EXPLORING EARLY-STAGE DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION

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Abstract

Research problem: Digital transformation or technology integration in secondary mathematics education in South Africa is at an early stage. Technology integration can be used in either an enhanced manner (substitution or augmentation) or a transformational manner (modification or redefinition) as described by the substitution-augmentation-modification-redefinition (SAMR) model. The enhancement level is regarded as the early stage in this research study. Previous studies on South African schools have not thoroughly investigated the data and dimensions associated with shifting digital transformation in secondary mathematics education beyond the early stage. Hence, this study investigates the use of digital technologies for teaching mathematics in secondary schools, which are critical for the deep conceptual understanding needed for better education outcomes. **Method/approach:** Grounded in a social constructivist approach, this qualitative study undertook two complementary case studies. Western Cape Education Department (WCED) and Gauteng Department of Education (GDE) schools were examined via semi-structured interviews, participant observations, and document analysis to collect the necessary data. This was done to examine the study's four dimensions, namely the digital skills of educators, digital leadership, digital infrastructure, and the digital teaching experience. The data were collected purposefully from key secondary mathematics stakeholders (teachers, district officials, academics, local development agency officials, and independent experts) in the Western Cape and Gauteng provinces. The study explored the early use of dynamic software applications – GeoGebra and Geometer's Sketchpad, amongst others. **Findings:** The findings from the two case studies identified the need for (i) a holistic digital transformation in the secondary mathematics environment framework; (ii) an appropriate governance structure for digital education policy design, implementation, and monitoring; (iii) a continuous evolving technical architecture; and (iv) a focus on digital pedagogy for mathematics, to shift digital transformation in secondary mathematics beyond the early stage. **Conclusions:** The use of digital technologies such as Excel, GeoGebra, and Geometer's Sketchpad in a transformational manner for teaching mathematics in secondary schools is linked to the promotion of deep conceptual understanding for the improvement of mathematics education outcomes. Based on the data analysis, the study proposed a digital transformation in secondary mathematics education 2022 (DT-SME 2022) framework as a theoretical and practice-oriented framework for South Africa. The study theorises that shifting digital transformation in secondary mathematics education beyond the early stage can be facilitated by applying the DT-SME 2022 framework, which advocates (i) the kinds of intermediate and advanced digital skills that are crucial for the successful implementation of digitally supported teaching of secondary school-level mathematics; (ii) attention to digital leadership, including the establishment of a formal governance structure for the participation of all stakeholders during the design, implementation, and monitoring of digital education policy; (iii) an effective technical architecture to address connectivity issues; and (iv) a constructive and enjoyable digital teaching experience that encourages learning-centred pedagogical approaches.

Keywords: digital pedagogy, digital transformation in schools, dynamic software, early-stage, enhancement, secondary mathematics education

Abstrak

Navorsingsprobleem: Digitale transformasie of tegnologie-integrasie in sekondêre wiskunde-onderwys in Suid-Afrika is in 'n vroeë stadium. Tegnologie-integrasie kan op óf 'n verbeterde wyse (substitusie of aanvulling) of 'n transformasionele wyse (modifikasie of herdefinisie) gebruik word soos beskryf deur die substitusie-aanvulling-modifikasie-herdefinisie (SAMR)-model. Die verbeteringsvlak word as die vroeë stadium in hierdie navorsingstudie beskou. Vorige studies oor Suid-Afrikaanse skole het nie die data en dimensies wat verband hou met die verskuiwing van digitale transformasie in sekondêre wiskunde-onderwys na die vroeë stadium deeglik ondersoek nie. Daarom ondersoek hierdie studie die gebruik van digitale tegnologieë vir die onderrig van wiskunde in sekondêre skole, wat van kritieke belang is vir die diep konseptuele begrip wat nodig is vir beter onderwysuitkomste. **Metode/benadering:** Gegrond in 'n sosiaal-konstruktivistiese benadering, het hierdie kwalitatiewe studie twee komplementêre gevallestudies onderneem. Wes-Kaap Onderwysdepartement (WKOD) en Gauteng Departement van Onderwys (GDO) skole is deur middel van semi-gestruktureerde onderhoude, deelnemerwaarnemings en dokumentontleding ondersoek om die nodige data in te samel. Dit is gedoen om die studie se vier dimensies te ondersoek, naamlik die digitale vaardighede van opvoeders, digitale leierskap, digitale infrastruktuur en die digitale onderrigervaring. Die data is doelgerig ingesamel van belangrike sekondêre wiskunde-belanghebbendes (onderwysers, distriksamptenare, akademici, plaaslike ontwikkelingsagentskap-amptenare en onafhanklike kundiges) in die Wes-Kaap en Gauteng provinsies. Die studie het die vroeë gebruik van dinamiese sagtewaretoepassings – onder andere GeoGebra en Geometer's Sketchpad – ondersoek. **Bevindinge:** Die bevindinge van die twee gevallestudies het die behoefte geïdentifiseer vir (i) 'n holistiese digitale transformasie in die sekondêre wiskunde-omgewingsraamwerk; (ii) 'n toepaslike bestuurstruktuur vir ontwerp, implementering en monitering van digitale onderwysbeleid; (iii) 'n voortdurend ontwikkelende tegniese argitektuur; en (iv) 'n fokus op digitale pedagogie vir wiskunde, ten einde digitale transformasie in sekondêre wiskunde verby die vroeë stadium te verskuif. **Gevolgtrekkings:** Die gebruik van digitale tegnologie soos Excel, GeoGebra en Geometer's Sketchpad op 'n transformerende wyse vir die onderrig van wiskunde in sekondêre skole is gekoppel aan die bevordering van diep konseptuele begrip vir die verbetering van wiskunde-onderwysuitkomste. Op grond van die data-analise het die studie 'n digitale transformasie in sekondêre wiskunde-onderwys 2022 (DT-SME 2022) raamwerk voorgestel as 'n teoretiese en praktykgerigte raamwerk vir Suid-Afrika. Die studie teoretiseer dat die verskuiwing van digitale transformasie in sekondêre wiskunde-onderwys na die vroeë stadium vergemaklik kan word deur die toepassing van die DT-SME 2022-raamwerk, wat (i) die soorte intermediêre en gevorderde digitale vaardighede voorstaan wat deurslaggewend is vir die suksesvolle implementering van digitaal ondersteunde onderrig van wiskunde op hoërskoolvlak; (ii) aandag aan digitale leierskap, insluitend die vestiging van 'n formele bestuurstruktuur vir die deelname van alle belanghebbendes tydens die ontwerp, implementering en monitering van digitale onderwysbeleid; (iii) 'n effektiewe tegniese argitektuur om konnektiwiteitskwessies aan te spreek; en (iv) 'n konstruktiewe en genotvolle digitale onderrigervaring wat leergesentreerde pedagogiese benaderings aanmoedig.

Sleutelwoorde: digitale pedagogie, digitale transformasie in skole, dinamiese sagteware, vroeë stadium, verbetering, sekondêre wiskunde-onderwys

Ushwankathelo

Ingxaki yophando: Inguqu yedijithali okanye ukudityaniswa kwethekhinoloji kwimfundo yasesekondari yemathematika eMzantsi Afrika ikwinqanaba lokuqala. Oku kusekelwe kuhlanganiso lwe-tTechnoloji lunokusetyenziswa ngendlela eyandisiweyo (ukutshintsha okanye ulwandiso) okanye ngendlela yotshintsho (uhlengahlengiso okanye ukuchazwa ngokutsha) njengoko kuchazwe ngomzekelo wokutshintsha-ukuguqulwa-ukuguqulwa-uhlengahlengiso (i-SAMR). Umgangatho wophuculo uthathwa njengenqanaba lokuqala kolu phononongo lophando. Izifundo zangaphambili kwizikolo zaseMzantsi Afrika azikhange ziyiphande ngocoselelo idatha nemilinganiselo enxulumene nokutshintsha kwenguqu kwidijithali kwimfundo yezibalo zasesekondari ukuya ngaphaya kwenqanaba lokuqala. Kungoko, olu phononongo luphanda ngokusetyenziswa kweetekhnoloji zedijithali ekufundiseni imathematika kwizikolo zasesekondari, ezibaluleke kakhulu ekuqondeni okunzulu okufunekayo kwiziphumo zemfundo ezingcono. **Indlela/indlela yokusebenza:** Ngokusekelwe kwindlela yonxibelelaniso lwentlalo, olu phononongo lomgangatho lwenziwe luphonononge iimeko ezimbini ezihambelanayo. , ezizezi, iSebe leMfundo leNtshona Koloni (WCED) nezikolo zeSebe leMfundo laseGauteng (GDE) zavavanywa kusetyenziswa udliwano-ndlebe olunesiqingatha semi-structured, imigqaliselo yabathathi-nxaxheba, nohlalutyo lwamaxwebhu ukuze kuqokelelwe idatha eyimfuneko. Oku kwenzelwa ukuhlola imilinganiselo emine yolu phando, eyile: izakhono zedijithali zabafundisi-ntsapho, ubunkokeli bedijithali, iziseko zophuhliso zedijithali, kunye namava okufundisa ngedijithali. Idatha yaqokelelwa ngenjongo evela kubathathi-nxaxheba abaphambili bemathematika esekondari (ootitshala, amagosa ezithili, izifundiswa, amagosa ee-arhente zophuhliso lwengingqi, neengcali ezizimeleyo) kwiPhondo leNtshona Koloni naseGauteng. Uphononongo luphonononge ukusetyenziswa kwangaphambili kosetyenziso lwesoftware eguqukayo-iGeoGebra kunye neGeometer's Sketchpad, phakathi kwezinye. **Iziphumo:** Izinto ezifunyenweyo kuzo zonke iinkalo zophononongo lwezifundo ezimbini zichonge imfuneko (i) yenguqu epheleleyo yedijithali kwisikhokelo semo engqongileyo yemathematika esesekondari; (ii) ulwakhiwo olufanelekileyo lolawulo loyilo lomgaqo-nkqubo wemfundo yedijithali, ukuphunyezwa kunye nokubeka iliso; (iii)) ulwakhiwo lobugcisa oluqhubekayo, kunye (iv) nokugxila kwi-digital pedagogy yemathematika, ukuze ibe zizinto ezibalulekileyo zokusebenza eziyimfuneko ekutshintsheni inguqu yedijithali kwimathematika yesibini ngaphaya kwenqanaba lokuqala. **Izigqibo:** Ukusetyenziswa kobuchwepheshe bedijithali obufana ne-Excel, i-GeoGebra, ne-Geometer’s Sketchpad ngendlela yotshintsho ekufundiseni imathematika kwizikolo zasesekondari kunxulunyaniswa nokukhuthazwa kokuqonda okunzulu kwengqiqo yokuphuculwa kweziphumo zemfundo yemathematika. Ngokusekelwe kuhlalutyo lwedatha, uphononongo lucebise inguqu yedijithali kwimfundo yasesekondari yemathematika ka-2022 (DT-SME 2022) njengesakhelo sethiyori nesiqhelaniswe neprakthiza eMzantsi Afrika. Uphononongo luthi uguquko lwedijithali kwimfundo yezibalo zasesekondari ngaphaya kwenqanaba lokuqala lunokuququzelelwa ngokusebenzisa isakhelo se-DT-SME 2022, esixhasa (i) iintlobo zezakhono zedijithali eziphakathi kunye neziphambili ezibaluleke kakhulu ekuphunyezweni ngempumelelo kokuxhaswa ngedijithali. ukufundisa imathematika kwinqanaba lezikolo zasesekondari; (ii) ingqwalasela kubunkokeli bedijithali, kubandakanywa ukusekwa kobume bolawulo olusesikweni ukulungiselela ukuthatyathwa kwenxaxheba kwabo bonke abachaphazelekayo ngexesha lokuyila, ukuphunyezwa, nokubekwa esweni komgaqo-nkqubo wemfundo yedijithali; (iii) uyilo lobugcisa olusebenzayo ukulungisa imiba yoqhagamshelwano; kunye (iv) namava okufundisa ngedijithali awakhayo nayonwabisayo akhuthaza iindlela zokufundisa ezigxile ekufundeni.

