouraged each other's strengths to do quality work. In this research, the findings revealed that interdependent collaboration in PBL enhanced self-directedness so that learners were responsible for their own learning and relied on one another as a PBL group rather than on the teacher. This finding echoes the argument by Stehle and Peters-Burton (2019), who stated that collaboration enhances SDL. It further validates the finding of Nursa'ban et al. (2019) that the implementation of PBL promotes SDL. The theme 'quality of the group process and outcome as a measure of success' is based on Keobiditse's response when asked to describe how he knew that collaboration had been enhanced. This theme was further corroborated by the learners' achievement.

As was mentioned earlier, the teacher-based assessment rubric for the PBL activity (Golightly 2013) was used to assess learners during the implementation of PBL. Keobiditse used Golightly's rubric to assess his learners' work on various aspects of PBL. To ensure reliability of the data, both authors also marked learners' work independently, and consensus was sought for each mark on each criterion. The average marks of the teacher-based assessment rubric are presented in Table 8.2.

Table 8.2 shows that Keobiditse's learners were awarded a mark of 3 for 'Demarcation of the problem' and 'Writing skills', suggesting that they were good. His learners were considered to be efficient with a mark of 5 for 'Formulation of learning objectives'. Formulation of learning objectives is also mentioned in the SDL process (Knowles 1975). This result shows that collaboration during the implementation of PBL enhanced SDL. With reference to the criterion 'The scope and quality of provisional research', Table 8.2 indicates that Keobiditse's learners scored an average mark of 18 (excellent). This criterion is also found in the SDL process. Concerning the criterion 'Identification and recommendation of possible solutions for the problem', Keobiditse's learners were deemed excellent, with an average mark of 14. This criterion is also found in the SDL process described by both Knowles (1975) and Cheng et al. (2010). Finally, as was mentioned earlier, the total weighting of the PBL activity equates to 60 marks. As shown in Table 8.2, Keobiditse's learners were good at completing the task and presenting their solutions in a professionally written manner. The learners could successfully complete the task, provide solutions and make recommendations for the problem. The learners' overall performance was good, with an average overall score of 43.

The results of this research show that, during PBL implementation, the following are logical inferences and conclusions: learners can work together

TABLE 8.2: Marks of the teacher-based assessment rubric for the PBL activity.

Elements	**Criteria**					**Total score**
	Demarcation of the problem	**Formulation of learning objectives**	**The scope and quality of provisional research**	**Identification and recommendation of possible solutions for the problem**	**Writing skills**	
Weight (score)	4	12	20	20	4	**60**
Keobiditse's mark	3	5	18	14	3	**43**
Author 1's mark	3	5	18	14	3	**43**
Author 2's mark	3	5	18	14	3	**43**
Average	3	5	18	14	3	**43**

Source: Adapted from Golightly (2013).

to find answers before they can be guided; PBL promotes learner interdependency; learners rely more on themselves as a group than on the teacher; and learners acquire interdependency, which is how most science careers function in the real world. These inferences and conclusions are based on the teacher participant's perceptions about learners during the implementation of PBL.

The findings of this research corroborate the findings of previous work in this field advocating for the implementation of PBL in sciences education (Nursa'ban et al. 2019; Thakur et al. 2018; Valdez & Bungihan 2019). Furthermore, in line with Sekarini et al. (2020) and Thakur et al. (2018), this research suggests that the implementation of PBL provides an effective learning model that could be used in developing collaboration as a 21st-century skill.

What are the beginner physical sciences teacher's challenges, if any, when implementing problem-based learning to enhance the development of collaboration as a 21st-century skill in learners for self-directed learning while teaching Particulate Nature of Matter?

Some of the challenges mentioned by Keobiditse in his portfolio were discomfort using an unusual approach and correcting a learner in a group in such a way that the learner is not embarrassed:

> 'When learners were working in groups and I wanted to correct or motivate one learner, I had to do it in a manner that does not embarrass him/her. Sometimes one learner has a misconception, it is difficult to clear it in a way that is "civil" and encouraging such that, that learner understands that he/she is wrong but also know that it is okay to be wrong; this was a challenge.' (Keobiditse, beginner physical sciences teacher, 11 March 2020)

Keobiditse was uncomfortable implementing PBL in his chemistry classroom. It is difficult to explain this finding. However, this might have been because of Keobiditse being new to teaching (see Van Heerden 2019) and having to face some challenges such as personnel, organisations and environments (see Robson & Mtika 2017).

One interesting finding that emerged from this research was that Keobiditse struggled to find positive ways to correct and clear a learner's misconceptions without embarrassing them in front of other group members. This might be related to the kind of person the teacher was or the kind of learners the teacher had, because he knew them better. It is also possible that a PBL approach can be affected by the size of the class – larger class sizes might experience challenges in implementing a PBL approach and achieving desired outcomes (Valdez & Bungihan 2019). The challenges identified in this research are not new to the field but are well known to both beginner and experienced teachers across disciplines in education.

Conclusion

Before the TPD programme, Keobiditse had limited knowledge of teaching using PBL. Furthermore, he demonstrated an acceptable understanding of PBL. As regards Keobiditse's knowledge of 21st-century skills, he did not mention collaboration. In line with Dudu (2014) and Lee and Blanchard (2019), it was found that TPD may enhance teachers' knowledge and implementation of PBL to promote collaboration as a 21st-century skill for SDL. After a TPD programme, while teaching PNM, Keobiditse's implementation of PBL enhanced the development of collaboration as a 21st-century skill for SDL in learners. However, he did experience some challenges in this regard. It is recommended that intervention programmes be presented to enable teachers to improve their skills in implementing PBL in the Physical Sciences classroom.

Chapter 9

Assessing pre-service mathematics teachers' problem-solving proficiency using multiple-solution tasks: An imperative for self-directed learning

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Abstract

The development of SDL skills relies heavily on the ability of individuals to assess and prioritise their learning needs. Self-directed learning skills are important for the development of competent mathematics teachers who can adapt to various situations. In this chapter, I explore the effects of using geometry multiple-solution tasks (MSTs) on pre-service mathematics teachers' SDL and their competency in solving geometry problems using multiple-

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solutions task questions (MSTQs). Data were collected by means of Williamson's Self-rating Scale for Self-directed Learning (SRSSDL) Questionnaire, a MSTQs instrument and semi-structured interviews. Results from the SRSSDL Questionnaire showed that the intervention was successful in increasing the SDL of students with an initially moderate SDL score compared to those with an initially high SDL score. Furthermore, the results revealed that students with an initially high SDL score were more competent in solving geometry problems compared to students with an initially moderate SDL score. From these results, it can be inferred that there is a close connection between SDL and one's problem-solving capabilities. Overall, the intervention had educational importance, especially on students with an initially moderate SDL score. Some of the implications of the findings on both mathematics teacher education and the scholarship of SDL are discussed.

Introduction

The assessment of teacher knowledge is of paramount importance in both teacher training institutions and professional development courses because it helps to evaluate their CK competency, which has implications for their classroom practice (Shulman 1986). Teacher knowledge also influences their attitudes towards mathematics and its pedagogy (Ernest 1989). Studies have shown that teachers' mathematical knowledge is positively associated with learner achievement (Hill & Chin 2018; Hill, Rowan & Ball 2005), even though the nature and extent of the exact teacher knowledge influencing learner achievement are largely unknown (Ball, Thames & Phelps 2008). Solving mathematical problems in different ways can be in contention in this regard. Mathematics teacher knowledge is also important in noticing and supporting learners' mathematical thinking (Hill & Chin 2018), which enhances the learning process (Schoenfeld 2017). Similarly, facilitators'[23] knowledge of their students' (prospective teachers) CK can help them to support students' development of CK and problem-solving (Chick & Beswick 2018). Therefore, assessing pre-service student teachers' (PSTs) knowledge of problem-solving as a component of mathematics teaching and learning is justified.

Multiple-solution tasks are promising teaching and learning tools given that they reveal and enhance PSTs' mathematical problem-solving competency (Guberman & Leikin 2013). Multiple-solution tasks, amongst others, can be used to reveal one's connectedness of mathematical knowledge (Polya 1973; Schoenfeld 1994), differentiate between PSTs who belong to high and regular-level teaching (Levav-Waynberg & Leikin 2012), enhance their proficiency in problem-solving (Leikin & Elgrably 2020), expertise in teaching (Leikin &

23. In this study, I use the term facilitators to refer to lecturers who train teachers from universities and practicing teachers in South African basic education.

Levav-Waynberg 2007) and reveal how teachers facilitate learning in their classrooms (Leikin 2011). Furthermore, the requirement of multiple solutions to mathematical problems allows problem-solvers to express their creative solutions and exercise independent thinking (Leikin et al. 2013). The originality in the solutions presented by problem solvers during the production of multiple solutions is evidence that they have identified strategies, knowledge connections and resources required to solve the problem. Furthermore, the requirement of multiple solutions as a mathematical challenge to PSTs allows them to be less reliant on facilitators (Ingram et al. 2020). Schukajlow and Krug (2013, 2014) have also shown that the requirement of multiple solutions can enhance students' metacognition and self-regulation. The requirement of multiple solutions to mathematical problems is not a requirement in South African basic and HE. Hence, the production of multiple solutions to geometry problems is an activity that can encourage students to be more self-directed in their learning. Despite several benefits of incorporating MSTs in teacher education, no empirical study was found in the South African context investigating this practice. Furthermore, the effects of incorporating MSTs in PSTs' courses on their SDL have never been investigated globally. This provided a rationale for conducting this study with PSTs enrolled in a geometry module at one South African university.

■ Problem statement

During their practice, teachers continually engage with learners of different capabilities and learning needs. Some learners produce creative solutions that deviate from the usual solutions produced by other learners in the classroom (Mhlolo 2017). There is evidence that mathematics PSTs usually compute different solutions to the same problem in their classroom – some use different methods to obtain the same answers, and some misrepresent mathematical information which could lead to incorrect answers (Mhlolo 2017). Hence, there is a need for facilitators who cannot only present mathematics in multiple ways to cater for PSTs' different needs but also equip PSTs with multiple ways of solving mathematical problems. Furthermore, Schoenfeld (2016:22) stressed that 'teachers must perceive implications of the students' different approaches, whether they may be fruitful, if not, what might make them so'. The main challenge, as observed in research by Leikin et al. (2013) and Mhlolo (2017), is that when PSTs produce these creative solutions, most facilitators fear entering the unknown domain and dismiss these solutions without giving them any consideration. In such a case, facilitators need to be cognisant of multiple solutions and able to differentiate between correct and incorrect solutions. Furthermore, facilitators need to be able to perform error analyses to either support or build from it when facilitating PSTs' mathematical development (Ball, Hill & Bass 2005). This means that facilitators themselves need to be able to produce multiple solutions to mathematical problems. This need is exacerbated by the recognition that work-related problems usually involve multiple pathways to finding a solution, which means that workers must also be competent in exploring different avenues to find solutions to problems (Jang 2016). Studies have indicated that facilitators do not value multiple solutions in mathematics classrooms, and they have difficulty in grading learners' different solutions (Bingolbali 2011; Mhlolo 2017). Notwithstanding such findings, some facilitators value the production of multiple solutions in mathematics and vow that such solutions should be included in the school curriculum and the training of mathematics teachers (Stupel & Ben-Chaim 2017). In a recent study, challenging tasks[24] were used to facilitate mathematics learning in New Zealand, and findings suggest that challenging tasks developed learners' autonomy, as they were seen to be less reliant on the teacher when solving problems after the intervention (Ingram et al. 2020), hinting at the development of some self-direction in the learners. Hence, producing multiple solutions to mathematical problems can be thought of as an activity that can emancipate students from depending on teachers for solutions. The requirement of multiple solutions to geometry problems provides an extra load for PSTs to search for more information than they normally would if they were asked for just one solution, which transforms the task from being routine to a challenging task.

As an imperative for the 21st century, SDL is one factor that is important when producing multiple solutions to mathematical problems because this activity requires resilience and autonomy from problem solvers (Guglielmino 2013; Ingram et al. 2020). Furthermore, the activity of looking for multiple solutions means that PSTs have to continually reflect on the problem and use their past experiences, knowledge and problem-solving strategies to find different approaches to the solution of the problem (Schoenfeld 1994). Hence, PSTs need to continually reassess their learning needs, set new goals and find learning strategies and materials that could help them to achieve the set goals. In this chapter, I present empirical evidence of PSTs' experiences during the activity of finding multiple solutions to geometry tasks and how it affected their SDL. The study also aimed to assess PSTs' competency in finding multiple solutions for five specific geometry problems. I aim to answer the following research questions in this chapter:

- How does solving MSTs display PSTs' proficiency in geometry problem-solving?
- What are the SDL benefits of computing multiple solutions to geometry problems in a remote learning environment for pre-service mathematics teachers?

24. Challenging tasks require 'students to connect different aspects of mathematics together, to devise solution strategies for themselves and to explore more than one pathway to solutions' (Sullivan et al. 2013).

Theoretical and conceptual framework

What are multiple-solution tasks in mathematics?

In mathematics, MSTs are mathematical problems that afford opportunities to problem solvers to solve using different methods. They can be characterised as similar to Leikin and Levav-Waynberg's (2008) connecting tasks that contain a directive to produce multiple solutions. Multiple-solution tasks are different from tasks that have multiple answers. They can be solved using different strategies including different representations on mathematical concepts, different properties, theorems or definitions, and different branches of mathematics to obtain the same answer (Leikin & Levav-Waynberg 2008), whereas tasks with different answers once solved produce different answers that are all mathematically correct.

Solution spaces in multiple-solution tasks

In finding multiple solutions to mathematical problems, Leikin and Levav-Waynberg (2008) proposed the notion of solution spaces, which refers to a group of all solutions to problems that can be computed by individuals, groups or experts in a particular domain. They refer to these solution spaces as individual, collective and expert solution spaces. Of the three solution spaces, the most complete one is an *expert solution space*, which represents all solutions to a particular problem known by a particular professional mathematician (Leikin & Levav-Waynberg 2008; Levav-Waynberg & Leikin 2012). The second most complete solution space is the *collective solution space*, which represents the set of all solutions produced by a group of people working together (Leikin & Levav-Waynberg 2008; Levav-Waynberg & Leikin 2012). This solution space supports individuals in producing their own solutions to mathematical problems (Leikin & Levav-Waynberg 2008); hence, it expands individual solution spaces. Lastly, the *individual solution space* presents all the solutions produced by an individual without the aid of another person and the solutions that individuals produce with the help of others through the process of what Wood, Bruner and Ross (1976) coined as scaffolding through the zone of proximal development (Vygotsky 1978). The solution produced by an individual independently is referred to as an *available solution*, while one produced by an individual with the help of others is a *potential solution* (Levav-Waynberg & Leikin 2012). Individual and collective solution spaces are a subset of expert solution spaces and are affected by each individual's problem-solving experiences and tasks requirements (Leikin & Levav-Waynberg 2008). In this study, I only focused on PSTs' individual solution spaces.

Why produce multiple solutions to mathematical problems?

A consortium of mathematics teachers approves that mathematics teaching, amongst other things, should ensure that learners develop connections that would allow them to recognise that different approaches to the same problem can yield similar solutions (National Council of Teachers of Mathematics [NCTM] 2000). One of the key abilities indicating conceptual understanding of mathematics is to represent mathematical concepts in different forms, which is interconnected with the ability to employ different approaches to solving mathematical problems (Even 1998). There is emphasis that learners' development of mathematical thinking and problem-solving rests upon the teacher's ability to integrate multiple representations of mathematical concepts into the classroom (Tall 1988, 1991; Tall & Vinner 1981). Polya (1973) asserted that proficient and experienced mathematics teachers can solve mathematical problems in multiple ways. Polya (1973:61) further stressed that asking questions such as 'can you derive the result differently' can drive students to reach more elegant and simpler solutions. Moreover, producing multiple solutions to mathematical problems contributes to facilitators' mathematical thinking and creativity in the subject (Leikin & Levav-Waynberg 2008; Silver 1997; Stupel & Ben-Chaim 2017). Hence, teachers are continually encouraged to teach their learners to use multiple representations in their mathematics learning (NCTM 2000). Engaging in MSTs affords learners opportunities to make connections between different problem-solving strategies, thus developing their mathematical thinking (Stein & Smith 1998; Tekkumru-Kisa, Stein & Doyle 2020).

Multiple representations of mathematical knowledge have been shown to enhance problem-solving repertoire through supporting different idea processes, promoting deeper learning, constraining interpretations (Ainsworth et al. 1997; Rau & Matthews 2017), promoting CK and expanding teachers' solution spaces (Guberman & Leikin 2013; Leikin & Levav-Waynberg 2008). Furthermore, engaging in the activity of producing multiple solutions to mathematical problems facilitates the development of complex problem-solving, a most desired skill in the 21st century (Jang 2016). Finding multiple solutions further shows the interconnectedness of the different sub-domains of mathematics, like how a geometry problem can be solved using trigonometry or even complex numbers (Schoenfeld 1994; Silver et al. 2005), and enhances learners' interest, autonomy and competence in the number of solutions they produce (Schukajlow & Krug 2014). Furthermore, MSTs are useful in strengthening procedural fluency and conceptual understanding (Große & Renkl 2006), which are two significant strands of indicting a leap in mathematical proficiency (eds. Kilpatrick, Swafford & Findell 2001). Employing MSTs in the classroom promotes classroom engagement where productive discourse becomes a prominent part of the teaching and learning process

(Stupel & Ben-Chaim 2017). Producing multiple solutions also enhances students' self-regulation in their learning and performance in mathematical problem-solving (Schukajlow, Krug & Rakoczy 2015), which points to the possibility that producing multiple-solution may enhance SDL. Exploring PSTs' abilities to produce multiple solutions to mathematical problems is useful, as it allows for the identification of their specific CK needs (Dreher, Kuntze & Lerman 2016), hence affording teacher trainers an opportunity to support this knowledge before they graduate to teach mathematics.

Some dangers of employing multiple-solution tasks in mathematics teaching and learning

Just like any other task that provides problem solvers with a higher cognitive demand, MSTs might pose several dangers to learning in the classroom if not handled with care. Different solutions to mathematical problems place different cognitive demands on problem solvers (Stein & Smith 1998). Even though students who engage in high cognitive demand tasks perform better than their counterparts involved in lower cognitive demands tasks (Silver & Stein 1996), the process of facilitating these tasks is crucial. Facilitators are warned not to pose mathematical problems that discourage learners from learning but to pose problems that are challenging but accessible for learners to solve. Mathematical problems should be posed at the appropriate Grade level of learners and should be posed in such a way that they stimulate learners' curiosity. Hence, facilitating teaching and learning through high cognitive demand tasks requires the kind of scaffolding that allows learners to participate in classroom discourse and gives them the autonomy to express their curiosity (Sullivan et al. 2014). Several studies provide reasons why utilising multiple representations of understanding the content in education is advantageous, while also warning that these representations need to be handled with care as they can inhibit learning if misused (Ainsworth 2008; Bamberger 2014; Chang, Cromley & Tran 2016). These studies particularly warn against using representation that might not have relevance in the mathematical domain (Duval 2006). The activity of finding multiple solutions can derail the learning process and can drive learners to focus on a certain part of mathematical knowledge instead of the whole domain of mathematics; Große and Renkl (2006) warned that this activity can add extra cognitive load on learners, which can inhibit learning. Furthermore, Schukajlow et al. (2015) suggested that employing only MSTs in the classroom is not as useful as employing MSTs together with teacher scaffolds in cooperative learning groups and compared these within the whole class. During this activity, facilitators should notice and discourage passive behaviour from learners who only observe other learners or the facilitator producing solutions, because they would not improve their mathematical knowledge and problem-solving (Schukajlow et al. 2015).

Why focus on geometry?

International tests have conclusively presented evidence that South African learners perform very poorly in mathematics when compared to their counterparts from other countries (Reddy et al. 2016). Euclidean geometry is a mathematics sub-domain of the South African curriculum that has been identified as challenging not only for learners but for teachers as well (Luneta 2014; Naidoo & Kapofu 2020; Van Putten, Stols & Howie 2010). After analysing the readiness of Grade 10 learners for Euclidean geometry, Alex and Mammen (2014) concluded that a majority of the Grade 10 learners in their sample were at Van Hiele Level 0, implying that they were not ready to deal with Euclidean geometry-related content. Luneta (2015) analysed 1000 Grade 12 learners' examinations scripts and found that learners made basic conceptual mistakes when answering geometry questions, and a majority of them were operating at Van Hiele Level 2 instead of Level 3. In a recent study, most Grade 11 female learners deemed Euclidean geometry difficult and confusing, and they said that they tended to memorise geometry theorems without making any links to geometry problem-solving (Naidoo & Kapofu 2020). Despite numerous suggestions for improvement given by the Department of Basic Education (DoBE), this poor performance continues to soar, and there is no sign of improvement yet (DoBE 2019). This is a cause for concern for the mathematics education fraternity given that the applications of Euclidean geometry are vast. Even though there is a plethora of factors that may affect learners' struggle in geometry, in this chapter, I focus on teacher knowledge, as teachers are in the front line of ensuring learners' development in geometry.

In addition to focusing on teacher knowledge, I have also uncovered that most teachers struggle with mathematical content that relates to geometry. Van der Sandt and Nieuwoudt (2003) reported that most South African mathematics teachers are not properly trained to teach Euclidean geometry proficiently. Later, they provided evidence that PSTs' geometry knowledge deteriorated throughout their training, indicating that teacher training programmes do not maintain nor improve PSTs' geometry knowledge (Van der Sandt & Nieuwoudt 2005). After using Usiskin's Cognitive Development and Achievement in Secondary School Geometry and follow-up interviews, Van Putten et al. (2010) also concluded that many mathematics teachers were not well equipped to teach Euclidean geometry during their training. Observations made by Atebe and Schäfer (2011) indicate that teaching methods used in South African classrooms afford learners limited opportunities to learn Euclidean geometry effectively. A study conducted by Luneta (2014) has also shown that first-year students who enrolled for a Foundation Phase teaching degree operated at Van Hiele Level 1 of geometrical thinking while they were expected to complete their Grade 12 operating at Van Hiele Level 3.

These PSTs take their poor geometry knowledge to their classroom practice, which leads to them delivering poor geometry lessons to learners and directly contributing to the rising poor performance in geometry-related problems observed in previous diagnostic reports of Grade 12 examinations (DoBE 2019). This poor performance in geometry and lack of conceptual understanding observed in learners and teachers mean that they need to be offered different learning opportunities in their mathematics classrooms. This situation presupposes the need to train PSTs intensively in Euclidean geometry-related content and scaffolding their facilitation of effective mathematics classrooms. I also focused on Euclidean geometry in this chapter because it is a field populated by the possibility of developing MSTs that can be used by teachers to deepen learners' mathematical problem-solving and understanding. As Stupel and Ben-Chaim (2017) asserted, Euclidean geometry provides teachers with a goldmine of MSTs where various approaches and methods – ranging from geometrical, algebraic or trigonometric, vector and complex numbers – can be used to find the solution.

Teacher knowledge

I see problem-solving as the centre of developing mathematical knowledge, amongst others. Hence, I hold that students should be afforded opportunities to solve problems in more than one way to develop proficiency in problem-solving (Silver et al. 2005). In conceptualising teacher knowledge, Shulman (1986) identified three categories, namely, CK, pedagogical content knowledge (PCK) and knowledge of curriculum (Hill & Lubienski 2007; Shulman 1986). However, this chapter primarily focuses on PSTs' problem-solving of MSTs, which mainly relates to their CK. Content knowledge focuses on the knowledge in teachers' minds which encapsulates not only factual mathematical knowledge but also conceptual knowledge and knowledge of multiple representations of mathematical knowledge (NCTM 2000; Shulman 1986). Content knowledge is important for mathematics teachers to facilitate deeper learning from multiple perspectives and nurture learners with multiple mathematical problem-solving strategies. I consider the ability to produce multiple solutions to mathematical problems an integral part of teacher knowledge. Focusing on facilitators' CK is important because it is the most integral part of teaching mathematics, and the provision of multiple solutions is reliant on the interconnectedness of facilitators' CK. Facilitators' CK comes in handy when facilitating lessons to develop learners' abilities to produce unanticipated solutions and is the centre of judging whether learners' solutions are correct or contain misconceptions or errors (Silver et al. 2005). The ability to produce multiple solutions to mathematical problems can be seen as an attribute of proficiency in mathematical problem-solving (eds. Kilpatrick et al. 2001).

Conclusion: Conceptualising multiple-solution tasks in self-directed learning

In Chapter 1, Knowles' definition of SDL is presented and operationalised. Self-directed learning holds benefits for learning and is relevant to 21st-century education. Notable from the conceptualisation of SDL by Knowles (1975) are the main characteristics that reveal students' SDL, like taking initiative for their own learning. Self-directed learners also exhibit signs of 'curiosity, initiative, persistence, independence, discipline, and self-motivation' in their learning (Van der Walt 2016:3–4) and are likely to attempt challenging problems that require a high level of problem-solving during their learning (Banerjee 2011; Guglielmino, Guglielmino & Long 1987). Motivation to learn is also one characteristic that can foster SDL in students (Mentz & Van Zyl 2018). What is critical to consider in the conceptualisation of SDL is the level of autonomy given to problem solvers to follow their individualised approach to finding a solution to a certain problem.

Furthermore, I have highlighted and operationalised the definition of MSTs in mathematics education and problem-solving. It is clear from research on MSTs that problem solvers can be taught different strategies of solving a problem in multiple ways, but one cannot teach all problem-solving strategies to problem solvers, because there is a plethora of mathematical problems that can be solved in multiple ways. Hence, for problem solvers to solve mathematical problems in multiple ways, they need to be able to assess their knowledge (or strategy) limitations to solving a particular problem and devise their own learning methods to overcome these limitations and allow them to solve the problem. A PBL environment is a good example of such a practice, except that the mathematical problem posed as an MST can be an abstract mathematical problem instead of a real-life problem. Also, the method of learning does not always have to be facilitated by a more knowledgeable other. Problem-based learning has been shown to improve problem solvers' SDL (Barrows 1986; Hmelo-Silver 2004) and the activities of searching for multiple solutions to mathematics problems can be considered as an SDL enterprise undertaken by problem solvers.

South African learners are not required to produce multiple solutions to mathematical problems, even in their high school years, but there is evidence that the mathematical problems they encounter in their learning can be solved in multiple ways. Hence, the requirement of multiple solutions from them means that they have to go beyond their usual problem-solving activities and find other different strategies to solve the problem and get the same answer. This going beyond means that they need to identify what they must learn, devise methods of learning what they must learn from different resources and apply what they have learnt to find multiple solutions to given problems (Ingram et al. 2020). This is close to the characteristics of SDL operationalised by Knowles (1975), which means that the requirement of multiple solutions to mathematical problems can be regarded as an SDL activity for problem solvers because they need to manoeuvre ways in which they can find the solution to the problem. Problem solvers must be intrinsically motivated to want to solve the problem instead of relying on external incentives, because even though multiple solutions are required, once a problem solver finds one solution, they can decide to give up. Garrison's (1997) idea of 'collaborative constructivism' is important, as problem solvers might decide to seek help from more knowledgeable others in their remote environments, positioning knowledge not only as personally constructed but also as socially constructed. This activity of locating and seeking help from others is characterised as an SDL competency and is therefore important to consider as a predictor of problem solvers' SDL (Knowles 1975).

Empirical investigation

The aim of this chapter is to explore PSTs' experiences of finding multiple solutions to Euclidean geometry problems and how this exercise affected their SDL.

Research design

This interpretive study followed a mixed-methods design. Both qualitative and quantitative data were collected on PSTs' experiences of computing multiple solutions to geometry problems and how this affected their SDL. For the quantitative part of the study, the design of the study was structured to contain a pre-test, an intervention and a post-test. Students had to complete a questionnaire for the pre- and post-tests. The intervention required that students produce multiple solutions to the given geometry problems and submit to the lecturer on a weekly basis. It was compulsory that students produced the multiple solutions to geometry problems (intervention) as these were part of the module outcomes, but completing the pre- and post-test questionnaires was voluntary. Thereafter, for the qualitative part of the study, a sample of the participants completed an MST and participated in semi-structured interviews.

The module

The participants in this study were third-year PSTs from a selected university in South Africa who were enrolled for a module focusing on Euclidean geometry. In this module, PSTs were trained on both the CK of Euclidean geometry and its didactics thereof. One of the module's sub-aims is to promote PSTs' production of multiple solutions to geometry problems, and hence, the students engaging in this module were suited for this study. During a period of 12 weeks, PSTs were required to come up with different solutions to different geometry problems as part of the module outcomes. The module was presented in a remote learning environment, where teaching and learning occurred on Sakai, the university data management system called eFundi. In order to assess PSTs' individual multiple-solutions spaces, they were given tasks in which they were required to produce multiple solutions and submit them to the researcher. The efforts to produce multiple solutions were from individual students consulting any source that could help them find different solutions to the problem. The module encapsulates geometry content indicative of Grade 12 content from CAPS and beyond.

Participants

Prior to the commencement of the intervention, an independent person recruited PSTs to participate in the study. Pre-service student teachers had to complete a consent form. Thirty-two PSTs completed and submitted the consent form, indicating their willingness to voluntarily participate in this study. Upon finalisation of the module marks, a sample of three PSTs was purposefully selected from the 32 participants and was approached to complete the MSTQs and participate in semi-structured interviews. These three participants were selected based on their dominant participation in and contribution to the production of multiple solutions during the intervention.

The intervention

The intervention was designed as part of the module outcomes for the Euclidean geometry module which entailed the production of multiple solutions to geometry problems. As part of this outcome, PSTs were required to produce multiple solutions to different geometry problems, handpicked by the lecturer, based on their affordances and opportunities to produce multiple solutions. This was done as an individual activity which contained different problems where PSTs were required to individually compute multiple solutions on a weekly basis. The arrangement was that on the first Friday of the beginning of the semester, PSTs would be given their first task, which would be due the following Friday, and the same cycle continued for a period of 12 weeks.

Methods of data collection

In this study, PSTs were required to complete Williamson's (2007) SRSSDL Questionnaire before and after the intervention in order to measure the impact of the intervention on their SDL. This questionnaire was chosen because its reliability has been verified from different contexts and in both students and workers (Cadorin et al. 2011; Golightly & Brockett 2010; Mentz & Van Zyl 2016). Both descriptive analysis and inferential statistical analysis were used to analyse the data from the SRSSDL Questionnaire. After the intervention, three participants completed a task with five geometry problems where they were required to produce multiple solutions. Thereafter, they participated in a semi-structured interview where they had to share their experiences of computing multiple solutions to geometry problems. This was done in order to elaborate on the results obtained from the SRSSDL Questionnaire. The questions from the semi-structured interview schedule focused on two major themes addressed in this chapter: the production of multiple solutions and PSTs' SDL. The transcripts of the semi-structured interviews with PSTs were analysed using open data-driven coding[25] (DeCuir-Gunby, Marshall & McCulloch 2011) to identify codes that related to PSTs' experiences of computing multiple solutions and their SDL. Both the task sheet submitted by the participants and the interview transcripts formed part of the data sources for this study.

Instruments

The study involved three research instruments – Williamsons' SRSSDL, task sheets for participants to produce multiple solutions and semi-structured interviews.