Amagama angundoqo: i-digital pedagogy, inguqu yedijithali ezikolweni, isoftware enamandla, inqanaba lokuqala, uphuculo, imfundo yemathematika yasekondari

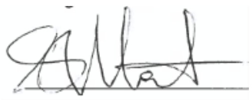
Isifinqo

Inkinga yocwaningo: Uguquko lwedijithali noma ukuhlanganiswa kobuchwepheshe emfundweni yezibalo zasesekondari eNingizimu Afrika kusesigabeni sokuqala. Ukuhlanganiswa kobuchwepheshe kungasetshenziswa ngendlela ethuthukisiwe (ukufaka esikhundleni noma ukukhuliswa) noma indlela yokuguqula (ukuguqulwa noma ukuchazwa kabusha) njengoba kuchazwe imodeli ye-substitution-augmentation-modification-redefinition (SAMR). Izinga lokuthuthuka lithathwa njengesigaba sokuqala kulolu cwaningo locwaningo. Izifundo zangaphambilini ezikoleni zaseNingizimu Afrika azizange ziphenye ngokucophelela idatha nobukhulu obuhlobene nokuguquguquka kwedijithali emfundweni yezibalo zamabanga aphezulu ngale kwesigaba sokuqala. Ngakho-ke, lolu cwaningo luphenya ukusetshenziswa kobuchwepheshe bedijithali ekufundiseni izibalo ezikoleni zamabanga aphakeme, okubalulekile ekuqondeni okujulile komqondo odingekayo ukuze kube nemiphumela engcono yemfundo. **Indlela/indlela yokwenza:** Ngokusekelwe endleleni ye-social constructivist, lolu cwaningo lwequalitative lwenze izifundo eziyisibonelo ezimbili ezihambisanayo. Izikole zoMnyango wezeMfundo eNtshonalanga Kapa (i-WCED) kanye noMnyango wezeMfundo waseGauteng (GDE) zahlolwa kusetshenziswa inhlolokhono engahleliwe, ukubonwa kwababambe iqhaza, nokuhlaziywa kwamadokhumenti ukuze kuqoqwe idatha edingekayo. Lokhu kwenzelwa ukuhlola izinhlangothi ezine zocwaningo, okuwukuthi amakhono edijithali othisha, ubuholi bedijithali, ingqalasizinda yedijithali, nolwazi lokufundisa lwedijithali. Imininingwane iqoqwe ngenhloso kubabambiqhaza ababalulekile bezibalo zesekondari (othisha, izikhulu zesifunda, izifundiswa, izikhulu ze-ejensi yokuthuthukiswa kwendawo, nochwepheshe abazimele) esifundazweni saseNtshonalanga Kapa naseGauteng. Ucwaningo luhlole ukusetshenziswa kwasekuqaleni kwezinhlelo zokusebenza zesoftware enamandla - i-GeoGebra ne-Geometer's Sketchpad, phakathi kokunye. **Okutholakele:** Okutholwe ocwaningweni lwezimo ezimbili kukhombe isidingo (i) soguquko oluphelele lwedijithali ohlakeni lwendawo yesibili yezibalo; (ii) uhlaka olufanele lokubusa lokuklama, ukuqaliswa, nokuqapha kwenqubomgomo yemfundo yedijithali; (iii) i-architecture yobuchwepheshe eqhubekayo; kanye (iv) nokugxila ku-digital pedagogy yezibalo, ukuze kugudluzwe uguquko lwedijithali kuzibalo zesibili lube ngaphezu kwesigaba sokuqala. **Iziphetho:** Ukusetshenziswa kobuchwepheshe bedijithali obufana ne-Excel, i-GeoGebra, ne-Geometer’s Sketchpad ngendlela yenguquko yokufundisa izibalo ezikoleni zamabanga aphakeme kuxhunywe ekuthuthukisweni kokuqonda okujulile komqondo ukuze kwenziwe ngcono imiphumela yemfundo yezibalo. Ngokusekelwe ekuhlaziyweni kwedatha, ucwaningo luhlongoze uguquko lwedijithali emfundweni yezibalo zamabanga aphakeme 2022 (DT-SME 2022) njengohlaka lwethiyori kanye nolwenzeko lwaseNingizimu Afrika. Ucwaningo luthi ukushintsha uguquko lwedijithali emfundweni yezibalo zesibili ukudlulela esigabeni sokuqala kungenziwa lula ngokusebenzisa uhlaka lwe-DT-SME 2022, olumela (i) izinhlobo zamakhono edijithali amaphakathi nathuthukile abalulekile ekuqalisweni kokuqaliswa okuyimpumelelo kokusekelwa ngedijithali. ukufundisa izibalo zezinga lesikole samabanga aphezulu; (ii) ukunaka ubuholi bedijithali, okuhlanganisa ukusungulwa kwesakhiwo sokuphatha esisemthethweni sokubamba iqhaza kwabo bonke ababambiqhaza ngesikhathi sokuklama, ukuqaliswa, nokuqapha inqubomgomo yemfundo yedijithali; (iii) isakhiwo esisebenzayo sokubhekana nezinkinga zokuxhuma; kanye (iv) nolwazi olwakhayo nolujabulisayo lokufundisa lwedijithali olukhuthaza izindlela zokufundisa ezigxile ekufundeni.

Amagama angukhiye: i-digital pedagogy, ukuguqulwa kwedijithali ezikoleni, isofthiwe enamandla, isigaba sakuqala, isithuthukisi, imfundo yezibalo zesibili

Statement of Original Authorship

I, Songezo Mata, hereby declare that this thesis is my original work. The thesis was submitted to the Faculty of Humanities, University of Witwatersrand, Johannesburg, for the partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD) in the field of Interdisciplinary Digital Knowledge Economy Studies (IDKES). It has never been previously submitted to meet the requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference.

Signature: 

Date: 26 January 2024

Dedication

James 2:26 (CEB) says that faith without actions is dead; this scripture has inspired me all my life. This work is dedicated to the principals, teachers, learners, schools, the leadership in the West Coast Education District , the Western Cape Education Department, and the Saldanha Bay Industrial Development Zone Licencing Company (SBIDZ-LC) who afforded me the privilege of being part of the teacher professional development (TPD) programme, the Professional Practice: Applications of Dynamic Software (PP: ADS) short course for grade 8 and 9 mathematics teachers in the Saldanha Bay circuit.

This work is also dedicated to my grandmother, Nongamile Josephine Mata; my grandfather, Mzwandile Livingstone Mata; and my great-grandfather, Walter Mata. It is also dedicated to my wife, Simnikiwe Queen Mata, who always listened to my frustrations during my studies. I also want to thank my late mother, Nomazizi Mata, and my aunts Fuziswa Mata, Lizeka Mata, and Noxolo Mata. I am also grateful to my supportive siblings: Khunjuzwa Mata, Ncedisa Mata, Nomasixole Mata, Fikiswa Mata, Ncumisa Mata, Mnoneleli Mata, Lindiwe Mata, and Yandiswa Mata; and to the Daniel family on my father’s side: Vuyo, Siviwe, Zoliswa, Unathi, Zonke, and Ziyanda.