Quantitative data: The self-rating scale for self-directed learning

The SRSSDL Questionnaire was designed for individuals to rate different elements related to their self-direction in their learning. The questionnaire comprises 60 items that are categorised under five broad areas of SDL, namely: *awareness, learning strategies, learning activities, evaluation* and *interpersonal skills* (Williamson 2007). Pre-service student teachers responded to each of the 60 questions in the questionnaire through a five-point Likert scale. This scale showed PSTs' frequency of performing a certain task indicated by the statements of the 60 questions in the SRSSDL. In this five-point Likert scale, the numbers 1 to 5 indicated the following frequencies: 1 = never, 2 = seldom, 3 = sometimes, 4 = often and 5 = often. In SRSSDL, a lowest score of 60 and a highest score of 300 can be obtained, and a score ranging from 60 to 140 is regarded as an indication of a low level of SDL, 141–220 as moderate and 221–300 as high (Williamson 2007). Most importantly, the finding that all five broad areas of SDL in SRSSDL upon validation studies by Williamson (2007) recorded a Cronbach's coefficient above 0.70 indicated that this questionnaire is reliable. Another Italian validation study that evaluated the SDL of 334 nurses using the SRSSDL and obtained a Pearson coefficient of 0.73, which indicated good reliability and Cronbach's alpha coefficient of 0.94, indicated that the

25. Data-driven codes are codes that emerge from the data and are generated by reducing the data into themes that describe participants' experiences (DeCuir-Gunby et al. 2011).

SRSSDL had internal consistency (Cadorin et al. 2011). In South Africa, Mentz and Van Zyl (2016) measured the SDL of 57 CAT first-year teachers' SDL and found that the SRSSDL is also reliable in the South African context with a Cronbach's alpha coefficient of 0.83. The validity and reliability Cronbach's score for this study is reported on in the findings of this study.

Qualitative data: The multiple-solution task questions

Data were also collected through an MSTQ task sheet containing five geometry problems. Three participants had to compute multiple solutions to the problems. A total of 13 solutions to these five problems were possible. These geometry problems were chosen because they bore the characteristic of many geometry problems – the ability to afford problem solvers the opportunity to compute multiple solutions.

Qualitative data: Semi-structured interviews

Interviews are the dominant tool for collecting qualitative data in social sciences research. They allowed the interviewer to probe participants' experiences that could not be revealed by psychometric tests or a problem-solving task. In this study, the semi-structured interviews allowed for a further probing of PSTs' experiences of computing multiple solutions to geometry problems in the module and the MST. Furthermore, the interviews also allowed me to capture participants' SDL experiences that might have been the result of engaging in the intervention. The interview data provided an extensive elaboration of the data collected by means of the SRSSDL and the MST.

Ethical issues

Permission to conduct the study was granted by the university where the study was conducted. Students signed a consent form, indicating their voluntary participation in completing the SRSSDL Questionnaire and also the semi-structured interviews. The consent form assured students that their identities would be protected through the use of pseudonyms, that they could discontinue their participation whenever they wished to do so and that withdrawal from the study would not affect them in any way. To ensure that participation in the study did not affect students' marks in the module, data (MSTQs and interviews) were collected after the module marks had been finalised.

Methods of data analysis

The data from the SRSSDL Questionnaire were analysed by obtaining the mean and standard deviation for each of the five SDL broad areas in the pre- and post-tests. Cohen's (1998) effect sizes were calculated to determine any practical significances of PSTs' responses between the pre-test and the post-test, with the cut-off points of 0.2 for low effect, 0.5 for medium effect and 0.8 for large effect. Even though the *p*-values of the SRSSDL Questionnaire were tabulated, I did not report any statistical significance of the intervention because a random sample was not selected. The *p*-values were included for the completeness of the findings. I transcribed, coded and analysed the interview data. The transcripts were analysed by looking for codes that represented characteristics of SDL, and these codes were grouped under different themes used to support the data from the SRSSDL Questionnaire. The qualitative instruments were triangulated to ensure the trustworthiness of the findings in this study. Furthermore, member checking and verbatim quotes from the participants were employed to support credibility and trustworthiness. I did not aim to generalise the findings, as the findings only reflect the experiences of the participants in the specific context in which the study was conducted.

Results

Here, I present findings from both the quantitative and qualitative data used to illuminate answers to the above-mentioned questions. These findings do not only reveal PSTs' experiences of computing multiple solutions to geometry problems but also reveal their SDL-related experiences before and after the intervention. I begin by analysing the quantitative data from the SRSSDL and then broaden the picture by including the qualitative data from the MSTQs and the semi-structured interviews.

Quantitative results from the self-rating scale for self-directed learning

A *dependent t-test* was conducted with the student data from the pre- and post-tests. Of the 32 students enrolled for the module, only 31 completed the pre-test, and 24 completed the post-test. As I conducted a *dependent t-test,* the pre-test data of the students who did not complete the post-test were excluded, reducing the sample size to 24 participants. Just as confirmed in previous findings that Williamson's SRSSDL Questionnaire has validity in different contexts, the questionnaire also showed that it was valid and reliable in the context of the current study with a Cronbach's alpha coefficient of 0.834. Statistical findings from the *dependent t-test* are represented in Table 9.1 to understand the effects of the intervention on students' SDL.

Table 9.1 reveals that the effect sizes of each SDL area range from no effect to small effects, with the overall score revealing no effect, meaning that the intervention did not have any practical significance for PSTs' SDL. However, if one compares the individual SDL areas, it is clear that the intervention did

TABLE 9.1: Comparison of pre-test and post-test for the participants in the self-rating scale for self-directed learning.

SDL areas	Pre-test (*n* = 24)		Post-test (*n* = 24)		Effect size	*p*
	Mean	SD	Mean	SD		
Awareness	48.82	6.42	46.96	7.66	0.24*	0.24
Learning strategies	45.46	8.35	45.86	6.70	0.05	0.78
Learning activities	44.83	10.11	45.27	7.43	0.04	0.78
Evaluation	49.04	7.47	46.78	7.23	0.30*	0.03
Interpersonal skills	46.88	8.17	47.42	6.64	0.07	0.64
Overall score	**235.05**	**36.80**	**232.26**	**32.30**	**0.08**	**0.58**

SDL, self-directed learning.
*Small effect.

TABLE 9.2: Participants' scoring in the self-rating scale for self-directed learning range.

Range	No of participant			
	Pre-test	%	Post-test	%
60–140	1	4.2	0	0
141–220	7	29.2	8	33.3
221–300	16	66.7	16	66.7
Total	24	100	24	100
Effect size	*0.471*			
p	*0.070*			

have a small practical significance for PSTs' *awareness* and *evaluation*. No practical significance can be attached to *learning strategies, learning activities* and *interpersonal skills* after the intervention. Thereafter, PSTs' responses were also divided according to the SRSSDL scoring categories of low (60–140), moderate (141–220) and high (221–300) to measure their level of SDL after the intervention. Table 9.2 represents the distribution of PSTs' scoring in the SRSSDL between the categories in the pre- and post-tests. The overall effect size between the categories shows that there was a movement of students between the categories.

In the low category, there was one student in the pre-test and none in the post-test; hence, no statistical analysis was performed in this category. Moreover, because of the small number of participants in each category in the pre- and post-tests, I could not perform the *dependent t-test*. Hence to determine the effect sizes of this sample size, I used the Wilcoxon signed-rank test. table 9.3 reveals that the mean scores for students with initially moderate SDL scores increased in four SDL areas except for *awareness* which remained with the same mean score. Furthermore, the effect sizes of these students reveal that the intervention had practical significances that range from small to large (table 9.3).

Table 9.3 reveals that there was a large improvement in PSTs' *interpersonal skills,* with medium practical significances for *learning strategies* and *learning activities*, indicating a high and medium practical significance of the intervention in these SDL areas. However, in this group of PSTs, there was a

TABLE 9.3: Comparison of pre- and post-test results for students with an initial moderate self-directed learning score in the Self-Rating Scale for Self-Directed Learning Questionnaire.

SDL areas	Awareness		Learning strategies		Learning activities		Evaluation		Interpersonal skills		Overall score	
(*n* = 7)	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Mean	43.57	43.57	38.11	41.57	38.00	42.88	43.00	43.85	39.57	44.43	202.32	216.32
SD	5.74	7.44	3.61	5.35	4.58	4.89	5.65	4.63	4.43	5.71	16.10	28.88
Effect size	0.10*		0.36**		0.39**		0.14*		0.54***		0.47**	

SDL, self-directed learning.
0.1*Small effect, 0.3**Medium effect, 0.5***Large effect.

TABLE 9.4: Comparison of pre- and post-test results for students with an initially high self-directed learning score in the Self-Rating Scale for Self-Directed Learning Questionnaire.

SDL areas	Awareness		Learning strategies		Learning activities		Evaluation		Interpersonal skills		Overall score	
(n = 16)	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Mean	51.60	49.19	50.02	48.42	49.68	47.64	52.69	49.43	51.69	49.94	255.38	244.56
SD	4.98	6.91	4.88	5.83	6.48	6.03	4.95	5.34	4.36	4.30	20.41	23.81
Effect size	0.28*		0.15*		0.29*		0.061***		0.30**		0.44**	

SDL, self-directed learning.
0.1*Small effect, 0.3**Medium effect, 0.5***Large effect.

small practical significant change for *awareness* and *evaluation.* Nonetheless, the overall impression from table 9.3 is that there was an increase in SDL for PSTs with initially moderate SDL scores after the intervention. Concerning PSTs who initially had high SDL scores, their mean scores (table 9.4) revealed a slight decrease in their SDL for all SDL areas. Despite this decrease, the intervention still showed some practical significance in the overall score of students with an initially high SDL score.

The mean scores (table 9.4) show that PSTs' post-test scores are lower than those of the pre-test. Pre-service student teachers with initially high SDL scores achieved lower scores in the post-test, which might be an indication that these PSTs may have over-rated themselves initially, or the intervention did not foster SDL. Similar results were obtained by Mentz and Van Zyl (2018), who found that cooperative learning does not improve the SDL of students with an initially high SDL score.

☐ Qualitative analysis: Pre-service student teachers' self-directed learning-related experiences

The interviews focused on asking participants questions that could reveal problem-solving skills relating to SDL. All three students who completed the MSTQs and engaged in the interviews were at initially moderate (P1 and P2) and initially high (P3) SDL levels. Upon analysing the interview transcripts, it was clear that students did possess some SDL-related skills in their problem-solving and learning. Here, I report on participants' general perceptions of engaging with MSTs, which links to the improvement of their SDL. All of the participants' responses indicated that, even though they pursued learning in order to pass, they took *the initiative to learn*. This was characterised by utterances such as 'I always aspire to learn something new, … learning something new means I would have to go beyond my limits' (P3, student teacher, 21 Oct. 2020), and they indicated that engagement with MSTs *motivated* them to take the *initiative to look for more information*:

> 'I always aspire to learn something new and also retain the knowledge that I learnt in the past. So I have got time to make for quick revision of the thing I have done in the past and then read something after that, either read something new or practice something new.' (P3, student teacher, 21 Oct. 2020)

> 'It's an initiative that I have to take, I have to choose and say I need to learn then I learn, … especially if you look at the conditions that we are in today, it is now self-directed learning, you just have to do most of the things by yourself.' (P2, student teacher, 19 Oct. 2020)

> 'I enjoy learning new things. So, alternatively, learning something new means I would have to go beyond my limits, I'll have to then learn new information and go looking for information.' (P3, student teacher, 21 Oct. 2020)

The above findings directly relate to SDL, as they reveal that engaging in MSTs problem-solving motivated students to take initiative for their own learning. P3 with an initially high SDL score displayed more elements of taking initiative for learning as compared to P1 and P2, with an initially moderate SDL score. Furthermore, participants revealed that engaging MSTs problem-solving allowed them to take the initiative to look for more information whenever they got stuck in finding solutions. They indicated that they consulted both human and material learning resources:

> 'I used the keywords when I searched in the searching engine. Secondly, I sometimes Google the main topic, … I try my ways maybe the textbook and find other problems that are related to the problem that I have, … I go to research now, I need to do my research may be on the Internet, find a problem that is related to that problem, … It will force me to consult now, on my peers, or anybody because now I cannot do it myself, but I want to have the solutions of the problem.' (P2, student teacher, 19 Oct. 2020)

> 'I look for keywords that I can look up, either on YouTube or over the Internet so I could actually grasp elements that could connect me to the solving of the problem, … In that case I will actually consult either my peers, if I don't find help, then I will consult somebody who is superior, meaning somebody that is a teacher to me.' (P3, student teacher, 21 Oct. 2020)

> 'I checked the textbook … I attempted to give it to another colleague of mine….' (P1, student teacher, 14 Oct. 2020)

Another important finding from the participants pertaining to their SDL is that the lack of material resources, such as a stable Internet connection and access to computers, may hinder their learning, according to P2:

> 'I think the only thing that I can change is the financial constraints, Internet connection, gadgets, and all that needs to be improved like a stable Internet connection. You find

> that you are reading a certain article and then they reference another person, you need the Internet and a laptop to search for it and try to understand it.' (P2, student teacher, 19 Oct. 2020)

Hence, even though the engagement with MSTs can motivate students to take the initiative look for more information, the lack of such resources may be a hindrance to their learning. What was also evident from their utterances was that they looked for information for different reasons: P1 mentioned that he looks for more information in order to boast to his fellow students that he had learnt something that they did not know; P2, on the other hand, seemed to be looking for more information because he was stuck; and P3 looked for more information because he enjoyed learning:

> 'Indeed. It motivated me because I feel so superior on my other colleagues and friends … I feel like I have learned something, which they didn't know. So I can say I was boasting and bragging that I have learned something.' (P1, student teacher, 14 Oct. 2020)

> 'If I am working with a problem and … I get stuck I am forced to go out and research, if I try to research and I do not find anything, then I need to consult from my peers, maybe my lecturers or my peers have seen that problem…' (P2, student teacher, 19 Oct. 2020)

> 'I enjoy learning new things. So alternatively learning something new means I would have to go beyond my limits, I will have to then learn new information go looking for information, so yes, doing multiple solutions problems gave me a hustle, pushed me to go and learn a bit more.' (P3, student teacher, 21 Oct. 2020)

Even though these participants were motivated by different reasons to study further, the most noticeable SDL-related observation is that they were indeed *motivated* to learn more instead of giving up when they faced unfamiliar problems. In addition to motivation, P3 indicated *resilience* in his learning as he stated that:

> 'I hate comfort, simple put, and giving up is a sign of being comfortable with what you know and you don't want to learn something else. So I won't be the type to give up, I rather push until I reach a breaking point and I know that by the time I reach the breaking point it means I am very close to finding whatever that I need.' (P3, student teacher, 21 Oct. 2020)

Furthermore, P3 indicated that his learning was not centred on examination but to prepare himself for the unforeseeable future, while the other participants (P1 and P2) were clear that they learnt for the examination. This confirms the findings from the SRSSDL Questionnaire that P3 had a much higher perceived SDL compared to P1 and P2:

> 'I will partially listen to it but if it is not for examination purposes, no … well, we are learning for examination, we are learning for grading.' (P1, student teacher, 14 Oct. 2020)

> 'I would rather focus on the topic that would be examinable.' (P2, student teacher, 19 Oct. 2020)

> 'I will make sure that I concentrate as much as I can in order to learn what I have to learn because I believe that even though it is not examinable now, chances are during my teaching years I might need to use that kind of a skill.' (P3, student teacher, 21 Oct. 2020)

However, P3 further indicated a struggle with *self-management* of his learning – he struggled to manage time for learning and other activities:

> 'Yes, I am happy with the pattern that I am using to study, but one thing that I need to work on is maximizing on the time, I tend to get a bit distracted and the distraction end up taking more time, so maximizing on the amount of time that I have given myself so that I could be effective in the next session.' (P3, student teacher, 21 Oct. 2020)

I want to conclude this section by giving a synopsis of PSTs' experiences that were not related to SDL, most of which were visible in the utterances of P1 and P2, visibly with an initially moderate SDL score. These experiences represent utterances that show that in particular elements of their learning, P1 and P2 were not self-directed at all, while P3 exuded SDL all round. When asked how he approached unfamiliar problems, P1 said, 'if I don't have a hint about it, I will check the follow-up question' (P1, student teacher, 14 Oct. 2020), which were signs of 'giving up' whenever he encountered a difficult problem. In contrast, P2 seemed not to have recognised lack of knowledge as a learning opportunity; instead, whenever he solved unfamiliar problems, he preferred to start with what he knew about the problem. When asked why he did not start with what he did not know, P2 mentioned that, 'if I start with what I don't [know], I am stuck because what I don't know, I don't know' (P2, student teacher, 19 Oct. 2020). He was clear that his theoretical belief about learning was that it started with prior knowledge: '...because I normally have this belief that learning start from what you know, from your previous experiences' (P2, student teacher, 19 Oct. 2020). There was also evidence the P2 was scared of challenges and wanted to stay in his comfort zone from his utterance: 'I will look at the concept, if it's so complex, I would avoid it, but if it is easy to complement then I will learn it' (P2, student teacher, 19 Oct. 2020). Furthermore, statements such as 'we are learning for examination, we are learning for grading, like marks' (P1, student teacher, 19 Oct. 2020), 'I would rather focus on the topic that would be examinable' (P2, student teacher, 19 Oct. 2020) and 'I want to get the final answer, I want to solve it, that's the main thing' (P1, student teacher, 14 Oct. 2020) show that P1 and P2 were still concerned about getting correct answers, examinations and their grades even after the intervention. This may mean that they might have thought that they were self-directed in their learning, but when they encountered problems, they still reverted to their problem-solving methods that showed no self-direction in learning. These experiences of P1 and P2 are in line with the current view that teaching and learning in schools and universities still follow the traditional approach of focusing on examinations and grades instead of learning (Aldridge, Fraser & Sabela 2004; Ogbuehi & Fraser 2007).

Pre-service student teachers' experiences of computing multiple solutions to geometry problems

The selected three participants were given five MSTs to solve and were given 30 days to submit, which they all did. The solutions to these problems relied mainly on participants' geometry knowledge and their problem-solving strategies. Participants either solved the problem correctly, incorrectly or did not make an attempt to solve the problem. Table 9.5 summarises the number of solutions obtained from participants' responses in the MSTQs after the intervention. From Table 9.5, it is clear that P1 and P2 were not able to compute all the possible solutions to these MSTs, while P3 was able to find all the solutions. There was evidence of participants who were able to obtain one solution instead of two or three as the MSTQ required. This is an indication that, even though these participants (P1 and P2) were able to find solutions to these geometry problems, they were not competent enough to find alternative solutions.

P3, with an initially high SDL, was able to find all the solutions to the problems, while P1 and P2 with an initially moderate SDL were not able to find all the solutions (Table 9.5), which is evidence that PSTs' self-directedness in learning has an effect on their multiple solutions problem-solving. As is evident from the qualitative SDL-related experiences of the participants, P3 seemed more self-directed in his learning compared to P1 and P2, and his submission of the MSTQ solutions indicated that he was able to obtain all the multiple solutions to the MSTs. As observed from P1's responses, he attempted to solve problem 2, but admitted in his solution that there was 'no way forward' [P1, student teacher, 14 Oct. 2020] and that his solution was 'wrong' [P1, student teacher, 14 Oct. 2020] (Figure 9.1). When asked about this during the interview, P1 indicated that he could not relate the two circles even though he knew one theorem:

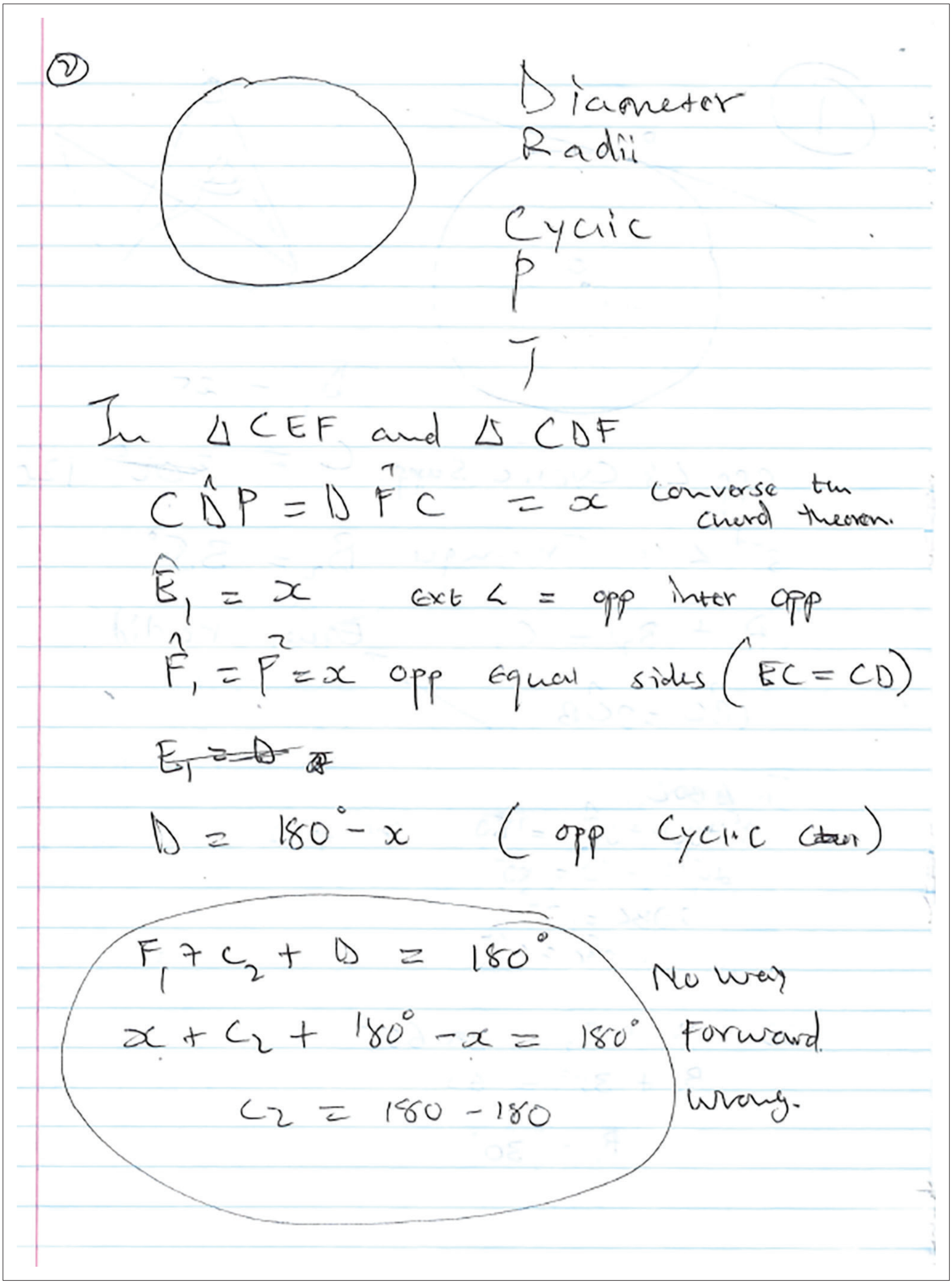
> 'I knew how to use the information of the first circle. The circle which is having points on the circumference which is E C F D. ... Then the second circle, the one that is having A E F and B, I couldn't use it to relate to the information given, that was the main problem.' (P1, student teacher, 14 Oct. 2020)

Further questioning revealed that P2 had limited knowledge of cyclic quadrilateral theorems, as his focus was on one theorem instead of the other theorems and corollaries.

TABLE 9.5: Number of solutions obtained by participants per problem.

Participant	Problem 1	Problem 2	Problem 3.1	Problem 3.2	Problem 4	Problem 5
P1	1	0	2	No attempt	No attempt	No attempt
P2	2	2	1	No attempt	1	1
P3	2	2	2	2	2	3

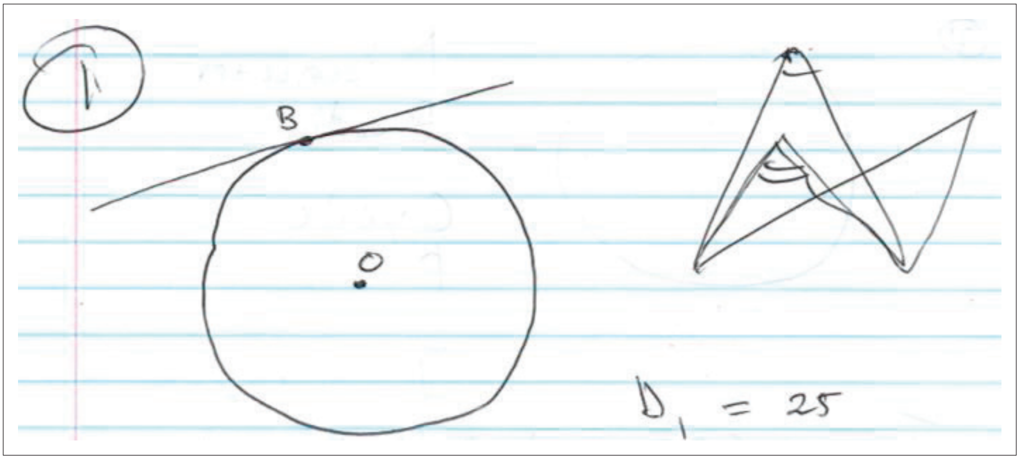
0, attempt but no correct solution; 1, one solution; 2, two solutions; 3, three solutions.



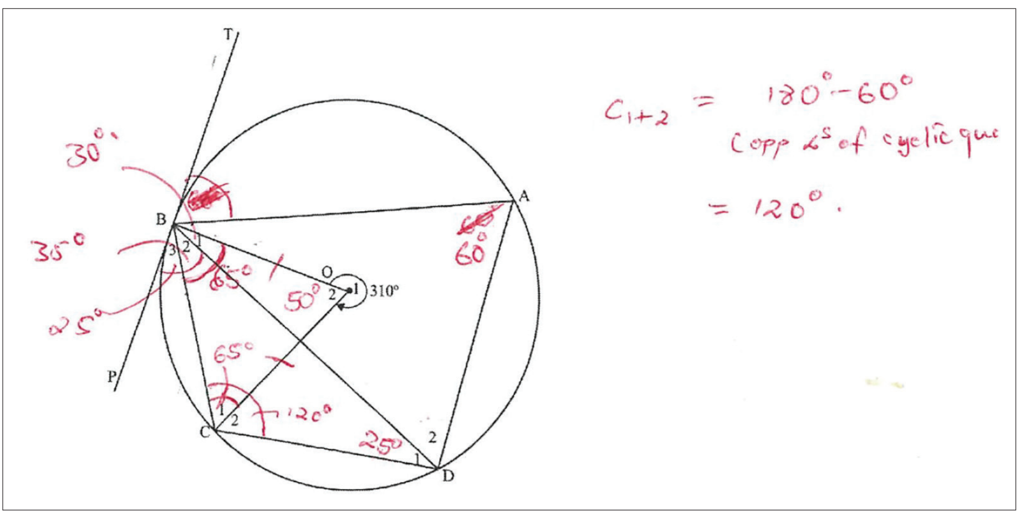
Source: Scan of participant P1's Response to a question, scanned by Sfiso Mahlaba, published with permission from participant P1.

FIGURE 9.1: P1's Response to question 2 in the multiple-solutions task questions.

The use of visual representations also seemed dominant in P1 and P2's responses as they, in most cases, attempted to represent the geometrical theorems separately or even use colour-coding to visualise the geometrical theorems individually (Figure 9.2 and Figure 9.3). This mnemonic of spatio-graphic thinking is one important factor of developing geometrical thinking and problem-solving (Watson, Jones & Pratt 2013), but these students had not developed that geometry problem-solving knowledge because even though they used it, they could not find the multiple solutions to all the geometry problems.



Source: Scan of participant P1's Response to a question, scanned by Sfiso Mahlaba, published with permission from participant P1.
FIGURE 9.2: Visual representations in finding the solutions by P1.



Source: Scan of participant P2's Response to a question, scanned by Sfiso Mahlaba, published with permission from participant P2.
FIGURE 9.3: Visual representations in finding the solutions by P2.

What is interesting is that P1 was able to find at least one solution where he used a mnemonic, but he could not find the solutions to the problems where he did not use a mnemonic. This grounded P1's mathematical problem-solving on the usage of mnemonics and procedures; if he could not remember the mnemonic or the procedure, he could not solve the problem. This was also evident in his utterances, saying that 'I think if we can be given a method that if you are having this type of question, follow this method, and if you are having this type of question follow that method' (P1, student teacher, 14 Oct. 2020).

In contrast, P2 filled information on the diagram and used colours to differentiate between different shapes in the given diagram for visualisation as a problem-solving strategy. P2 mentioned that 'I fill the diagram with as much information as I can before I can even look at the question' (P2, student teacher, 19 Oct. 2020), which is symptomatic of looking for a certain procedure to solve the problem and an attempt to remain within his comfort zone. This shows that, even though P1 and P2 were able to find some solutions to the geometry problems, they were not competent enough in their problem-solving strategies to solve geometry problems. What differentiates P3 from P1 and P2 is that his approach to problem-solving, though systematic, was supported by valid reasons of why certain routes were taken. He mentioned that:

> 'The method I normally use is to deconstruct the question, break it into smaller pieces and see if I can relate it to anything that I have learnt prior and the reason I do that is because I have noticed that breaking things down into smaller pieces helps to actually find solutions to the bigger picture because these smaller pictures have linkages on how to find the solution to the bigger picture.' (P3, student teacher, 21 Oct. 2020)

Willingness to produce multiple solutions to mathematical problems can also be related to SDL, as it depends on the goal for such action. When asked if they would produce multiple solutions to mathematical problems, the PSTs had different answers. P2 and P3 were clear that they would produce multiple solutions to mathematical problems if they were not restricted to time, like in an examination. P2 indicated with conviction that '… definitely. It shows understanding. Because, it really shows that you really understand what you are talking about, you are representing it in different ways and with valid reasons why it can be done in this way and that way' [P2, student teacher, 19 Oct. 2020]. He was, however, clear that he would not produce multiple solutions in the examination because of the focus on marks and the time limitation: 'no, you cannot do that in an examination… because the examination is about marks and time' (P2, student teacher, 19 Oct. 2020). P3 mentioned that 'in a context where I am not limited to time I would do that, to show that this problem has more than one solution' (P3, student teacher, 21 Oct. 2020). P3's non-production of multiple solutions in the examination was only hindered by time, while P2 also drew attention to the concentration on grading. P2's focus on the marks was similar to that of P1, who was clear that he would not produce multiple solutions to mathematical problems if they were not to be marked:

> 'If they say extended and say we are going to mark them and select the one that you got more marks on, rather than saying we mark the first one, if you got two in the second one if you get one, we are going to select like the second one, because you've got more marks there, I will produce as many as I can.' (P1, student teacher, 14 Oct. 2020)

He lamented that his past educational experiences have discouraged him to search for multiple solutions because his teachers always marked the first attempt and ignored the other attempts instead of marking the correct attempt. He mentioned that: 'We are discouraged to do that. At a young age, I used to attempt questions differently, the teacher will say I will mark the first solution.' (P1, student teacher, 14 Oct. 2020). On account of their experiences of producing multiple solutions, PSTs felt that it was a good experience, even though P2 indicated that he felt like he was doing the same thing in different ways. Table 9.5 shows that P2 was able to find most solutions to the problems but could not find the alternative solutions because of feeling like he was doing the same thing differently:

> 'It was a good experience (to produce multiple solutions). But if you look at those other problems that have one solution, sometimes you can claim to say we have two solutions but rather you still have that same solution and you have written it in different ways. Because to have different solutions you might have rewritten it in a different way using the same theorems.' (P2, student teacher, 19 Oct. 2020)

This is an indication of various things: (1) P2 still lacked problem-solving strategies for geometry and the 'control' to choose useful actions that could help in finding the solutions, (2) P2 might still have lacked understanding of multiple solutions, and (3) he was not self-directed enough to take the initiative to learn more about what multiple solutions meant and only read what was provided during the module. P3 also mentioned that finding multiple solutions to geometry problems was a good experience, as it motivated him to learn more about geometry knowledge that was helpful for him finding the solutions to the given problems. He mentioned that:

> 'It was a thrilling experience, because it pushed me to get a much greater understanding of corollary theorems, I had to understand those because I was not that big on them, so it pushed me to learn more about them and how to use them, and also it became an eye opener on a lot of things that I had actually forgotten, so it pushed me to learn more or re-learn some of the things that I have actually done.' (P3, student teacher, 21 Oct. 2020)

Furthermore, P3 mentioned that, besides exploring the different ways in which the problem could be solved, he would show learners multiple solutions to provide them with different ways of solving mathematical problems:

> 'To basically explore different ways in which the problem can be solved and I would do it to show the learners that they should not be restricted to one way or one method of finding the solution.' (P3, student teacher, 21 Oct. 2020)

The production of multiple solutions to mathematical problems is also believed to open up opportunities to solve the problems in an easier way, as explained earlier by P2. P3 also reiterated:

> 'The more I do something, the more it opens up easier ways of doing it. For example, if I can get a trigonometry sum that required me to prove something and I didn't know compound angles I would go the longer route but if I knew compound angles I would just employ a new concept of compound angles to that to help me to shorten the steps of the solution, and not only will I have two solutions because of that now, I would have the first one that would be the long route, I would have the second one that uses compound angles. So it gives me two things, which means that I have learnt something new and I have managed to find a new way of doing it.' (P3, student teacher, 21 Oct. 2020)

From the findings in the MSTQs task sheets and the interviews, it is clear that P3 found more solutions compared to P1 and P2, which implies that his geometry problem-solving competency was much more advanced compared to the other participants. Furthermore, this analysis shows that P3 was more self-directed in his learning compared to P1 and P2, which concurs with the earlier findings from the quantitative measurement of SDL. Hence, it can be concluded that the more self-directed PSTs are, the more competent they are in their problem-solving.

Discussion

This section addresses the research questions posed earlier in this chapter. It provides relative answers to the questions based on findings from the participants. The questions addressed in the section are:

- How does solving MSTs in a remote learning environment display teacher competency in geometry problem-solving?
- What are the self-directed benefits of computing multiple solutions to geometry problems in a remote learning environment for pre-service mathematics teachers?

These questions are addressed based on the findings from the quantitative and qualitative investigations conducted in this study.

Self-directed learning-related experiences of engaging with multiple-solution tasks

The findings from Williamson's SRSSDL Questionnaire show that there was a large amount of student movement between different SDL ranges from initially moderate to high perceived SDL and vice versa (Table 9.2). Overall, the intervention did not improve students' SDL but did have a small practical significance in their awareness and evaluation SDL areas (Table 9.1). This means that, after the intervention, students became more aware of the factors that contributed to their SDL and were more aware of strategies to use in order to monitor their learning (Williamson 2007). Table 9.3 shows that the intervention did have small to large practical significance for students with an initially moderate SDL score, while Table 9.4 shows that the intervention did not have much significance for students with an initially high SDL score, but it did have some practical significance in some SDL areas, which still resulted in lower SDL in the post-test. This is not only evident in the effect sizes of the SDL areas between the two group ranges but also in the increase in the mean scores of the initially moderate group (Table 9.3) and the decrease in the mean scores of the initially high group (Table 9.4). Unlike the results from Rezaee and Mosalanejad (2015), the results obtained from this study are similar to those obtained by Havenga (2016) and Mentz and Van Zyl (2018) which show that interventions improved the SDL scores of students with an initially moderate SDL score and did not have an effect on the SDL of students with an initially high SDL score. This can be attributed to the fact that students who already have a high SDL score would take the initiative to ensure that they get all the solutions to mathematical problems and learn more, as seen in the case of P3, who in his interview responses was evidently more self-directed than the other two participants. Hence, the intervention compelling students with high SDL (P3) to produce multiple solutions does not influence them to produce multiple solutions, because they are always ready to take any learning challenge that requires them to learn more about mathematical problem-solving. It can be concluded then that the introduction of MSTs does not affect the SDL of students with high SDL scores but does affect students with moderate SDL scores. In fact, problem-solving and SDL are indispensable and are continually supporting each other (Lin et al. 2019).

The SDL-related benefits of engaging in intervention, as evident from PSTs' participation in the interviews, can be summarised as follows:

- Students took the initiative for their learning by looking for more information to help them find multiple solutions.
- They became more motivated to learn more because they wanted to find multiple solutions.
- They took the initiative to locate both human and material learning resources whenever they were stuck in a particular problem.
- P3 indicated that, even though it was not a requirement in CAPS to produce multiple solutions, he did teach his learners (during WIL) multiple solutions to give them different options for solving mathematical problems.
- The engagement in the intervention also revealed that the student measuring high on SDL showed resilience and grit in his learning by ensuring that he kept on trying until he found all the different solutions to geometry problems.

A recent study positioning SDL as a 21st-century skill claimed that teaching and learning should focus on developing students' SDL so they can move away from eyeing the product to valuing the learning process (Du Toit-Brits & Blignaut 2019). This means that students like P1 who focused on finding the solution to a problem instead of learning should be guided to value individual learning like P3.

Teacher competency in solving geometry problems

Schoenfeld (1994) argued that students should work on problems that would introduce them to mathematical thinking. He (Schoenfeld 1994) described four properties of the problems that can serve this purpose, one of which is quoted below:

> For many reasons, I tend to prefer problems that can be solved, or at least approached, in a number of ways. It's good for students to see multiple solutions, since they tend to think, on the basis of prior knowledge, that there is only one way to solve any given problem (which is usually the method the teacher has just demonstrated in class). I need for them to understand that the 'bottom line' is not just getting the answer but seeing the connections. Moreover, on the process level, the possibility of multiple approaches lays open issues of executive decisions – what directions or approaches should we pursue when solving problems, and why? (p. 69)

Here, Schoenfeld characterised MSTs as the foundation of developing students' mathematical thinking. Most of these characteristics were visible in the data from this study. With reference to Table 9.5, it can be concluded that P3 had a high geometry problem-solving competency after the intervention compared to P1 and P2. This is evident in the fact that P3 was able to find all the multiple solutions required in the MSTQs. It can be concluded then that the intervention does affect the geometry problem-solving competency of some students, especially those with an initially high perceived SDL. The findings from the MSTQs and the interviews further aligned with the findings from Sim and Oh (2012), who found that SDL-related qualities have the ability to improve mathematical problem-solving. Even though students who had an initially moderate SDL score increased their SDL more than the students with an initially high SDL score, they still could not find all the multiple solutions to the problems in the MSTQs. Despite these findings, Guberman and Leikin (2013) revealed that the employment of MSTs could improve problem-solving ability in both low- and high-achieving students. The high SDL level and problem-solving competency of P3 influenced his teaching choices during WIL, as he indicated that he was able to integrate multiple solutions when teaching fractions to his Grade 8 learners. This finding implies that teachers' high perceived SDL level in conjunction with high competency in problem-solving can influence teachers to guide learners in finding multiple solutions to mathematical problems.

Some level of low problem-solving competency in students with initially moderate SDL scores was evident in P1 admitting that he was 'stuck' and there was no way forward in his solution (figure 9.1). Visualisation skills have long been deemed critical in solving mathematical problems (Bansilala & Naidoo 2012; Bishop 1989), and this significance was seen in this study when P1 admitted that he could not relate the two circles in problem 2. Furthermore, to signify the role of visualisation during problem-solving, P2 used colouring (figure 9.3) to visualise theorems during problem-solving. Tutak and Adams (2017) have shown that the lack of geometry CK in pre-service mathematics teachers can hinder their abilities to solve geometry problems, as seen on the part of P1. Furthermore, what was evident from P1 and P2 was the use of mnemonics to remember theorems (Figure 9.2 and Figure 9.3). Even though these participants were able to identify the theorems, either by using colour-coding, filling information in the diagram or drawing a visual that represented the theorems, they could still not find all the solutions required in the MSTQs. These PSTs still approached mathematical problem-solving through the procedural approach. P1 even mentioned: 'I think, uh, it is the procedure that, eh, Euclidean geometry was introduced to us. That's the problem, eh, they only taught us to solve using procedure and less application' (P1, student teacher, 14 Oct. 2020). This shows that, even after the intervention, his procedural approach to mathematical problem-solving was still the preferable method for problem-solving, and whenever procedures failed, he was always stuck (figure 9.1). Participants knew the benefits of producing multiple solutions, for example, they stated that producing multiple solutions showed that one had a deep understanding of the content, problem-solving strategies and also gave learners options of methods to use when solving mathematical problems. In this regard, Silver (1997) asserted that, through the use of MSTs, teachers can enable learners to discover their potential creativity and enhance learners' mathematical problem-solving. In conceptualising a theoretical framework for assessing problem-solving, Schoenfeld (1985) observed that the beliefs one holds about the nature of mathematics can affect one's problem-solving. Relating this theoretical framework to the current study, it is clear that P2's inability to find multiple solutions to most of the problems was triggered by his beliefs about problem-solving and mathematical learning.

Hence, engaging in the intervention revealed students' geometry problem-solving competency through their abilities to provide multiple solutions to the posed problems. Participants who could solve the problems, for example, find at least one solution to the problem, show that they had a complete understanding of geometry and could solve geometry problems; however, their competency was low compared to students who could find multiple solutions to geometry problems. The mathematical challenge provided by the requirement of multiple solutions in the teaching and learning of mathematics is critical for the learning process (Guberman & Leikin 2013), and being able to solve mathematical tasks in different ways is a sign of achieving competency in problem-solving (Polya 1973). Furthermore, the production of multiple solutions to mathematical problems represents a competency in divergent thinking that allows students to communicate their original mathematical ideas and problem-solving strategies during problem-solving. Hence, engaging in the production of multiple solutions to mathematical problems does not only reveal competency in problem-solving but also reveal resilience in learning. Multiple-solution tasks have also been shown that they can be useful in improving the development of mathematics teachers' knowledge and also their knowledge for teaching and learning (Leikin & Levav-Waynberg 2008) and in geometry specifically (Leikin & Levav-Waynberg 2012).

Limitations and recommendations

One of the limitations of the current study is the duration of the intervention. It was very unfortunate that the intervention could not be extended beyond the 12-week period because of the limitations on the duration of the course in which the intervention was implemented. A longer engagement with MSTs might have influenced PSTs' problem-solving, as Schoenfeld (1994) described that problem-solving enriches the longer one engages in it. Furthermore, a larger sample from a variety of contexts might have enriched the data obtained and provided a better understanding of PSTs' SDL. As I purposely sampled participants for the interviews, I could not capture all the problem-solving experiences of the PSTs. The findings of this study are thus not generalisable to the larger population. This means that further research in different contexts is required to ensure the generalisability and transferability of the findings.

There is a need for further research to understand the specific SDL characteristics of students with high SDL that allowed them (P3) to obtain multiple solutions in all the problems in the MSTQs. Furthermore, the lack of empirical research on the usefulness of MSTs in the teaching and learning of mathematics in both basic education and HE in South Africa is of concern. The numerous benefits of MSTs highlighted by research in different countries mean that this practice is useful in mathematics education and should be engaged with in South African education. I recommend that a study be conducted with a much larger population from different contexts where more students would be involved in the completion of MSTQs and participate in interviews to provide a broader understanding of the relationship between engaging in MSTs and mathematical problem-solving. It is clear from the findings that engaging in the intervention had some factors that affected students' SDL, but given the small scale of this study, it was difficult to pinpoint these factors and reach a generalisable stance of the findings. Nonetheless, the increase in students' SDL could not be attributed to the intervention only, as it was clear in the case of P1, P2 and P3 that some personal attributes contributed to their production of multiple solutions to mathematical problems.

Conclusion

In this chapter, I explored the effects of engaging in the production of multiple solutions to Euclidean geometry problems on students' SDL. Furthermore, I explored how engagement in this intervention revealed students' competency in solving geometry problems. The findings show that the intervention did not have a practical significance for students' SDL but it was able to increase the SDL of students with an initially moderate SDL score. This increase in the SDL scores of the students with initially moderate SDL scores after engaging in the intervention can be of educational importance in the teaching and learning of mathematics. This means that, after the intervention, students with an initially moderate perceived SDL were a little aware of the factors contributing to their development of SDL qualities and they were in a position to monitor their learning activities (Williamson 2007). However, students with an initially high perceived SDL score achieved lower scores in the post-test, which might be an indication that they over-rated themselves in the pre-test, but after the intervention, it became clear that their initial scores were not reflecting their true level of SDL. This means one of two things: first, the students thought they were self-directed prior the intervention, but when confronted with the intervention that required more self-direction, they realised that they were not quite as self-directed as they thought they were before the intervention; second, the activity of producing multiple solutions to mathematical problems may have not appealed to these students' SDL as expected. Findings from the interviews indicated that some characteristics of SDL were influenced by the intervention and also individual personal attributes. The findings from the MSTQs task sheets indicated that students with an initially high perceived SDL were more competent in finding multiple solutions (P3) to geometry problems compared to those with an initially moderate perceived SDL (P1 and P2). Furthermore, P3 was clear about his motivation to learn instead of obtaining good results (P1 and P2). He succinctly explained his problem of time management when he started to look for more information and resources as he dug deeper into his learning. It is clear that P3 had much love for learning, and his inquisitiveness was clear compared to P1 and P2, who were concerned only with their grades. In this study, P3 was a typical SDL learner because he took full responsibility for his learning, while P1 and P2 only followed the instructions from the facilitator to obtain good marks without seeing the real benefits of searching for multiple solutions.

Even though they engaged in the intervention, P1 and P2 still focused on assessment and marks. The overall findings indicate that MSTs can be a strategy that can be used to advance the SDL of students with an initially moderate SDL and also reveal students' competency in geometry problems for those with an initially high perceived SDL.

Chapter 10

Being, becoming and belonging: The ethnosemantic structure of folk arithmetic of street vendors as self-directed learners

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Abstract

The comparison of oral and written arithmetic practices in informal and formal contexts indicates a need to search for ways of analysing cognitive performance in the context of self-directed problem-solving in order to capture such

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complex phenomena not so far explored in the literature. In particular, studies of the effects of unschooling on cognitive development have resulted in the idea that school concepts and everyday concepts developed through unschooled self-directed strategies may not be the same. With respect to street and school mathematics, research has identified important differences in the type of representation used; street mathematics is self-directed and oral and preserves much of the meaning of the situation at hand, whereas mathematical practice in school is written and drill-oriented and strives for generality. This chapter examines whether the acquisition of numeracy using self-directed approaches and engagement in specific numeracy practices in workplace settings differentially modifies the type of representation in groups of street vendors and illiterate adults living in non-symbolic cultural contexts. The ethnosemantic analysis of vending practices presented focuses on the structure of logical relationships and the underlying complex computations inherent in a folk system of arithmetic that have been developed and appropriated by semi-illiterate street vendors in a self-directed manner.