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List of Acronyms and Abbreviations

BRICS	Brazil, Russia, India, China, and South Africa
CSIR	Council for Scientific and Industrial Research
DBE	Department of Basic Education
DCDT	Department of Communications and Digital Technologies
DSI	Department of Science and Innovation
DT	Digital Transformation
ESD	Ekurhuleni South District
GDE	Gauteng Department of Education
GSP	Geometer’s Sketchpad
ICASA	Independent Communications Authority of South Africa
ICT	Information and Communication Technology
IDZ	Industrial Development Zone
ITU	International Telecommunication Union
JND	Johannesburg North District
JWD	Johannesburg West District
MTLF	Mathematics Teaching and Learning Framework
NDP	National Development Plan
NSC	National Senior Certificate
PDFDL	Professional Development Framework for Digital Learning
PP: ADS	Professional Practice: Applications of Dynamic Software for Secondary Mathematics Teachers
SAMR	Substitution, Augmentation, Modification, and Redefinition
SBIDZ-LC	Saldanha Bay Industrial Development Zone – Licencing Company
SITA	State Information Technology Agency
SME	Secondary Mathematics Education
SU	Stellenbosch University
TPD	Teacher Professional Development
TPACK	Technological Pedagogical Content Knowledge
TIMSS	Trends in International Mathematics and Science Study
USAASA	Universal Services and Access Agency of South Africa
WCED	Western Cape Education Department
WEF	World Economic Forum
Wits	University of the Witwatersrand

Chapter 1: Background: Context and Challenges

1.1 INTRODUCTION

This research was inspired by my interest in understanding the growing global trend of technology integration in education. Technology integration, which this study refers to as digital transformation, is linked to the improvement of education outcomes. Additionally, UNESCO (2023) indicates that the use of technology in teaching and learning is associated with an improvement in the quality of instruction and engagement and in learner support. In particular, technology integration using the dynamic software application GeoGebra in the teaching and learning of secondary mathematics promotes higher learning gains (Adelabu et al., 2022; Manganyana et al., 2020; Mthethwa et al., 2020; Mushipe & Ogbonnaya, 2019; Ogbonnaya & Mushipe, 2020).

However, it must be noted that technology integration in the teaching and learning of mathematics in secondary schools does not guarantee transformational use associated with deep conceptual understanding for improved learning gains. A study by Hojsted (2020) investigated the potential of the dynamic software environment (DGE) GeoGebra for reasoning competency in grades 7 and 9 in Danish schools. The study discovered that measuring and dragging are used to some degree, feedback to a lesser degree, while tracing is almost non-existent. The study further showed that there are signs that DGEs are used as a substitute for the paper-and-pencil environment to solve tasks that were originally designed for paper and pencil (this is the enhancement stage or early stage).

The integration of technology (e.g., dynamic software applications, such as GeoGebra and Geometer's Sketchpad, amongst others) in education is described by Puentedura's (2006) substitution-augmentation-modification-redefinition (SAMR) model (see Chapter 2 for details). In this model, the transformation level of technology integration is constituted by the modification and redefinition stages; the enhancement level, referred to here as the early stage, is constituted by the substitution and augmentation stages. Additionally, the transformation stage is linked to Hojsted's (2020) four dynamic software affordances, namely, feedback, dragging, measuring, and tracing; these affordances produce dynamic visual imagery that can be linked to deep conceptual understanding for improved educational outcomes.

Internationally, South Africa is ranked low in the quality of mathematics and science education, coming last out of 138 countries (WEF, 2015) and being placed 63rd out of 120 countries in the International Mathematics Olympiad (IMO) medal count (WEF, 2017). Additionally, the South African TIMSS 2019 score was 489 points below the centre of 500 points, with the Western Cape and Gauteng having TIMSS scores of 441 and 421 points, respectively. Furthermore, South Africa's poor performance in mathematics, despite the introduction of a White Paper on e-Education in 2006, 18 years ago, and the Professional Development Framework for Digital Learning (PDFL) in 2018, shows that technology integration, particularly in secondary mathematics, has not yielded the intended results of higher learning gains.

According to Reddy (2019, p.184), "South African mathematics achievement, though improving, is still low and unequal." The author adds that the "highest improvement was at the lower levels of the achievement spectrum, that is, for the most disadvantaged groups, probably as a result of social protection policies instituted by the state." The author further notes that inequalities in education continue, despite policies being in place, due to a lack of accompanying resources and support infrastructure for effective implementation. Moreover, the Reddy (2019, p.185) argues that:

> Disrupting inequalities will require political will, additional resources and support and the commitment from all members of society. The process to increase achievement levels is not linear or smooth. It will involve the interplay of home and school material conditions, accompanied by high quality classroom teaching and learning interactions. This process will take time and we must set realistic expectations for the changes.

However, it is also important to note that the implementation of digitally supported teaching and learning in South African schools generally faces several challenges. An investigation carried out by Mokotjo and Mokhele (2021, p.963) on the challenges faced by teachers on the integration of the dynamic software GeoGebra in the teaching of mathematics found "that SA high schools are being robbed and vandalised of ICT equipment due to security issues; each school owned only one data projector which stifles efforts to strengthen teachers' knowledge and skills in integration for GeoGebra in mathematics classrooms."

This shows that while the implementation of digitally supported teaching and learning of secondary mathematics has the potential to improve outcomes, challenges such as security and limited resource availability cannot be ignored. As indicated earlier, the availability and use of digital tools do not guarantee transformational use, which means that technology can be used in an enhancement manner, with no functional change (Hojsted, 2020; Puentedura, 2006). The studies that have been conducted in South Africa show better performance of the experimental group compared to the control group where the GeoGebra software is used; perhaps wide usage of the tool in the education system will reflect in the matriculation results. Nevertheless, technology integration levels (enhancement level or transformation level) were not assessed in these studies.

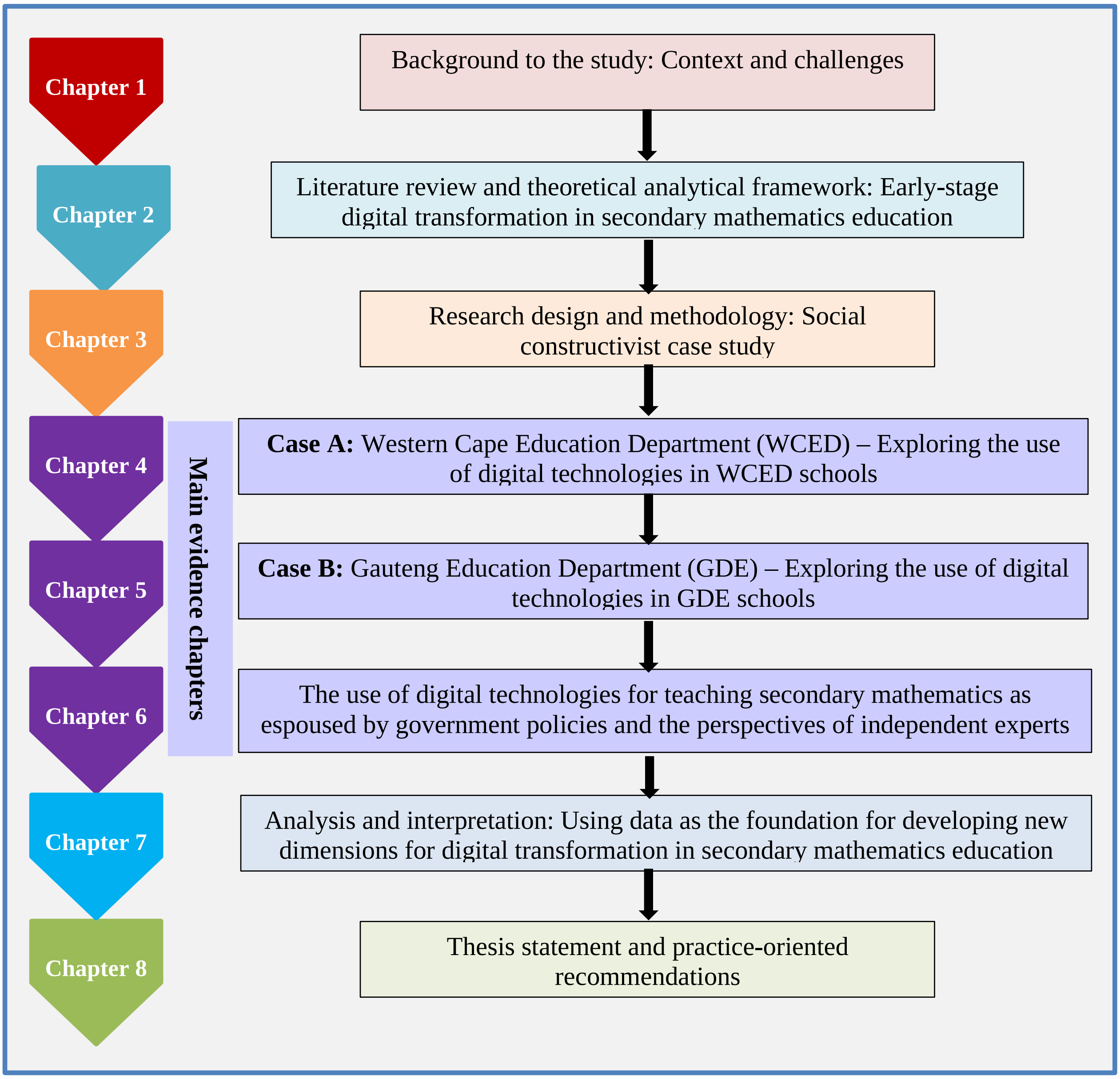
This study argues that the country is still in the early stages of digital transformation in secondary mathematics education and analyses why this is so. Previous studies have not thoroughly investigated the data and dimensions associated with shifting digital transformation in secondary mathematics education beyond the early stage (or transformation stage). Hence, this study makes the following claims:

Claim 1: South African secondary mathematics education is still at an early stage of digital transformation, equivalent to the enhancement stage of Puentedura's (2006) SAMR model. The evidence for this claim is the low pass rate in secondary school-level mathematics, low global rankings in mathematics, the prevalence of basic digital skills among teachers, and technology being used almost exclusively in a substitutional manner.

Claim 2: Digital transformation (DT) in secondary mathematics education can be shifted beyond the early stage by the application of the proposed DT-SME 2022 framework, which advocates that (i) educators need intermediate and advanced digital skills, because these are crucial for the successful implementation of digitally supported teaching of secondary school level mathematics; (ii) attention must be paid to digital leadership, including the establishment of a formal governance structure for the participation of all stakeholders during the design, implementation, and monitoring of digital education policy; (iii) an effective technical architecture is needed to address connectivity issues; and (iv) a constructive and enjoyable digital teaching experience is needed that encourages learning-centred (i.e., a balance between teacher- and learner-centred) pedagogical approaches. The evidence is in the data gained from document analysis, observations, and key respondent interviews.

To carry out the investigation, the study explores two cases (via document analysis, observations, and interviews): case study A, the Western Cape Education Department (WCED), and case study B, the Gauteng Department of Education (GDE) (see Chapter 2 for details). Additionally, the study examines the use of digital technologies for teaching secondary mathematics as espoused by government policy documents, including the perspectives of independent experts, both of which do not form part of the two case studies. The government policy documents considered are from the national government and the independent experts are academics located in various institutions around the country. The thinking and analysis presented in this social constructivist case study are based on trying to understand the world in which we live and work by developing subjective meanings of the lived experiences through understanding the language and actions (Creswell & Poth, 2018). Figure 1 shows the thesis flow chart.

Figure 1
Thesis flow chart



The following sections set out the research problem statement, the research purpose statement, the research questions, and the research aims and objectives. This is followed by a more detailed background to the research, which explains the rationale for the problem statement and research questions, the research methodology, the context of the case studies selected, and the contribution of the study, including its limitations and definitions of key concepts.

1.2 RESEARCH PROBLEM STATEMENT

In recent years, there has been growing concern about technology integration and its contribution to the improvement of education outcomes, particularly in the teaching and learning of mathematics in secondary schools. The Curriculum Assessment Policy Statement (CAPS) promotes the use of technology in the teaching and learning of mathematics (DBE, 2011). Research has shown that the use of technology in the classroom has the power to improve learner achievements (Makotjo & Mokhele, 2021). However, using technology in the teaching and learning of mathematics in secondary schools has not produced the expected high pass rates in mathematics for university entrance. In 2022, the mathematics pass rate in matric was 55 percent (DBE, 2022). A review by Bray and Tangney (2017, p. 268) showed that the most common goal of technology integration initiatives was to improve students' conceptual understanding (36%), followed by improved performance (31%), and then change in attitude (19%). The authors further discovered an important link between the use of technology to outsource the delivery of content and Puentedura's (2006) SAMR level of augmentation. Also, as indicated earlier, Hojsted (2020) also showed that the use of technology in Danish schools was at the SAMR substitution level. This shows that technology can be used in either an enhanced manner or a transformational manner. The SAMR enhancement level is constituted by the substitution and augmentation stages of technology integration, which this study equates to the early stage. Hojsted (2020) investigated the extent of the potential of the dynamic software application GeoGebra in relation to reasoning competency in Danish lower secondary schools. The study discovered that the use of technology in Danish schools was at the SAMR substitution level. The author adds that this indicates that technology is used as a substitute to solve activities that were initially designed for pencil and paper.

The eight mathematics competencies are described by Niss (2002): (i) mathematical thinking competency; (ii) problem handling competency; (iii) modelling competency; (iv) reasoning competency; (v) representations competency; (vi) symbols and formalism competency; (vii) communication competency; and (viii) aids and tools competency. The author describes reasoning mathematically as:

- following and assessing chains of arguments put forward by others;
- knowing what a mathematical proof is (and is not), and how it differs from other kinds of mathematical reasoning, e.g., heuristics;
- uncovering the basic ideas in a given line of argument (especially a proof), including distinguishing main lines from details, ideas from technicalities; and
- devising formal and informal mathematical arguments, and transforming heuristic arguments to valid proofs, i.e., proving statements.

Reasoning, according to the DBE's (2018d, p. 10) Mathematics Teaching and Learning Framework, is "justifying and explaining one's mathematical ideas and communicating them using mathematical language and symbols. Mathematical reasoning includes deductive and inductive reasoning processes." Additionally, reasoning competency is closely associated with conceptual understanding that explains the relationships between different concepts for the application and justification of ideas (DBE, 2018d). This study views mathematics reasoning competency as a key component of deep conceptual understanding that will critically improve education outcomes. As already indicated, this research study seeks to investigate approaches to shifting technology use, referred to here as digital transformation, beyond the early stage (or transformation level).

Previous studies on South African schools have not adequately studied the data and dimensions involved in shifting digital transformation in secondary mathematics teaching beyond the early stage. Hence, this research study seeks to answer the following question: How can digital transformation in secondary mathematics education shift beyond the early stage? This study seeks to reveal the important role of the digital skills of educators during the implementation of digitally supported teaching and learning of mathematics in South African secondary schools. It also investigates the role of leadership, infrastructure, and teacher practices during the implementation of digitally supported teaching in schools and provides practice-oriented recommendations.

1.3 RESEARCH PURPOSE STATEMENT

The purpose of this research study is to investigate approaches that can assist in shifting digital transformation in secondary mathematics education beyond the early stage. The research seeks to contribute to a specific narrow area of understanding and theorising digital transformation, using dynamic software applications in secondary mathematics teaching. The issue is important because the study moves from a grand theory discussion of digital transformation to highly specific digital transformation in education, particularly mathematics teaching in secondary schools. The study explores the role of the (i) digital skills of educators, (ii) education leadership, (iii) school digital infrastructure, and (iv) teachers' classroom practices. Data were collected via semi-structured interviews, document analysis, and participant observations.

1.4 RESEARCH AIMS AND OBJECTIVES

The overall research aim of the study is to investigate approaches to shifting digital transformation in secondary mathematics education beyond the early stage. The research objectives of the study are as follows:

(i) to investigate approaches to professional development that can advance the digital skills of educators for effective curriculum design and delivery for mathematics teaching and learning;

(ii) to determine the role of leadership (at both the provincial and district levels) in promoting or impeding (intentionally or unintentionally) the implementation of digitally supported teaching in schools;

(iii) to examine strategies for ensuring adequate school digital infrastructure in schools;

(iv) to investigate the role of digitally supported teaching in improving the digital teaching experience in secondary mathematics education.

1.5 RESEARCH QUESTIONS

Main research question:

The main research question is formulated as follows: How can digital transformation in secondary mathematics education shift beyond the early stage?

Research sub-questions:

The main research question is broken down into four research sub-questions to address the elements of the research specific to secondary mathematics education:

(i) How does professional development for educators advance the digital skills of educators for effective curriculum design and delivery for mathematics teaching and learning (human actors)?

(ii) How does the exercise of leadership (at both the provincial and district levels) promote or impede (intentionally or unintentionally) the implementation of digitally supported teaching in schools (human actors)?

(iii) What can be done to ensure that there is adequate school digital infrastructure (non-human actors)?

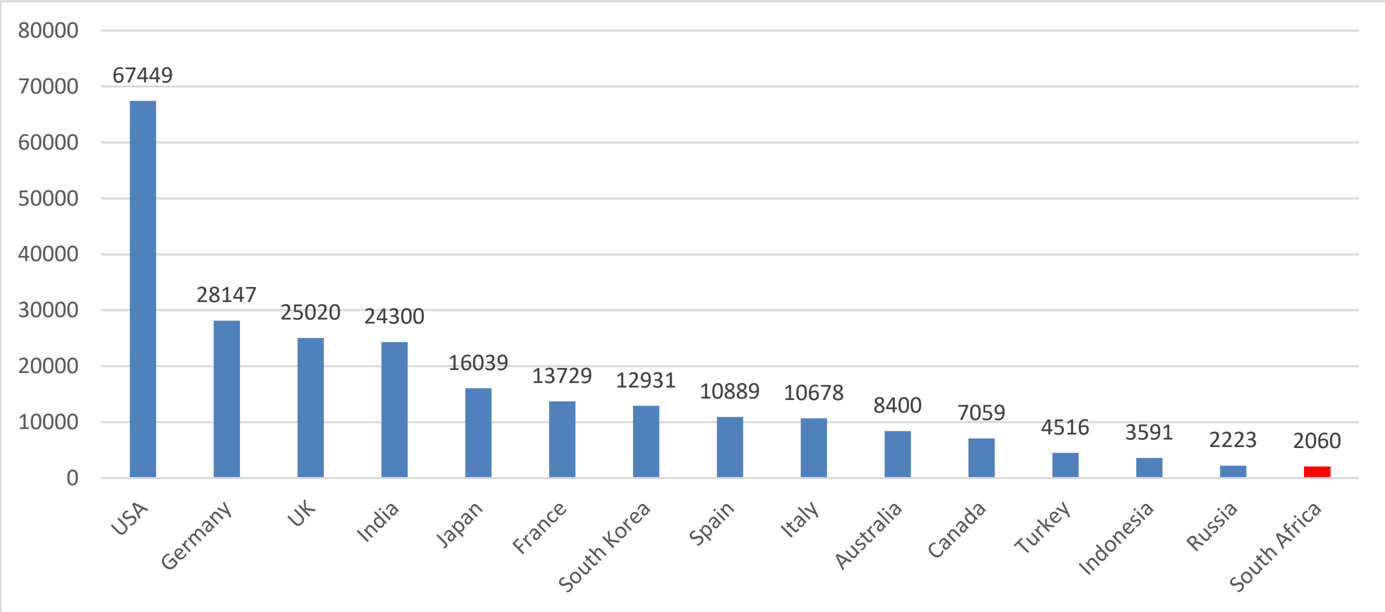
(iv) How can digitally supported teaching improve the digital teaching experience in secondary mathematics education (human actors)?

1.6 BACKGROUND DISCUSSION: RATIONALE FOR THE RESEARCH PROBLEM STATEMENT

The science, technology, and innovation (STI) system is driven by digitisation that is linked to science and engineering degrees, which are based on mathematics. Hanna (2016) argues that countries are experiencing a challenge in transitioning to the information society or digital innovation economy that is driven by digitisation (information, products, and processes) due to a lack of the advanced digital skills that are associated with science and engineering degrees. These challenges are apparent in three areas: Global Innovation Index (GII) rankings, competitiveness, and human resource capacity. The World Economic Forum (WEF) Report of 2017 placed South Africa at 58th out of 126 countries on the Global Innovation Index (GII). Additionally, the World Economic Forum Competitiveness Report of 2017–2018 (WEF, 2018) cites the shortage of skilled personnel and digital infrastructure as one of the factors contributing to South Africa’s low rankings. The White Paper on Science, Technology and Innovation of 2019 acknowledges that South Africa’s predicament of a lower skill base compared to other innovative economies is due to the poor quality of mathematics education, which impedes the progression to science and engineering degrees (DST, 2019).