Introduction

Global concerns about student achievement in schools have been overwhelmingly daunting. With the devastating effect of COVID-19 pandemic on multiple sectors of the world's wealth early in 2020, urgent measures to respond both to the immediate health crisis and to the severe economic, social and financial challenges had to be put in place to absorb and mitigate the massive human and economic devastation across the world. Education in particular succumbed to monumental struggles that demanded every resource and every effort to intensify its interventions. Part of several multi-faceted responses to address educational shortcomings because of the COVID-19 pandemic has been to resort to remote teaching and learning, which in turn compounded the problem as students as well as teachers struggled to navigate the online space. Specifically, in mathematics, unprecedented challenges in online delivery of instruction have emerged rendering success in acquiring basic competences almost impossible (Aldon et al. 2021; Carius 2020). As such, the focus of mathematics learning shifted towards capacitating learners with the necessary critical and reflective skills to be autonomous and assume ownership of their learning. This view of learning closely mimics the apprenticeship model of instruction that is embedded in engaged and networked communities of practice most commonly prevalent outside of formal school settings.

A good deal of studies investigated the multiplicity of ways in which mathematical concepts are acquired outside of school contexts by virtually appealing to research on the social construction of mathematical knowledge and problem-solving activity (Aguirre, Mayfield-Ingram & Martin 2013; Brandt & Chernoff 2014; Chahine & De Beer 2020; Chahine & Kinuthia 2019; Naresh & Chahine 2013). More concisely, I refer to the works of two groups of researchers, those interested in 'cognition in practice' or 'every day cognition' and those involved in ethnomathematics in an attempt to provide evidence that mathematical knowledge is situated, embodied and highly contextualised (Chahine 2013). Such research describes mathematical ideas that emerge in out of school mathematics as self-directed and created through negotiation of meaning in different cultures and communities to address everyday life challenges. At the heart of the evidence provided by this research is the role of schooling and the possibility of transfer of formal mathematics to out-of-school situations.

A renewed interest in research related to the significance of multicultural mathematics has been revitalised by considerable theoretical and methodological advancements in SDL approaches characteristic of non-formal settings or what is also known as autodidaxy (Popovic 2012). Caffarella (1993) recognised SDL as a self-initiated process where the learner is autonomous in managing their own activity. Such a perspective places an increased emphasis on a strong sense of responsibility, an intrinsic need for self-actualisation and immediate problem-solving skills, traits that are typical of workplace environments. For example, in studying the arithmetic of Liberian tailors, Reed and Lave (1981) found two inherently different modalities of doing mathematics. Tailors with no schooling experience employed a quantitative approach that emphasises a contextualised restructuring of quantities, which is conducted orally. Contrastingly, the schooled tailors used symbol-based computations that are more abstract and devoid of any context. Such different modes of doing arithmetic may be employed by the same individuals, especially if they use mathematics in everyday work settings (Nunes et al. 1993). Arguably, investigating the informal arithmetic procedures acquired through self-directed problem-solving in out of school settings, that is, the computational strategies that people use in solving word problems that require additive and multiplicative principles constitute the impetus for exploring empirical evidence for the manifestation of everyday cognition in real-life settings. Matang and Owen (2014) argued that arithmetic is a very simple aspect of mathematics. Furthermore, quantitative reasoning, while closely linked to real-life experiences, it is also part of mathematics as an abstract and formal body of knowledge (Schulz 2018). In contrast, Lave and Wenger (1990:6) contended that one of the several reasons for focusing on arithmetic was that 'arithmetic activity has formal properties, which makes it identifiable in the flow of experience in many different situations' and Lave (1988:5) explained that 'it (arithmetic) has a highly structured and incorrigible lexicon, easily recognizable in the course of ongoing activity' (cf. Brown, Collins & Duguid 1989:35).

Problem statement

The overarching aim of this chapter is to examine whether the acquisition of numeracy using self-directed approaches and the engagement in specific numeracy practices in workplace settings differentially modify each type of representation in groups of young street vendors and illiterate adults living in non-symbolic cultural contexts. The ethnosemantic analysis of vending practices I present focuses on the structure of logical relationships and the underlying complex computations inherent in a folk system of arithmetic that have been developed and appropriated by semi-illiterate street vendors in a self-directed manner.

Literature review

A good deal of studies investigated the multiplicity of ways in which mathematical knowledge is acquired outside of school settings (cf. inter al. Ndlovu & Nyoni 2010:110). In studying the numerical computations of Liberian tailors, Reed and Lave (1981) proposed that there were two qualitatively different modes of doing arithmetic. One approach focuses on a contextualised use of numbers as non-symbolic semantic representations emblematic of quantities, which we encounter in real-life settings while the other perceives of numbers as symbolic syntactic modalities that are generalised across functionalities and settings, a perspective most commonly prevalent in schools (Zebian & Ansari 2012). Nunes et al. (1991) argued that schooled practitioners who employ mathematical ideas in the workplace, especially in low-tech jobs, often resort to using a combination of symbolic and non-symbolic representations in computational arithmetic. If so, it may be useful then to describe and compare the uses of mathematics by the same group in the context-based (informal) and school-based (formal) settings.

Empirical evidence comparing informal and formal procedures in arithmetic have indicated that there are often multiple systems of arithmetic in the same culture, one related to the school culture and one that flourishes outside school. Saxe (1991), for example, identified two types of arithmetic practices among the Oksapmin in Papua New Guinea. One of these is based on the indigenous numeration system that uses body-part names as number labels. Both unschooled adults, particularly those involved in trading, and school children were observed to use the body-part system in arithmetic problem-solving despite the fact that school children received formal instruction on how to solve arithmetic problems using Western algorithms from teachers who did not know the Oksapmin language and numeration system. Similar observations were obtained by Ginsburg (1988) who studied arithmetic problem-solving among two groups in the Ivory Coast: one group, the Dioula, was involved in commercial activities; the other, the Baoule, worked in agriculture. Ginsburg expected these groups to have different needs and thus different levels of practice for arithmetic problem-solving. He observed that the unschooled children in the merchant group displayed more efficient arithmetic procedures than their agriculturist counter parts. With schooling, both groups tended to adopt written arithmetic procedures.

Arguably, the distinction between informal and formal computations in the context of arithmetic operations is necessary for several reasons. D'Ambrosio (2002) contended that arithmetic is an inherently basic branch of mathematics. Also, quantitative reasoning underlies and governs everyday practices (Nunes et al. 1993). In contrast, Lave et al. (1984, cited in Millroy 1992:6) stated that one of the several reasons for focusing on arithmetic was that 'arithmetic activity has formal properties, which make it identifiable in the flow of experience in many different situations', and Lave (1988:5) stated that 'it (arithmetic) has a highly structured and incorrigible lexicon, easily recognizable in the course of ongoing activity'.

Further studies comparing informal and formal procedures in arithmetic have indicated that there are often multiple systems of arithmetic in the same culture, one related to the school culture and one that flourishes outside school. Naresh and Chahine (2013) explored the computational strategies of bus conductors in Chennai, India, to develop a better understanding of the mathematics used in the workplace. In particular, the authors highlight the conductors' perception of their goals as they engage in self-directed experiences during their daily practice and the mental strategies they develop in the process. They further argued that the workplace setting demanded that the conductors perform mental mathematical calculations quickly and efficiently. In the absence of technological devices, the bus conductors resorted to mechanisms and heuristics to assist them in carefully avoiding errors in calculations. Naresh and Chahine asserted that the conductors, while immersed in their work activity, have established and achieved goals that involved significant mental mathematical functionalities not necessarily taught in schools but were rather motivated by the situational aspects that invoke the need to develop this mental modus operandi.

The impact of context on the problem-solving behaviour in out-of-school settings has motivated a number of explanations for the discrepancies between informal and formal learning, particular in a workplace setting (Jurdak & Shahin 2002). Two main positions can be invoked to explain the major differences between the two types of problem-solving behaviours that emerged as a result of situated reasoning. One theory focuses on the social interaction element of the context (Whimster 2018) and the other explores the social-cognitive career aspects (Bullock-Yowell et al. 2020). The first position maintains that the situation in which mathematical calculations are performed determines the role participants have with respect to each other's and thus influences people's success. They also propose that the social relationship established between vendor and customer is such that vendors feel more confident of their ability and perform better.

A social-cognitive interpretation would go along lines suggested by Vygotsky (1962), which emphasise the impact of the symbolic systems used in the two different situations rather than at the interaction between the people. Because the types of symbolic systems used in both situations are different, one being oral and the other written, children structure their activities in different ways. In order to sort out these possibilities, Nunes et al. (1993) conducted a replication of the study by Carraher et al. (1985) in which the relationship between the experimenter and the child remained constant, but problem-solving, which is supported by oral versus written practices of arithmetic, was observed. The vendors were 16 3rd-graders ranging in age from 8 to 13 years, randomly selected from two state-supported schools in Recife, Brazil. Children were interviewed individually and were asked to solve arithmetic problems in three conditions: (1) in a simulated store condition, the child being the store-keeper and the experimenter the customer, (2) embedded in word problems, and (3) as computation exercises. Results of the analysis showed that, in general, the vendors were far more successful in using oral arithmetic practices, which were elicited in a simulated shop, than written mathematics used for computational classroom-type exercises. Oral computation procedures involved the use of two reliably identifiable routines, decomposition and repeated grouping, that revealed the children's solid understanding of the decimal system.

The comparison of oral and written arithmetic practices indicates a need to search for ways of analysing cognitive performance not so far explored in the literature. Piaget's theory has provided a framework for looking at important 'conceptual invariants', like conservation, seriation, proportionality and so on, but it does not consider differences in performance in the cognitive tasks that are supported by the same invariants (Nunes et al. 1993). However, in the last two decades, researchers began to look into ways in which concepts are formed. In particular, studies of the effects of schooling on cognitive development have resulted in the idea that school concepts and everyday concepts may not be the same (Wellings 2003). With respect to street and school mathematics, Carraher and Schleimann (2002) identified important differences in the type of representation used. Street mathematics being oral, self-directed in the sense that it emerges from practitioners' self-chosen representations and tools that preserve much of the meaning of the situations at hand, whereas mathematical practice in school is written and avoids the specificity of situation in striving for generality. Gray (2017) confirmed the self-directedness of indigenous hunter-gathering cultures, who thrive in secluded regions and under harsh weather conditions use their self-regulated subsistence skills they acquired independently while in the field. He argued that hunter-gatherers develop their social learning behaviour through self-directed exploration and play. In a similar vein, Hewlett et al. (2011) explained:

> Foragers value autonomy and egalitarianism, so parents, older children, or other adults are not likely to think and feel that they know what is best or better for the child and are generally unlikely to initiate, direct, or intervene in a child's social learning. This is consistent with our finding that forager social learning is self-motivated and directed, but it also suggests that teaching and explicit instruction should be rare or absent. (p. 1173)

Solving arithmetic problems embedded in situations

Several studies have made it clear that children use a variety of different conceptual structures that result in different solution procedures for the same arithmetic problem (Scheibling-Sève, Pasquinelli & Sander 2020). This finding emphasised the need to consider how children think about certain problems. As a matter of fact, children's understanding of whole number addition and subtraction has been the focus of a great deal of research in the past 15 years and researchers have come a long way in understanding the variety of ways children think about single-digit addition and subtraction problems (Kullberg, Björklund & Brkovic 2020). The most important problems are those developing in the real world. Fuson (1992:244) argued that there are four basic addition and subtraction situations: 'compare', 'combine', 'change add to' and 'change take from'. She holds that the *compare* and *combine* situations are binary operations, whereas the change *Add To* and change *Take From* are unary operations where there is only one quantity to add to or take from. She also emphasised the fact that each addition and subtraction situation involves three quantities anyone of which can be unknown and the fact that addition is an operation that makes a sum out of two known addends, while subtraction is an operation that makes an addend out of known sum and another known addend. Hence, two out of the four major situations are addition situations (change add to, and combine), while the other two (compare/equalise and change Take from) are subtraction situations.

However, the most important idea in the aforementioned situations is the distinction between the problem situation and the solution procedure (Yeo 2007). Despite of the fact that addition and subtraction situations of whole numbers aim primarily at enhancing a better understanding of real-world situations, most of research use word problems that are 'restricted versions of real world problems in order to make it more concrete and less abstract'

(Fuson 1992:247). Researchers and teachers assume that because contexts are used, the content learned could transfer to real world (Ferlazzo 2017). Only lately, research began dealing with the difficulties of out-of-school situations where many variables are involved and are acting in a way that complicates the problem solution.

■ Approaches to self-directed problem-solving

Different approaches to self-directed problem-solving have provided different perspectives on the culturally creative ethnosemantic structure of street vending arithmetic. In many societies, mastering arithmetic skills is an important objective in the early years of schooling. The processes underlying acquisition of these skills have been described in a manner of information processing theories (Lawless 2019). In Lawless' (2019) description of the steps involved in solving a simple addition problem, a child or adult begins by encoding the problem and then attempts to retrieve an answer directly from a knowledge base consisting of stored facts. These facts are represented mentally in terms of associations, that vary in strength, between the problem stated (e.g. 2 + 5 =?) and possible answers (6, 7, etc.). If the strength between the retrieved answer and the problem (Act [An]) exceeds a certain confidence criterion (c), then the answer is stated. Otherwise, another retrieval is attempted. This cycle is repeated until an answer is retrieved with strength exceeding the confidence (c) or if the number of retrievals exceeds a certain limit (max.). At this point, retrieval stops and an answer is generated using a backup procedure, for example, counting mentally.

Kail (1994) argued that the general process does not change with age. However, a problem becomes more tied to the right answer through repeated exposure. Hence, in the case of street vendors, the environment as well as the frequency with which they experienced certain types of problems might have influenced the development of their self-directed arithmetic skills. Seemingly, street vending provided a supportive learning environment for self-directed problem-solving that allowed young vendors to acquire on-the-job arithmetic skills. Ginsburg (1988) asserted that by around age 5 or 6 years, almost every child can enrich his or her knowledge and techniques by learning the type of arithmetic taught in school. However, unlike their own, the arithmetic learned through formal schooling is written and codified with explicit rules and procedures, which are universal and seemingly far superior than their own informal arithmetic.

From a psychological perspective, Vergnaud (1989) examined the set of situations that involve addition or subtraction of two numbers or what he calls 'additive structures'. In his work, Vergnaud challenged the traditional view adopted by most teachers, which considers addition as a binary operation of two parts and subtraction as finding a missing part knowing a whole and the other part. He (Vergnaud 1988) added:

> [*B*]eside the binary combination of two parts into a whole, there is also the unary operation of a transformation of the initial state. There are essentially six different tasks related to the intermediate state-transformation-final state relationship, among which two are solved by adding and four by subtracting. (p. 34)

Furthermore, Vergnaud (1988) specified several important concepts that are involved in addition situations, like cardinality, transformations, inversion and directed numbers, in addition to intuitive conceptions that are implicit in students' problem-solving strategies.

Despite all the effort expended in teaching algorithms for solving computational problems, extensive research has indicated that some children do not use them but, instead, they resort to using methods of their own invention, a form of mental arithmetic to solve problems (Ross, Vallée-Tourangeau & Van Herwegen 2020). It has been also noted that children prefer to use these invented methods because they are more comfortable and meaningful than the algorithms they have learned in school (Ginsburg 1988). Extensive research on children's problem-solving strategies indicated that children invent methods in an attempt to solve the more difficult, verbal operation problems (Fischbein et al. 1985). Moreover, it has been found that children's choice of operations needed to solve a verbal problem depends, to a large extent, on the specific numerical data that are given in a problem (Daroczy et al. 2015). In one study, Hart (1981) established that pupils, from 12 to 15 years old, avoided to multiply by fractions and preferred rather more complicated, indirect strategies. For example, when faced with the problem 'A 15-cm eel has 9 cm of food; how much food should be given to a 25-cm eel?', none multiplied 9 by 5/3. Instead, they used the following strategy: '10 is two thirds of 15, two thirds of 9 is 6, and 25 is 15 + 10. Therefore, one has to add 9 + 6 = 15' (p. 91).