Furthermore, with a population of 60 million and a GDP of USD349 billion in 2017, South Africa was ranked 61st out of 137 in the Global Competitiveness Report (WEF, 2017), significantly behind countries that are much smaller in economic terms, such as Lithuania (41st), with a population of 3 million and a GDP of USD47 billion, and Rwanda (58th) with a population of 12 million and a GDP of USD9 billion. Moreover, South Africa has constrained human resource capacity for research (see Figure 2) and produced a smaller number of PhDs (2,060) in 2014, compared to countries such as France (13,729) and the United Kingdom (25,020) with similar population sizes. By 2017 this figure had risen slightly to 2,797 PhDs. Also, the shortage of advanced digital skills is viewed as a major stumbling block in designing artificial intelligence (AI) applications. Worldwide there is a limited number of computer scientists who are capable of building AI systems, with "only 22,000 PhD-level, and many large companies are competing to attract them" and "at least 10,000 open positions existing in the United States alone" (WEF, 2019, p. 10). Figure 2 shows the countries with the most PhD graduates.

Figure 2
Countries with the most PhD graduates



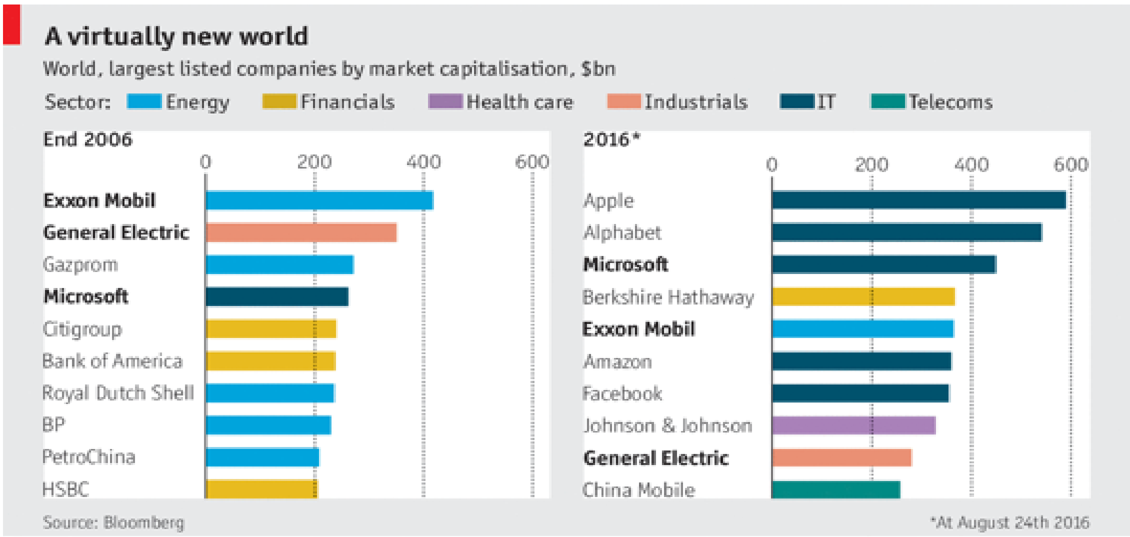
Source: Adapted from OECD, 2016

For countries to transition to the information society, a strong mathematics pipeline is needed from the lower grades to university for science- and engineering-related advanced digital skills i.e., coding, robotics, 3D printing, and AI, among others. These low rankings show that the country needs to improve its mathematics pipeline to transition to an information society.

There is also a shift in the world economy from a fossil fuel-dominated economy to a digital innovation economy. The top three listed companies in 2006 (see Figure 3) were mainly oil companies; these were replaced by primarily digital innovation companies in 2016 (Bloomberg, 2018). While innovations such as robotics for teaching and learning secondary mathematics contribute to increasing interest in science and engineering (Eguchi, 2014; Filippov et al., 2017), they are not sufficient for developing the associated advanced digital skills degrees whose foundation is mathematics. Additionally, countries with a better performance in secondary mathematics, which is the foundation of the science and engineering degrees that are instrumental in developing advanced digital skills, are better positioned in the digital innovation economy.

Figure 3

Global emergence of a digital innovation economy: Top ten companies in 2006 and 2016



Source: Bloomberg, 2016

The use of digital technologies in the classroom requires digital skills to operate devices and related software applications. Digital skills are becoming a common requirement for employment, communications, and job searches in this fast-changing digital era, and people are required to continually update their skills (ITU, 2018a). Additionally, the wide range of digital skills required in the digital economy leads to a further need for specific outputs or complementary skills to perform a job (ITU & ILO, 2018). Furthermore, the need for digital skills is also applicable in the education sector, because educators and learners should possess the relevant digital skills necessary for successfully embedding digital technologies in schools for teaching, learning, and assessment practices (PDST, 2017). To address the low level of digital skills of educators and learners, countries like Australia are constantly upskilling educators and learners through partnerships with the private sector, and such countries even have budget allocations for digital skills development (CSER, 2017). The South African government also views advanced digital skills as one of the critical skill sets needed in the country. In 2019 President Ramaphosa acknowledged that "digital skills, such as coding, are essential to integration in work and should be accompanied by soft skills such as emotional intelligence, interpersonal skills, and excellent communication skills" (Ramaphosa, 2019). Table 1 provides an overview of some of the available digital skills frameworks.

Table 1

Overview of some of the digital skills frameworks

Source	Dimensions
ITU (2018a)	Basic, intermediate, and advanced digital skills
Development Economics (2013)	Advanced-level digital skills, intermediate-level digital skills, and entry-level digital skills
DIGICOMP (2013)	Information, communication, content creation, safety, and problem-solving
Ala-Mutka (2011)	Computer literacy/technology literacy, internet (or network) literacy, and digital literacy
DigEuLit Project (2005)	Digital competence, digital usage, and digital transformation

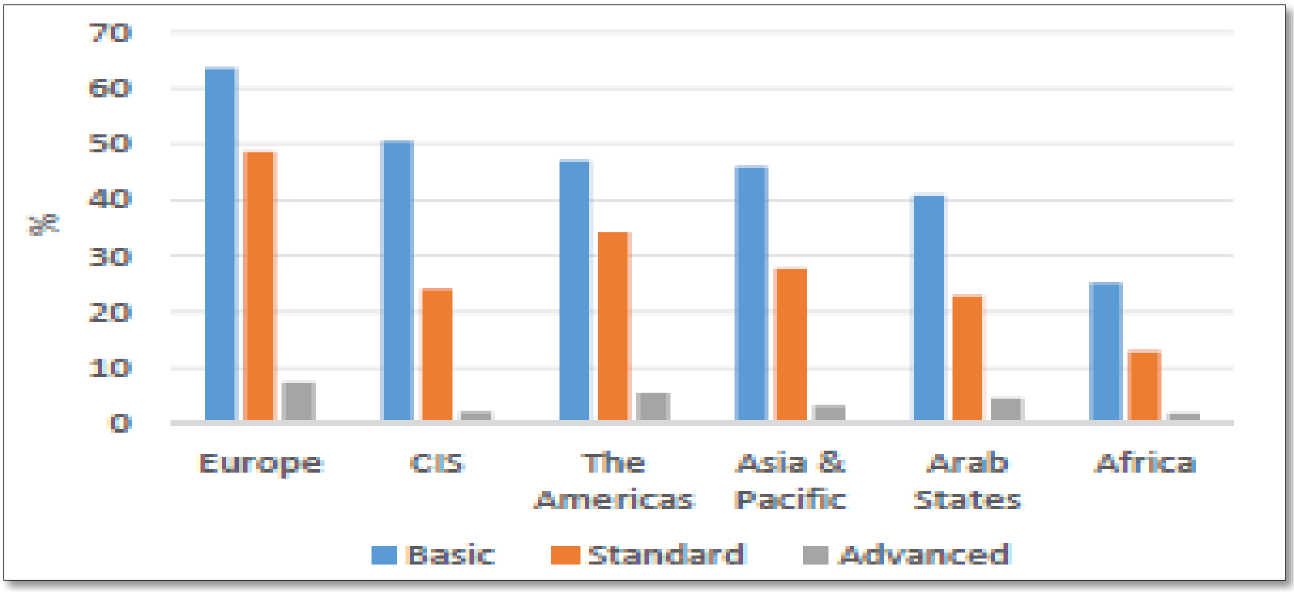
OECD (2004)	Basic users, advanced users, and ICT specialists
E-skills Forum (2004)	ICT user skills, ICT practitioners, and e-business skills
21st-century digital skills (van Laar et al., 2017)	Core skills: technical, information management, communication, collaboration, creativity, critical thinking, and problem-solving. Contextual skills: ethical awareness, cultural awareness, flexibility, self-direction, and lifelong learning

Source: Adapted from ECORYS, 2016; ITU, 2018a; van Laar et al., 2017

In this research, the ITU's (2018a) three broad categories, namely basic, intermediate, and advanced digital skills, will form the basis for analysing the digital skills of educators. Broadly, this study considers the digital skills of educators in line with the ITU's (2018a) categorisation as follows: (i) basic digital skills – deliver (use) content; (ii) intermediate digital skills – search and deliver (use) content; and (iii) advanced digital skills – create, search, and deliver (use) content. This study also regards intermediate and advanced digital skills as key for the successful transformational use of dynamic software applications in the teaching of secondary mathematics in schools.

According to AXIOMQ (2023), augmented reality (AR) and simulations, adaptive learning, education technologies based on artificial intelligence (AI), use of 5G technologies in education, automation, competency-based education, and learning analytics are the seven technologies that would reshape education in 2023. These technologies, whose foundation is mathematics, require advanced digital skills, which are less than 10 percent of people across all regions of the world have these skills (ITU, 2018b). Therefore, the low digital skills levels also apply to the education sector, where teachers and learners should be able to operate dynamic software applications or digital tools for the teaching and learning of secondary mathematics in schools. Figure 4 shows the global percentages of individuals with digital skills by region.

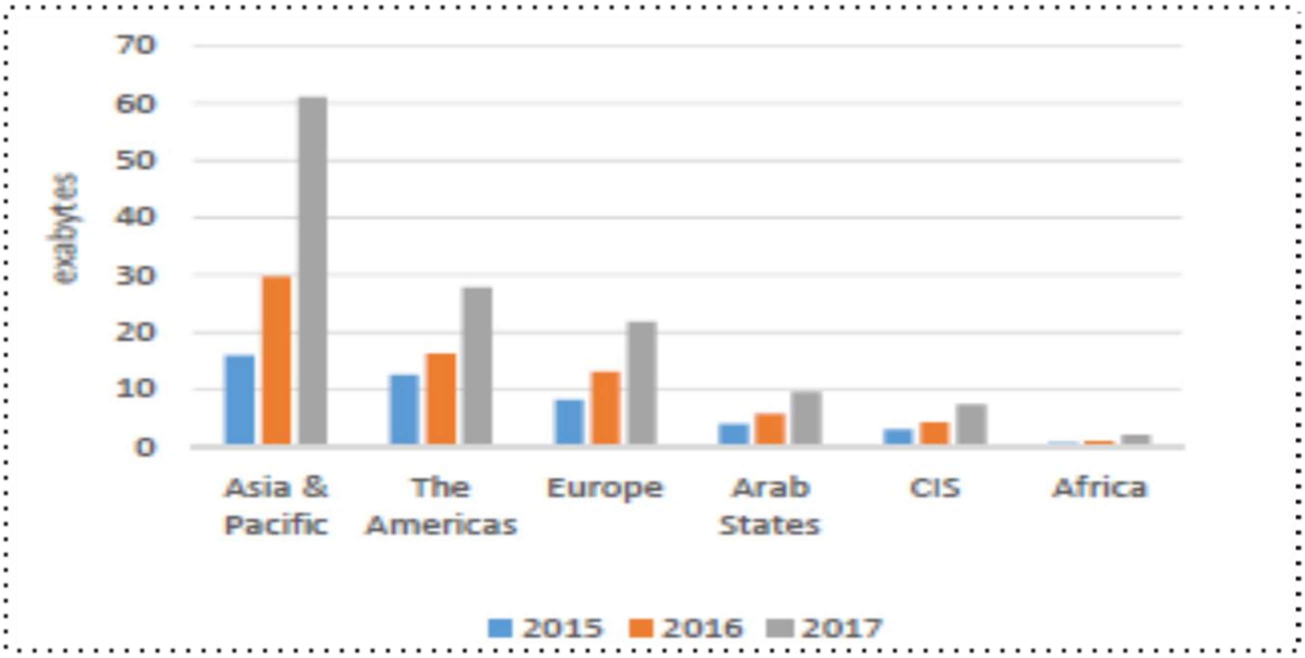
Figure 4
Percentage of individuals with digital skills by region



Source: ITU, 2018b

The proliferation of mobile technologies globally has given rise to an explosion in mobile-broadband data traffic, which can be attributed to mobile broadband connections through smartphones and network expansion. A close look at mobile-broadband traffic indicates that the African continent lags behind other parts of the world (ITU, 2017, p. 10). Unfortunately, the ITU report gives a mobile-broadband subscriber perspective and does not clarify mobile broadband availability, accessibility, and cost for enjoyable digital teaching experiences and outcomes. However, the ITU indicates that the primary users of broadband internet are high-income earners living in metropolitan areas, according to the World Bank (2017). This shows the rural–urban disparities in the provision of broadband-like internet connectivity to enable the digitally supported teaching of mathematics in public secondary schools; the majority of schools are in rural areas. Figure 5 shows the increase in mobile-broadband traffic by region and exabytes.

Figure 5
Mobile-broadband traffic by region and exabytes



Source: ITU, 2018b

Leadership at all levels is essential throughout the deployment of digitally enhanced mathematics teaching in secondary schools. One of the most significant parts of policy and strategy implementation is the supply of resources, support, teacher conditions, and training at the school level, among other things. According to EDT (2014, p.7), the success of school leadership depends on nine dimensions: (i) the definition of vision, values, and direction; (ii) improving conditions for teaching and learning; (iii) redesigning the organisation; (iv) enhancing teaching and learning; (v) redesigning and enriching the curriculum; (vi) enhancing teacher quality (including succession planning); (vii) building relationships within the school community; (viii) building relationships outside the school community; and (ix) placing an emphasis on common values. Furthermore, an earlier OECD report from 2008 identified four major policy levers for improving school leadership: (i) (re)defining school leadership responsibilities – focus on roles that can improve school results; (ii) distributing school leadership – engaging and recognising broader participation in leadership teams; (iii) developing skills for effective school leadership – across different stages of practice; and (iv) making school leadership an appealing profession. Pont et al. (2008, p. 9) emphasise the significance of school leadership:

> School leadership has become a priority in education policy agendas internationally. It plays a crucial role in improving school outcomes by influencing the motivations and capacities of teachers and the school climate and environment. Effective school leadership is essential to improve the efficiency and equity of schooling. As countries seek to adapt their education systems to the needs of contemporary society, expectations for schools and school leaders are changing. Many countries have moved towards decentralisation, making schools more autonomous in their decision-making and holding them more accountable for results. At the same time, the requirement to improve overall student performance while serving more diverse student populations is putting schools under pressure to use more evidence-based teaching practices.

The leadership aspects described above are closely related to the creation of an environment that is conducive to teaching. While the national education department leadership is responsible for developing policies, strategies, and curricula, district-level and school-level leadership is critical for implementing these policies and strategies by creating such an environment, which includes resources, support, and training, among other things. Thus, this study investigates the role of leadership at the provincial and district levels in encouraging or impeding the deployment of digitally enabled mathematics teaching in secondary schools.

South Africa's digital infrastructure is directly related to the availability of school-level digital infrastructure. This is why schools in rural and peri-urban areas are always behind in terms of technology availability, as most telecom service providers prioritise dense urban areas for commercial reasons. Furthermore, the country's mobile communications infrastructure is rapidly expanding in comparison to fixed lines. According to the ICASA study on the state of the ICT industry in 2016, mobile phones outnumber landline telephones, with mobile-cellular subscriptions reaching 159.27% per 100 inhabitants, and landlines accounting for only 4% of total subscribers (ICASA, 2016). Furthermore, while mobile phones are common in the country, their use in the classroom is mostly for content consumption. Furthermore, the study strongly advocates the use of laptops for digital mathematics instruction in secondary schools because content production (referred to as course design in this study) requires intermediate (search and use) and advanced (create, search, and use) digital abilities. As previously noted, basic digital abilities are only linked to use.

Moreover, the number of learners in the public education system is important in the rollout of digital infrastructure in schools (connectivity, bandwidth, devices, apps, and content, amongst others). In 2018, there were 4,568,673 learners in secondary schools; 7,509,476 learners in primary schools; 2,710,979 learners in technical and vocational education and training (TVET) colleges; and 7,352 "other" learners (DBE, 2018a). The latest figures in 2022 show that there were about 13,409,249 learners and 447,123 educators (DBE, 2022). This implies that policymakers should factor in the number of secondary mathematics learners for one laptop per learner strategies, including the deployment of related infrastructure, as an example. Figure 6 shows the school digital infrastructure requirements for the public education system.

Figure 6

School digital infrastructure requirements of the public education system

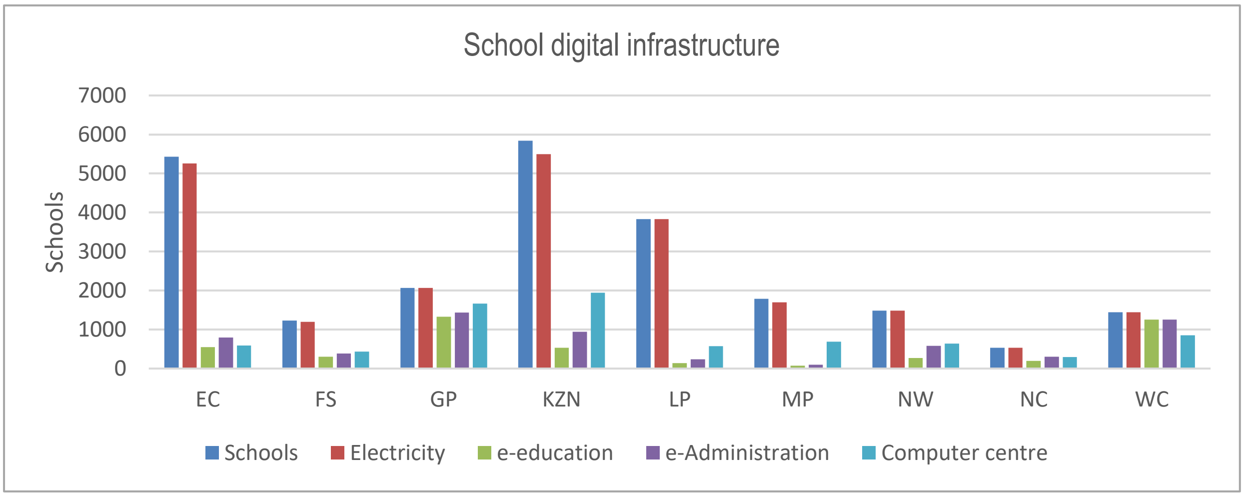
National department (1)	•Administration systems to inform policy; feedback on curriculum
Provincial education departments (9)	•Policy and administration data on schools, educators, and learners
Districts (75)	•Policy implementation and administration on schools, educators, and learners
Schools (24,894)	•Internet access, LAN, WAN, physical security, administration systems
Classrooms (320,000)	•LAN, projector and/or whiteboard, AV equipment, physical security
Educators (447,123)	•Laptop or desktop PC access, curriculum content, training and refresher courses
Learners (13,409,249)	•Device access – preferably personal, network access, login, BYOD, etc.