As a result of its frequent use, these invented methods become more and more implanted in children's repertoire of problem-solving strategies and with increased experience, these may develop into more complex techniques, which incorporate interesting mathematical principles. In fact, this view is implicative of Piaget's theory, which confirms that every mental operation is 'developmentally' rooted in practical situations. Using this argument, ample research has stressed the finding that each arithmetic operation becomes attached to an implicit, intuitive model with its own constraints and which sometimes dictates the choice of this operation (Fischbein et al. 1985; Ginsburg 1988; Nunes et al. 1993).

Several research studies have hypothesised that such implicit models facilitate, to a certain extent, the problem-solving behaviour of children but at other times it tends to slow down the solution process (Zander, Öllinger & Volz 2016). Such studies have attributed the drawbacks of these models to constraints that these models impose on the numbers used in a problem. More importantly, research findings have clearly established that, when attempting to explicitly represent what happens when using the intuitive model in solving arithmetic operation problems, many formally incorrect and meaningless algebraic procedures emerge (Kieran 1981). This finding obviously supports the belief that many of the obstacles children experience when solving computational exercises and word problems are inherently associated with the conflict they face between the formal, written, algorithmic arithmetic and the related intuitive, mental models. Admittedly, the major cause of this dilemma is basically the difficulty children encounter when originally introduced to written arithmetic symbolisation, which persists into elementary level and even higher. More and more studies confirmed the fact that given a choice, children seldom use written techniques to solve practical arithmetic problems (Van Lieshout & Xenidou-Dervou 2020). The most evident reason is that intuitive arithmetic develops in a natural way in the child's daily environment and that is why it is employed when dealing with practical problems. In this respect, Ginsburg (1988) has cited two basic reasons for children's difficulty in using written arithmetic. One is that children face difficulty in understanding the one-to-one correspondence between written symbols and the objects they represent. The second is that 'mathematical events' are by their very nature difficult to represent in writing. However, when asked to formally represent their intuitive arithmetic, children provide idiosyncratic algorithms that are basically a combination of their intuitive understanding with rules already learned in school.

Thompson (2007) established that young children learn about numerals and letters some time before they start school, but they hardly encounter written numbers as cardinal numerals in real-life situations. Such an insight could explain, to a certain extent, the young vendors' difficulty in using written symbols. Similar to Hughes' (1986) characterisation of children's self-created representations of numerals, the vendors' written representations can be classified into four categories: idiosyncratic, pictographic, iconic and symbolic. Therefore, I argue that the algorithms invented by young street vendors are often based on their understanding of the situation rather than on memorisation of procedures. Furthermore, I contend that perhaps if children were afforded opportunities to be self-directed learners in the mathematics classroom, they can develop their own written problem-solving methods, which are natural and which have many strengths. By the same token, I argue that learners at the secondary level do not necessarily use the algorithms they have learned and practiced in school in their everyday life but rather rely on their own idiosyncratic algorithms. As a mathematics educator for more than three decades, I have seen that one of the problems that children face when dealing with the formal school system is the difficulty of translating from different representation systems. In order to engage in self-directed problem-solving, children need to employ multiple modalities in representing the problem situation (Chahine 2013) and be able to translate within and between representations, that is, from the verbal to the written, from words to symbols, from the concrete to the abstract and from the informal to the formal.

Proportionality problems in street vending

Young street vendors are faced with proportion problems as they have to calculate the cost of several identical items or find how many things they can buy with a certain amount of money. Proportions are also widely used in scientific contexts. Despite its importance, it has been considered as one of the most difficult mathematical concepts, and this has probably made it the focus of many research studies.

Relevant literature suggested three different situation models that underlie proportion problems, namely, the isomorphism of measures, the product of measures and the multiple proportions model (Jitendra et al. 2015; Vergnaud 1988). The isomorphism of measures model involves only two variables, where each value in one variable corresponds to one value in the other. This can be exemplified in a problem situation that young street vendors encounter and that involves the relationship between the number of kg and price. In the product of measures model at least three variables are involved, the third being the product of the other two as is illustrated for example in finding the area of a rectangle. This situation cannot be described by one-to-many correspondence, but rather can be represented by a Cartesian product table. The third model, multiple proportion model, is similar to the isomorphism of measures model, where many variables are involved. The isomorphism of measures model is the simplest model and it is essentially the only model that best describes people's initial understanding of proportions (Baxter & Junker 2001). In employing the isomorphism of measures model, I argue that the street vendors' understanding of the situation is kept in view when the mathematical relations are analysed. Each variable remains independent of the other in the vendors' conceptualisation, and parallel transformations are carried out on both variables, thus keeping their values proportional. Hence, the importance of this model is that it includes the situation meaning as well as the mathematical relations in the same representation.

Regardless of the strategies employed in calculating proportions, Tournaire and Pulos (1985) and Vergnaud (1988) spoke of two kinds of ratios that can be compared, namely, 'internal' or 'external' ratio. Comparing ratios of the same nature involves the usage of an internal ratio, whereas external ratio entails the comparison of ratios of different natures. The comparison of ratios, however, must be preceded by a choice of a certain strategy (Tournaire & Pulos 1985). Vergnaud (1988) suggested that it is possible to identify children's strategies in solving proportion problems by examining the intermediary calculations they carry out. He also classified solutions into three types: scalar, functional and rule of three. While scalar solutions consist of carrying parallel transformation on the variables, functional solutions consist of computing, across variables, by establishing one ratio and then using it to calculate the other ratio. It is interesting to note that the choice of a scalar or a functional solution strategy is very much influenced by the context of the problem (Karplus et al. 1983) and by the numbers presented in the problem (Vergnaud 1988).

Methodology

This chapter explores the ethnosemantic structure of the folk arithmetic practices of young street vendors in their everyday work setting. The general methodological approach was employed in the open market, through naturalistic observation of the vendors in their work environment, and involved documenting the problem-solving behaviour on the arithmetic tasks encountered during their vending practice. Informal conversations were aimed at the collection of life stories of vendors, their cultural background and their mathematics experience in schools.

The street vending data examined in this case study were collected in the late 1990s in the Southern suburb of Beirut, the capital of Lebanon. During that period, Lebanon was a high-conflict zone recovering from the aftermath of more than 30 years of civil war and military conflicts that saddled the nation’s economy and damaged its vital infrastructure and facilities. Furthermore, and because of political instability in the region, Lebanon was the epicentre of refugees, attracting migrant families from neighbouring countries who sought refuge in Lebanon escaping political unrest and a declining economy. The two markets under study were destroyed by the Israeli invasion of Beirut in 2006.

Population and sample

Ten vendors, all males, were systematically sampled from a population of 25 young vendors from two market settings in the southern suburbs of Beirut: four vendors from market 1 and six vendors from market 2. The selected young vendors had at least 3 years of schooling and 1 to 8 years of vending experience. They were 10 to 16 years of age and worked 7 days per week with an average of 10 h per day. The two markets where the vendors worked attracted a large number of migrant workers who come from Syria and other neighbouring Arab countries in conflict areas and who fled because of political and economic instability. Because of poverty and lack of essential resources for survival, family members as well as children as young as 7 years of age work as street vendors to support their families.

Street vendors usually have their own three-wheel carriages on which to display their produce. At one side of each carriage, there is a small cupboard in which the vendors kept the scales, weights as well as plastic bags. Carriages and tables are arranged in such a way to make paths for people to walk. Beside each vendor's spot, empty boxes and cages are piled. The boxes and cages originally contained the produce they bought from the wholesale market. Each day, the empty cages and boxes are returned to the wholesale market to bring new packed ones.

Methods

The study employed two methodological approaches. In the informal setting, the 'naturalistic approach' was conducted by 'direct observations' (Hintze, Volpe & Shapiro 2002:993) of the vendors as they carry out their work activities in order to document their behaviour as they engage in solving arithmetic tasks executed during daily transactions. Four data collection techniques were used: participant observation, interviews, collection of artefacts and testing.

Participant observation required the researcher to play a dual role, being simultaneously involved in the activity of vendors as an insider while detached enough to allow reflection as an outsider. In the informal setting, that is, in the marketplace, I posed as a customer asking questions regarding possible transactions to purchase produce from the vendors. I also noted transactions carried out by the vendors selling other customers. As a customer, I also interviewed the vendors in their workplace setting, that is, the marketplace where I asked successive questions about the prices of fruits and vegetables in an attempt to make a purchase or a possible purchase. For example, I asked questions like 'how much have you sold today?', 'how was the market today, was it good or bad?' or 'have you changed your prices today?' I also asked questions to initiate a transaction such as 'I want x kg, how much do these cost?' or 'you bought x kg from wholesale market and you sold y kg, then how many kg are left?' or even questions concerning profit and loss such as 'by how much you increase or decrease your prices so as to maximize profit and minimize loss?'

I also presented the vendors with a written set of exercises, which were extracted from the transactions conducted by the vendors in the market as they attempt to make a sale or a possible sale. It is important to note here that a transaction involved more than one mathematical operation. This was because of the fact that vendors used more than a step to obtain an answer and each step employed was considered a written computation exercise. Problems were presented as either computation exercises or word problems. Written and oral communication with the vendors was conducted in Arabic, the mother tongue of the vendors.

Artefacts were also collected, which reflect aspects of the vendors' experience and knowledge. These included pieces of papers where vendors wrote their solutions and pictures of the scales and weights used in vending.

Procedure

Prior to data collection, vendors were informed about the study and parents' consent was sought as some of the vendors worked with their families. I had several informal conversations with the young vendors and their families in the market, collecting their life stories and exploring their school experience and their mathematics learning in school contexts. After these informal conversations and before conducting the semi-structured interviews, I observed the vendors each working at his own spot. These observations provided some information about their interactions with the customers and the types of computations they used when carrying out their transactions.

Data analysis

The unit of analysis selected was the problem-solving behaviour elicited when vendors encountered transactions in the market. Analytic induction was employed as the main analysis approach, which entailed an in-depth examination of the computational heuristics the vendors used as they performed their sales. The main purpose of this procedure was to generate a universal descriptive model that encompassed and explained all instances of the vendors' problem-solving behaviours transpiring in the informal setting. Two preliminary patterns of categories were extracted after coding the interview transcriptions and field notes and clustering initial and axial codes into concepts with the same underlying meaning. The first pattern pertained to the problem-solving behaviour of vendors on word problems and the second described their problem-solving behaviour on computation exercises. The coding system for word problems was identical to that describing the solution strategies in the workplace setting. The other system was completely different; it was rather based on error patterns that represented major coding categories. Data were assigned to these categories in order to test their workability. After several iterations and reformulations, different levels of categories and subcategories were developed.

Results

As a result of analysis, it was evident that the vendors' self-directed problem-solving behaviour comprised three major heuristics, three computational strategies and 11 computational sub-strategies. These heuristics, strategies and sub-strategies involved a combination of standard school-taught algorithms and nonstandard procedures invented by vendors in their work setting. It was possible to classify the heuristics used by vendors into three main categories: (1) building-up, (2) multiplicative, and (3) unit-driven. Also, combinations of these three heuristics were noted. It is worth mentioning here that the problem type influenced greatly the heuristic vendors used.

Building-up was the most frequently used heuristic by the vendors, and it did lead to successful solutions in problems involving one arithmetic operation. Of the heuristics used by vendors, 66% were building-up with a significantly high percentage of correct answers, namely, 92%. In fact, the ease with which problems were solved when using building-up heuristic suggests that this heuristic had been related more to the situational meaning of the problems rather than to the simple manipulation of symbols.

Type of heuristics employed

Multiplicative heuristics

In this heuristic, the terms within a ratio were related multiplicatively, and then, this relation was extended to the second ratio. Most of the time, the relationships were established between the numerators and denominators across or between ratios. Seemingly, solving problems using this heuristic entailed finding a relation between the first pair of numbers and then transferring this relation to the second pair. The relation was often a ratio simplified to X:1 where X is the retail price of 1 kg. Once the ratio was identified, it could be transferred to the second pair through multiplication. Multiplicative heuristic could be exemplified in the dialogue when I (I) approached Masri (M) selling 15 kg of eggplants for a restaurant, charging 1000 L.L./kg:

> I: 'How much did 15 kg cost?'
> M: '15000'
> I: 'How did you know?'
> M: '1 kg for 1000 then 100 kg for 100000'
> I: 'Did you use addition, multiplication, or division?'
> M: 'I didn't multiply nor subtract, I said 1 kg for 1 then 2 kg for 2, there is no need to be mixed-up.'

In another interview, and as mentioned elsewhere (Jurdak & Shahin 1999), I approached Ahmad (A) selling cucumbers:

> I: 'You are selling 1 kg of cucumbers for 1250 L.L, I will take 4 kg. How much do I owe you?'
> A (quickly): '5000 L.L.'
> I: 'How did you know?'
> A: '4 of 250 L.L gives 1000 L.L and 4000 L.L, hence I want 5000 L.L.'

Here, the comparison had been set between ratios of quantities of different attributes, namely, price and weight, and hence, ratios are said to be 'external' or 'functional'. Functional in the sense that what we really had was a quotient relating to two different variables or a function ratio. Thus, it was evident that, in using a multiplicative heuristic, the vendor had reached a functional solution.

It is interesting to note that the multiplicative heuristic was less employed than the building-up heuristic for it only represented 20% of the heuristics used. Of the problems solved by vendors using this heuristic, 79% were correct. The infrequent use of this heuristic may be because of the fact that vendors tended to avoid working with multiplication, as one vendor indicated: ‘we use addition because it is faster and easier, because sometimes we have many customers buying and we have to serve them all and multiplication takes time’.

☐ Unit-driven heuristic

This heuristic was prevalent when given the cost of N kg, the vendor had to find the cost of X kg; a multi-unit problem where the unit weight was not 1 kg. In fact, the vendors’ decision on the possibility and feasibility of the solution is driven by the unit weight given. Perceiving the unit as 1 kg did not help always in finding an appropriate and reasonable solution to the problem. In contrast, thinking of N kg as a unit allowed the vendors not only to solve the problem but also to generate many results by building-up from the initial solution. This could be clarified by the following interview with Ali who was selling oranges, 1½ kg for 1000 L.L.:

> I: ‘I want 3 kg; how much do I have to pay?’
> Ali (quickly): ‘2000 L.L.’
>
> Ali successfully solved the problem by considering 1½ kg as a unit rather than 1 kg, then by successively adding the cost of 1½ kg twice, he built up his solution strategy to calculate the cost of 3 kg.’
> I: ‘What if I wanted 10 kg?’
> Ali: ‘It does not work, you can take 9 kg for 6000 L.L., either 9 or 10 ½ kg.’
> I: ‘Why?’
> Ali: ‘Because then we would have to work with small unit currency.’

It is almost as if the solution process is revealed in finding an appropriate unit to the problem.

It is important to mention that the structure of the problem did not always lead to the vendors’ choice of this heuristic. For those who did use it, prices were mostly predetermined and when asked to explain their solution, they simply claimed that they have worked through taking multiples (doubling) and sub-multiples (halving) of the unit weight and accordingly computed the price. The others simply gave a reasonable estimate of the required retail price by finding the cost of 1 kg, thus considering cost (1 kg) as a unit price and building-up their solution. For example, Sami was selling 3 kg of oranges for 1000 L.L., I asked him to find the cost of 4 kg, he explained: ‘since 3 kg cost

1000 L.L. then 1 kg will cost 350 L.L.' When asked how he found out the answer, he replied: 'for 3½ and 3½ and 3½ makes approximately 1000'.

Combination of heuristics

It is worth noting that some vendors used a combination of different heuristics within the same problem, but the occurrence or usage of such combinations was minimal. Seven out of the 142 problems solved by the vendors involved successful combinations of scalar-functional solutions. Also, 18 problems were solved through a combination of unit-driven and scalar solution, 17 of which were correct. No combination of unit-driven and functional solutions was noted.