Source: Adapted from BMI-T, 2016; DBE, 2018a; DBE, 2021b

The adoption of digital infrastructure in schools also raises some important security challenges. For example, in 2018, thieves stole the following items: 185 tablets, eight laptops, two projectors, three desktop PCs, a plasma TV set, and R500 cash by tying up two security guards and breaking down the main vault with access keys (MyBroadband, 2018). Hence, a comprehensive approach is required to guarantee that infrastructure deployment is accompanied by appropriate security measures, training, and support, among other things. This can be accomplished through the creation of a technical architecture for schools, which is the goal of this study. It should also be highlighted that infrastructure deployment in schools does not always result in utilisation (Hojsted, 2020).

The distribution of digital infrastructure in public schools is skewed towards more urbanised provinces. The Western Cape and Gauteng are more urbanised provinces, as opposed to the Eastern Cape and KwaZulu-Natal, which are more rural, for example. Additionally, in the case of e-education, disparities can be observed between urbanised and more rural provinces, indicating that technology integration is more likely to occur in urban schools than in their rural counterparts. These are some of the factors considered by this study. The two case studies (WCED and GDE) were both conducted in urbanised provinces with no significant disparities concerning digital infrastructure in schools; these cases are therefore complementary. Figure 7 depicts the spread of school digital infrastructure, which includes electricity and computer centres. The x-axis legend letters represent the nine provinces of South Africa, namely Eastern Cape (EC), Free State (FS), Gauteng Province (GP), KwaZulu-Natal (KZN), Limpopo Province (LP), Mpumalanga Province (MP) North West (NW), Northern Cape (NC), and Western Cape (WC).

Figure 7
School digital infrastructure



Source: DBE, 2017

The DBE (2022) listed 11 categories of technologies or software applications that South Africa's curriculum, CAPS, has aligned for android, namely agricultural science, business studies, general learning apps, geography, inclusive education, languages, life sciences, mathematical literacy, physical science, safety, and mathematics. Additionally, the DBE identified 18 applications for secondary mathematics. Table 2 depicts 18 apps that cover the mathematics curriculum for grades 8 and 9.

Table 2
CAPS-aligned secondary mathematics apps for android

App	Grades	Content area	Curriculum topic
1. Complete Mathematics	8–12	Functions, algebra, probability, Euclidean geometry and measurement, trigonometry, statistics, analytical geometry	Basic mathematics, formula and equations, variation and proportion, exponents, logarithms, sequence, set, quadratic equations, surds, trigonometry, coordinate geometry, solid geometry, statistics, probability
2. Financial Calculator	9–12	Financial mathematics	Financial mathematics
3. GeoGebra	8–12	Euclidean geometry, functions	Circle geometry, functions
4. iTooch 7th Grade Math	9	Numbers, operations and relationships; functions, space and shape	

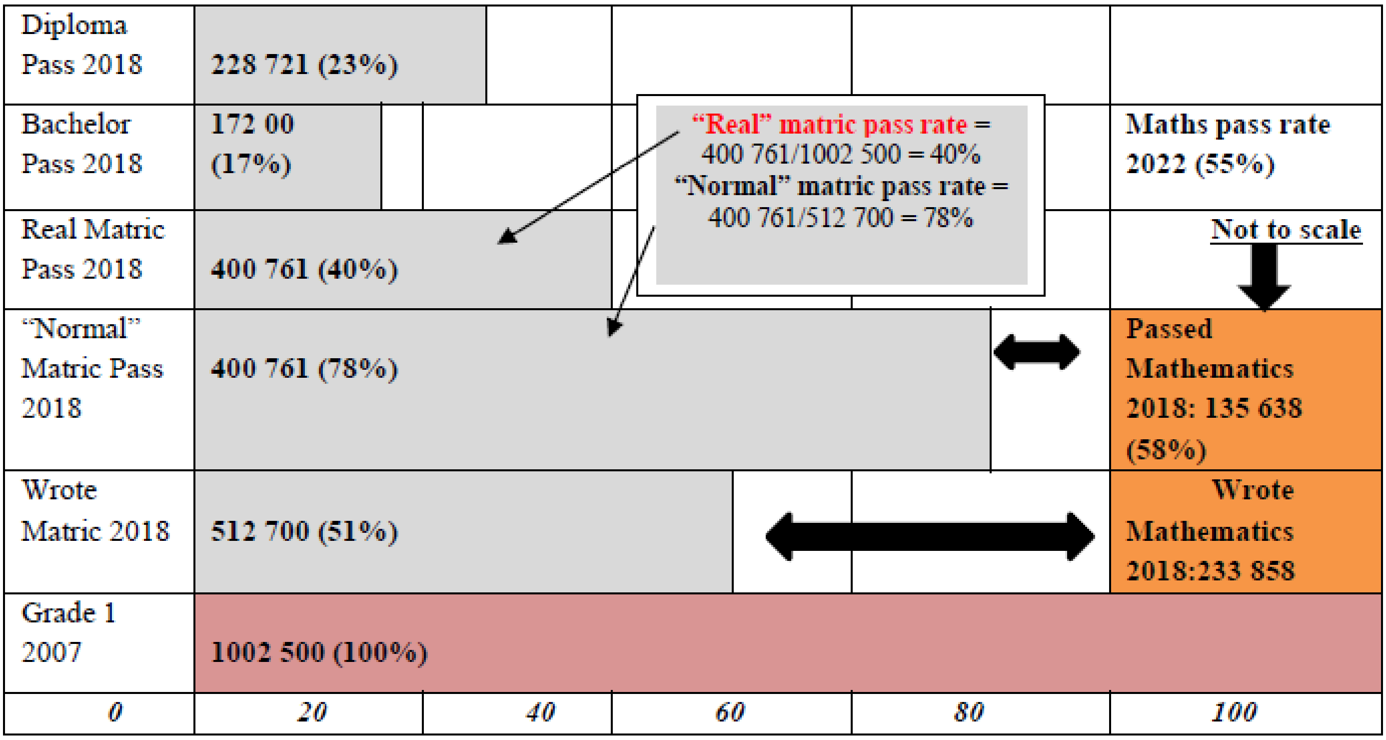
5. Kal Scientific Calculator	10–12	General	All [It is a scientific calculator]
6. Mathematics	10–12	Functions, algebra, probability, Euclidean geometry, measurement	Functions, algebra, probability, Euclidean geometry, measurement
7. Mathematics 2015	12	All	All [A package of NSC past exam papers from 2010 to date to trigger effective studying in preparation for the NSC final exams]
8. Mathway	9–12	Algebra, trigonometry, calculus, statistics	Algebra, trigonometry, calculus, statistics [CAS and calculator]
9. Math Exponents	8–9	Exponents, radicals	Algebra [exponents and radicals quiz questions]
10. Mathematics Formula List	9	All content areas except data handling	Quadratic equations, number system, divisibility rules, progressions, squares, cubes and fractions, graphs, geometry, trigonometry i.e., grade 9 and beyond
11. Math – mathematics is easy	12	Algebra, geometry, statistics	Algebra, geometry, statistics and more
12. Mathinary math	10–12	Geometry, algebra, probability, statistics	Geometry, algebra, probability, statistics
13. Mathematics Tests Grades 5–8	7–9	Number concepts including powers, fractions, decimals, percentages, and rounding off; shape and space.	
14. Math Tricks	5–8	Numbers and operations	Develop number concepts and calculation skills
15. Pocket Mathematics	10–12	Algebra, sets, classification of numbers, expressions, exponents, functions	Functions, algebra
16. Probability Mathematics	11–12	Probability	Probability formulas
17. Trigonometry Mathematics	10–12	Trigonometry	Trigonometric formulas and identities
18. Viewer for Khan Academy	6–12	All topics	All topics [Contains video explanations of many topics]

Source: DBE, 2022

South Africa is underperforming in both education system quality and mathematics. The country's education quality is ranked 114th out of 137 countries, and its primary education ranking is even worse (WEF, 2017). Figure 8 provides a snapshot of the public education system's performance.

Figure 8

Public education system performance



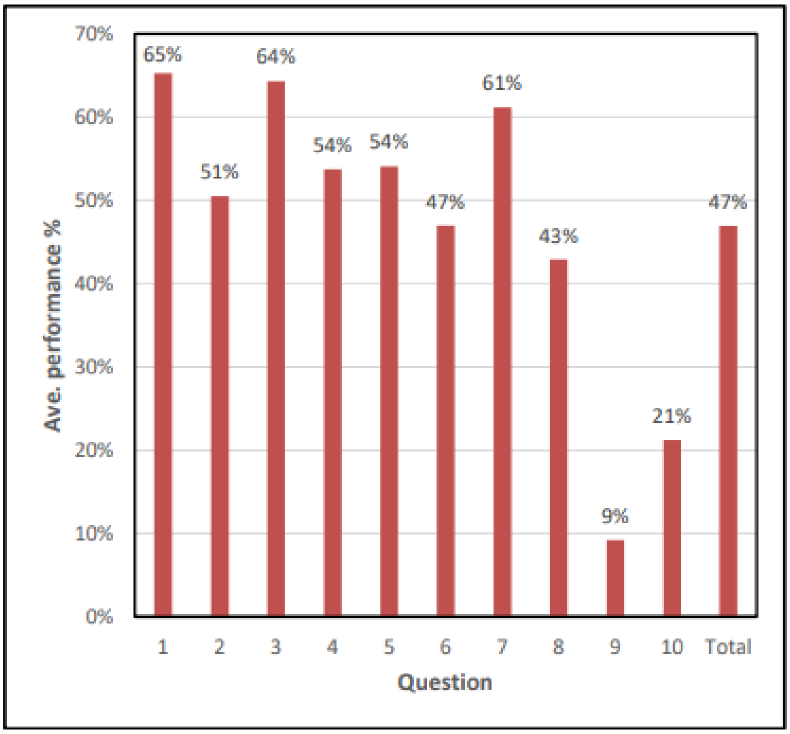
Source: Adapted from DBE, 2018a; Spaull, 2018

Additionally, South Africa is ranked 128th out of 137 nations for the quality of mathematics and science education, and is among the worst-performing countries, together with Mozambique (130th), Brazil (131st), Yemen (135th), and Lesotho (137th) (WEF, 2017). Furthermore, Spaull (2018) demonstrates the inadequacy of the education system by tracing the matriculants of 2018 who started grade 1 in 2007, revealing a "real matric pass rate" of 40%, implying that more than half of learners failed one or more years at school or dropped out completely. Moreover, for the past five years, national mathematics performance has remained below 60%: 58% in 2018, 54.6% in 2019, 53.8% in 2020, 57.6% in 2021, and 55% in 2022. Only 50% of matriculants with bachelor passes in mathematics are admitted to university to pursue science and engineering degrees, which are critical for the advanced digital skills that can transform South Africa into a digital innovation economy.