A combination of functional-scalar solution was exemplified by Mohammed's attempt to calculate the retail price of 7½ kg of apples, 1000 L.L./kg, he explained: '1 kg for 1000 then 7 kg for 7000 and half a kg for 500, then 7½ kg cost 7500 L.L.'. Thus, he partitioned his solution into functional, obtaining the cost of 7 kg through multiplication, and scalar, finding the price of ½ a kg that was 500 and then successively adding it to 7000 L.L. in order to calculate the cost of 7 kg.

In contrast, vendors also employed a combination of unit-driven scalar solutions. For instance, to calculate the cost of 15 kg of oranges, 1½ kg /1000 L.L., Wael simply built up his solution by working his way through taking 1½ kg as a unit of weight and successively adding the corresponding retail price. He proceeded as follows: '1½ kg for 1000 L.L. then 4½ kg will cost 3000 L.L., 10½ for 7000, 7 and 3 makes 10 ... then 15 kg cost 10000 L.L., I just added'.

An important result was the fact that the same vendor used two different solutions for solving two proportion problems involving the same numbers. This was clear, for example, when Masri was computing the cost of 2½ kg of tomatoes, 1000 L.L. / kg, he said: '1 kg for 1000 L.L. then 2½ kg will cost 2500 L.L.', thus using a functional solution. In another occasion, when asked about the cost of 2½ kg of cucumbers, 1000 L.L. /kg, he explained: '1 kg for 1000 L.L. and 1 kg for 1000 L.L. then 2 kg cost 2000 L.L. and ½ kg in 500 L.L. hence 2500 L.L.', thus using a scalar solution. Hence, there was no single specific heuristic that any of the vendors adopted, but there was a clear preference for using building-up heuristic.

Counting-up

Vendors used counting-up by hundreds, tens and one's as a self-directed problem-solving technique to approach an originally subtraction problem. They started with the smaller addend and counted up to the larger one, a general, powerful and rapid means of finding answers to take-away problems. This could be seen in an interview with Wael (W):

> I: 'How many cages have you bought from the wholesale market?'
> W: '14 cages'
> I: 'How many cages have you sold till now?'
> W: 'I don't know'
> I: 'How many cages are left?'
> W (pause): 'Nine cages.'
> I: 'Okay, there remains 9 cages and you have bought 14 cages, then how many have you sold?'
> W: 'Nine, 10, 11, 12, 13, 14, ... then I sold 5.'

Of the 32 subtraction problems solved orally by the vendors, it was possible to identify 15 clear examples of counting-up. There were 13 responses for which the vendors did not provide an explanation of how they achieved the result, most probably utilising number facts and four other problem solutions that were obtained through subtractive distribution. Of the responses to the change problems obtained through counting-up, 93% were correct.

Such counting skills, though considered elementary, have helped the vendors acquire some sound, intuitive understandings about addition and subtraction. In fact, vendors' use of this strategy represented their attempt to make use of what they have already known to solve novel problems. In doing so, they have established strong links between addition and subtraction operations, which in turn facilitated the learning of subtraction facts in relation to addition facts. A problem such as 10 000 L.L. – 3000 L.L., for instance, was thought of by Mohammed as '3000 L.L. and how many more L.L. to make 10 000 L.L.?'. Hence, addition and subtraction are thought of as related operations.

☐ Repeated grouping

Rather than approaching multiplication problems algorithmically, vendors used their knowledge about numbers and operations to choose a method appropriate to the problem at hand. Two computational sub-strategies were identified to address these types of questions, namely, 'convenient chunking' and distribution.

☐ *Convenient chunking*

When finding the retail price of 5 kg of potatoes knowing that 1 kg costs 750 L.L., instead of multiplying 5 by 750, Wael added the retail price of 4 kg to the retail price of 1 kg, he explained: '2 kg cost 1500 then 4 kg cost 3000 L.L. hence 5 kg will cost 3750 L.L.' As such, the values added represented convenient chunks that were easier to operate on than the multiplicands 5 and 750. Through constant monitoring, Wael kept track of intermediary products towards a solution. Calculation was completed when the proper number of 'times' has been added. The specific chunks chosen seemed to depend on both the numbers involved and the vendors' knowledge of number facts. Grouping 50's into 100's and 100's to 1000's brought an obvious advantage to their computations. But the process was even richer as vendors took some shortcuts to the solutions and it was not clear how to predict the number of chunks used. For instance, in finding the retail price of 10 kg of oranges, Wael worked out the subtotals of 5 chunks, each representing the cost of 2 kg. On another occasion, when finding the retail price of 10 kg of oranges also, where 1 kg cost 750 L.L., he successively added price (4 kg) plus price (4 kg) plus price (2 kg), hence chunking 10 into 4, 4 and 2.

Grouping numbers into convenient chunks clearly showed that the vendors had kept the meaning of the problem in mind while attempting to find a solution. They repeatedly referred to the parameters in the problem while mentally calculating. This was noticeable in multiplication problems where convenient chunking represented 79% of the computational sub-strategies used under repeated grouping.

Distribution

The distribution computational sub-strategy was detected when vendors transformed one of the multiplicands into a series of either sums or differences. Calculations were then proceeded by applying either additive, subtractive or 'fractional' distribution. Additive distribution was based on the principle of distributive law of multiplication over addition. Fractional distribution was usually applied to those tasks in which at least one factor contained 5 as a unit digit. Finally, the subtractive distribution sub-strategy was implemented using the distribution principle of multiplication over subtraction. Unintentionally, vendors sometimes expressed a factor as a difference of two numbers thus simplifying calculations.

Problem-solving behaviour when solving computation exercises

When solving written mathematical operation problems, vendors failed to deal with decontextualised numbers. Some were unable to read or write the numbers accurately, many lacked the basic understanding of the operations themselves, others became careless and confused, still others had special problems with language or in relating representations, symbols and even writing a numeral correctly. For example, Masri could count by ones and tens, knew which numbers were greater in magnitude than others, could add mentally and multiply using repeated addition, yet Masri could not write any mathematical symbol or numeral correctly. Detailed examination of vendors' written solutions of computation exercises afforded the detection of certain routines related to reading and writing numbers. It was possible to classify these routines into three categories: random handling of numerals, difficulty in specifying multiples of 10 and idiosyncratic interpretation of symbols.

□ Random handling of numerals

When writing or reading numbers, seven out of the 10 vendors did, occasionally, reverse digits of numbers. For example, when adding 12 + 12, mentally, Wael got 24 as an answer but wrote 42. Also, Ali subtracted 1000 from 7000 and obtained 6000 as an answer, which he wrote as 0006. In addition, some vendors tended to write the numbers differently than they say them. For instance, when Masri was adding 6000 and 6000 his answer was 12 000 but he wrote 16. Furthermore, vendors tended, at certain times, to write a number the same way as they say it. For example, adding 2250 and 1500 mentally, Masri got 3750 as an answer so he wrote 3 000 750, which was exactly the way he operated on the numbers when adding from left to right. It is important to note here that the difficulties most students faced in writing a numeral could be because of the discrepancy in the Arabic writing between digits and letters. In Arabic, the direction of text writing proceeds from right to left whereas in writing the digits of a number starting from the most significant digit to the ones digit, that is, from left to right.

□ Difficulty in specifying multiples of 10

This habit was the most prevalent for, eight out of the 10 vendors made errors in reading or writing numbers ending with a zero. For instance, Wael read 1000 as '10' and 10 000 as '100', while 2250 was read as '250'. Wael also wrote 1500 but read it as 'one and a half million'.

□ Idiosyncratic interpretation of operation symbols

Vendors had their own interpretation of the operation symbols +, -, ×. For example, Hasan was trying to add horizontally 1000 + 500 and then to write his response. Instead of writing the operation symbol '+' for addition, he simply drew a line. Also, this habit was noted in Masri's use of the symbols '=' and '≠' as alternatives to '+'.

It appeared from the practice that vendors' used to read and write their solutions to computation exercises that they have not retained basic knowledge of the mathematical symbol system used in schools. The difficulties that vendors encountered can be attributed to their lack of expertise in solving problems using symbols, a skill that is necessary to abstractly solve pure arithmetic operation exercises.

Discussion

Investigations of computations in everyday settings have provided important suggestions for interpreting the empirical findings of this study. These empirical results further confirm that it is one thing to learn mathematics in schools and quite another thing to solve problems in real life situations. Upon examining the self-directed problem-solving behaviour of street vendors in their workplace setting, it was clear that the computational strategies they created in the course of work transcended the formal strategies learned in school in terms of efficiency and accuracy. Admittedly, the vendors' use of informal computational strategies at work involved an in-depth understanding of the problem situation in a way, which rendered it meaningful. As a result, they kept the meaning of the problem in mind during problem-solving at work and quite often seemed to forget about this meaning when solving decontextualised exercises. It appeared that when solving pure computation exercises, the formal symbolism of arithmetic had moved the vendors away from their natural and intuitive problem-solving skills that were secured in the real-world experiences and towards rules of meaningless symbol manipulation. As a result, the vendors' mathematical understanding seems to be split between the concrete and the written, as if their problem-solving behaviour inhabited two different worlds, each with its own rules and strategies but with different connection between the two. This marked within-vendors' difference in performance when using formal and informal computational strategies can be attributed to the impact of two activity systems that the vendors engage in: one related to work and the other related to schooling. The computational fluency that the vendors acquired through their vending experiences had some unique characteristics that showed the imprint of the market on the mathematical ideas that were developed there, which were different from what prevail in typical mathematics textbooks. Seemingly, street vending afforded the vendors with a number of challenges and opportunities to develop conceptual understanding that consequently resulted in a more effective self-directed problem-solving on computational transactions. As a result, vendors consolidated a database of meaningful computational strategies and self-invented arithmetic algorithms. Such a finding supports the claim that, when children understand a problem, they are capable of creating, on their own, a method to solve that problem.

In contrast, the role of schooling in the development of vendors' mathematical knowledge was not a clear and simple one. While the performance of the vendors that were still in school was significantly higher on school-type algorithms than that of the vendors that dropped out of school, error rates associated with the use of written computational strategies seemed to increase considerably. It could be argued that students who did not experience a mathematical concept in multiple situations may take several years to be comfortable with school-type arithmetic concepts, like place value notation and column algorithms in which one operates on symbols rather than on quantities. Findings of this study show that vendors with relatively high levels of schooling begin to distance themselves from the characteristics of the sale situations in which they work and engage in analysing their sales in terms of more abstract notions. This perhaps was the main endowment that school has provided vendors who are still attending school, which was a deficit for their peers who were out of school and whose computational strategies were strictly tied to specific vending situations. Thus, while schools may promote the generation of general solutions, which are removed from specific situations; however, it seems that the cost of leaving the specific situation and generalising can be high. It is reasonable, then, to argue that school and work could be connected to self-directed problem-solving behaviour, which had influenced the vendors' performance in the formal and informal settings. Vendors who were still attending school fared better than those who dropped school, only on pure computation exercises. This could imply that schooling had improved the vendors' performance only in relation to the means of representation used in school. Schooling had a minimal effect on the performance of vendors who dropped out of school. In contrast, street vending afforded young vendors a context where they developed expertise as self-directed learners, engaged in the workplace environment as independent thinkers addressing ensuing problems and making connections between the abstract and the applied knowledge.

As a matter of fact, and drawing from Engeström's (1999) first-, second- and third-generation activity systems analysis, it might be argued that the mathematical goals in school are distinct from those undertaken in the vendors' practice at work. The principle motive of vendors is to make money, and therefore, the self-directed solutions adopted at work may not be, principally, mathematical. Furthermore, the vendors' motivation to engage in any computational transaction is derived from their performance as self-directed learners driven by curiosity, challenge and control. Being fully in charge of their own thought processes, it is easy to discern then that the young practitioners were able to enrich their problem-solving behaviour and to employ mathematical ideas malleably to their advantage in the ever changing and challenging workplace context.

In contrast, in school, mathematics is the object of study, and therefore, rather than being motivated by economic concerns, students in school may strive to do well on a test and to abide by rules of accuracy and precision. This difference in motives between work and school could imply that mathematical errors take on different meanings across the two contexts. When solving problems in the vending practice, vendors were often not concerned with achieving mathematically exact solutions to problems, whereas in the classroom, error is evaluated with reference to mathematical standards.

Moreover, social interactions contribute to the differential impact of vending and schooling. In vending, interactions are often between equals, either with other vendors or with customers, these are interactions for the purpose of doing their business. Furthermore, the vendors have the ultimate say on what determines the appropriate way to sell, it is the vendor himself who bears the loss or profit of his selling efforts, this loss or gain is linked to his mathematical proficiency. However, in school, interactions are set between the student and the teacher for only one purpose, namely to provide opportunities for learning for its own sake. Brockett and Hiemstra (1991:32) reminded us that SDL activities 'cannot be divorced from the social context in which they occur' because 'the social context provides the arena in which the activity of self-direction is played out'.

■ Conclusion

The ethnosemantic structure of the arithmetic of street vending could highlight questions related to which mathematical knowledge and competencies are valued, which groups are deemed doers of mathematics and what purposes does mathematics teaching and learning serve within and across cultural contexts. Many of the questions are at the heart of the debate on the role of mathematics in preparing the 21st-century workforce that is capable of self-directed, lifelong learning and that is fully equipped with a new set of foundational knowledge and skills to solve challenging problems. In this context, success in mathematics ensues not just from what one knows, but what one can do with that knowledge in and outside of formal school settings. In being, becoming and belonging, and as Brookfield (1985) made it clear from the outset:

> [*T*]he external technical and the internal reflective dimensions are fused when adults come to appreciate the culturally constructed nature of knowledge. In such a praxis of thought and action is manifested a fully adult form of autonomous, self-directed learning. (p. 31)

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Preface

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Chapter 1

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Chapter 2

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Chapter 3

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Chapter 7

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Chapter 10

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This book on self-directed learning (SDL) is devoted to original academic scholarship within the field of education. In this book, the authors explored how self-directed learning can be considered an imperative for education in a complex modern society. Although each chapter represents independent research in the field of SDL, the chapters form a coherent contribution concerning the scholarship of SDL and specifically the effect of environmental and praxis contexts on the enhancement of SDL in a complex society. Scholars working in a wide range of fields are drawn together in this scholarly work to present a comprehensive dialogue regarding SDL and how this concept functions in a complex and dynamic higher education context. This book presents a combination of theory and practice, which reflects selected conceptual dimensions of SDL in society as well as research-based findings pertaining to current topical issues relating to implementing SDL in the modern world. The varied methodologies provide the reader with different and balanced perspectives, as well as varied innovative ideas on how to conduct research in the field of SDL.

Self-Directed Learning: An imperative for education in a complex society does a splendid job of providing strong evidence for SDL as a way to prepare students with 21st-century skills, enabling them to be ready for the workforce where creativity, critical thinking, and problem-solving are paramount to success in creating innovations that will change the landscape of all societies. This book is an important one, as it provides diverse perspectives on SDL in multiple contexts. From street vendors' arithmetic skills to problem-based learning in chemistry, the book sets up for a healthy dialogue to ensure the regard of SDL and how it can occur in multiple ways, places, and contexts. The book offers multiple chapters examining SDL. The most powerful chapter showcases the street knowledge of vendors and their ability to execute mathematical functions compared to those within formal schooling. The qualitative methods used for this chapter afforded the reader a vivid portrait of how mathematics can be an integral part of a person's life when placed within the context of everyday life. The examples of the street knowledge provided throughout this chapter are powerful and full of wisdom, and align with the mathematics standards released years ago, proposing teachers afford students the chance for multiple ways of problem solving instead of using one formulaic method. This chapter, in particular, will empower the re-examining of teaching practices away from the abstract and into the actual way students 'think' about doing math. Researching student thinking is a powerful way to examine all subject matter and needs to be emphasised more in educational literature. This book will be an invaluable addition to the literature on self-directed learning and the research practices that best showcase how to analyse and interpret this complex phenomenon.

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