Furthermore, in algebra, the average performance in functions, calculus, and probabilities was below 50% in 2022 (DBE, 2022). Figure 9 shows the average performance per question in matric paper 1.

Figure 9

Average performance per question in paper 1



Q	Topics
1	Equations, Inequalities and Algebraic Manipulation
2	Number Patterns and Sequences
3	Number Patterns and Sequences
4	Functions and Graphs
5	Functions and Graphs
6	Functions and Graphs
7	Finance
8	Calculus
9	Calculus
10	Probability and Counting

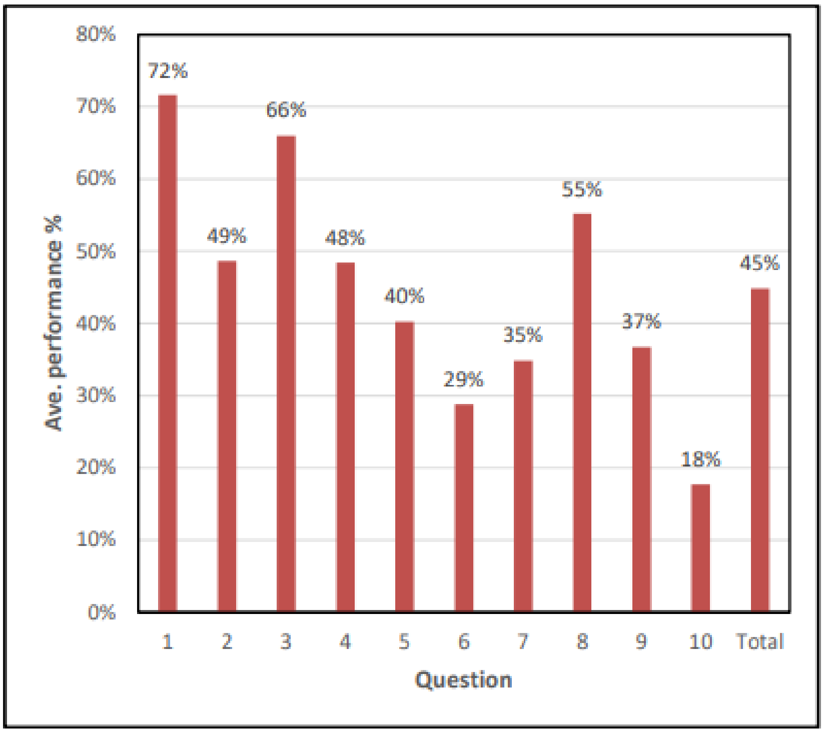
Source: DBE, 2022, p. 188 – Diagnostic Report

The DBE's (2022, p. 188) diagnostic report indicates that most "of the candidates did not attempt this question because they were unable to determine the distance function from the given information. Some candidates used trial and error to obtain the minimum distance between the points. They were not awarded any marks."

Moreover, in geometry, the average performance in data handling, analytical geometry, trigonometry, and geometry was below 50% in 2022 (DBE, 2022). The DBE's (2022, p. 188) diagnostic report recommends that "more time needs to be spent on the teaching of Euclidean Geometry in all grades. More practice in Grade 11 and 12 Euclidean Geometry will help learners understand theorems and diagram analysis. They should read the given information carefully without making any assumptions. This work covered in class must include different activities and all levels of the taxonomy." The use of dynamic software applications such as Excel, GeoGebra, and Geometer's Sketchpad, among others, can be useful in some of the content areas such as calculus, trigonometry, and geometry. Figure 10 shows the average performance per question in matric paper 2.

Figure 10

Average performance per question in paper 2



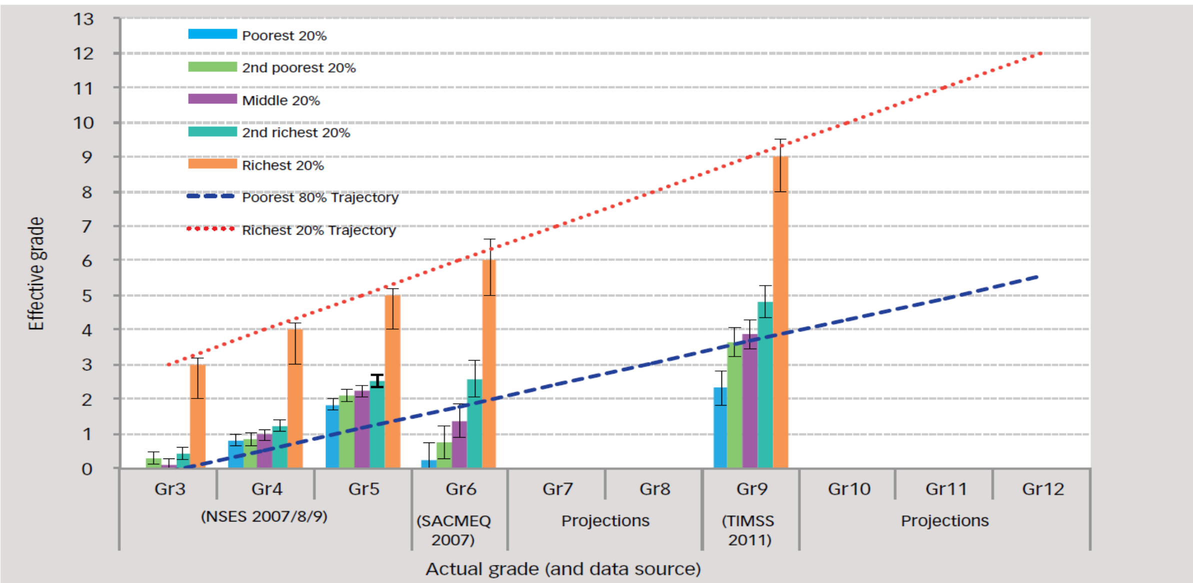
Q	Topic(s)
1	Data Handling
2	Data Handling
3	Analytical Geometry
4	Analytical Geometry
5	Trigonometry
6	Trigonometry
7	Trigonometry
8	Euclidean Geometry
9	Euclidean Geometry
10	Euclidean Geometry

Source: DBE, 2022, p. 188 – Diagnostic Report

Mathematics achievement in schools may be influenced by socioeconomic class. Better performance is associated with students from higher-income households. According to Spaull (2013, p. 36), "children from poor households in South Africa, who are the majority, are starting and staying behind" in what is referred to as the "poverty trap". This demonstrates that mathematics is not just a basis for science and engineering degrees (advanced digital abilities), but is also critical for improving individuals' socioeconomic well-being and overcoming the legacy of apartheid in South Africa. Figure 11 displays the mathematical learning routes according to socioeconomic position.

Figure 11

Mathematics learning path by socio-economic status



Source: Adapted from Spaull, 2013

Furthermore, the national poverty rating of schools (quintiles) is used to categorise South African schools for funding allocation purposes. Public schools in the country are divided into five quintiles, with quintile 1 being the "poorest" schools and quintile 5 being the "least poor" schools (WCED, 2013). The average mathematics achievement scores for learners in quintile 1, 2, 3, and 4 schools were not statistically different. The average achievement score of learners in quintile 5 schools was slightly above the TIMSS centre point and significantly higher than the average achievement scores of learners in quintile 1, 2, 3, and 4 schools (Reddy et al., 2022). Table 3 shows the national poverty rankings for schools.

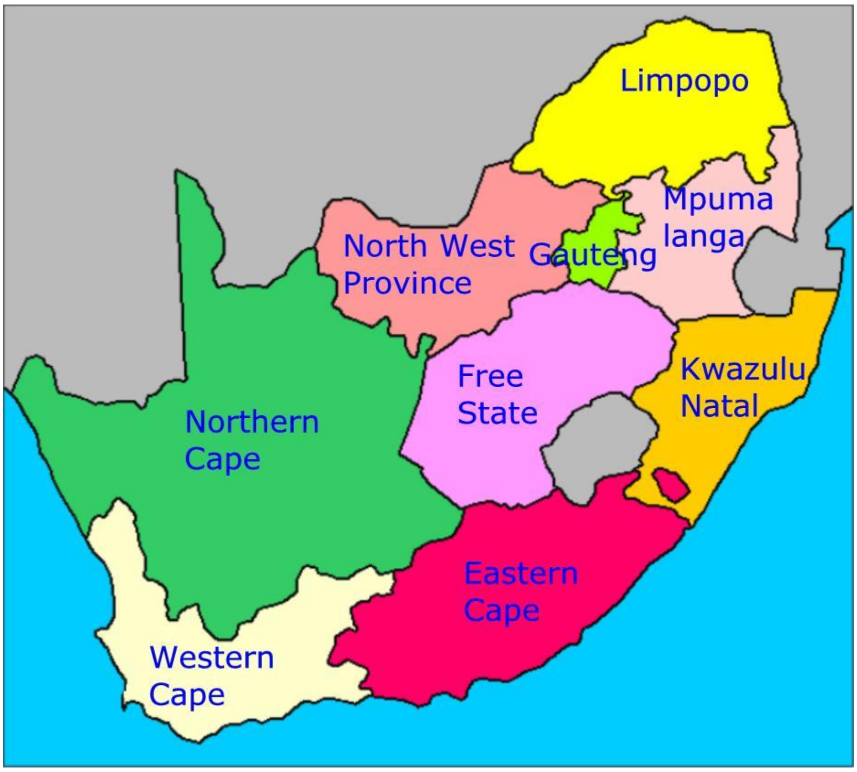
Table 3
National poverty ranking of schools in 2017

National Quintiles						
Province	**1**	**2**	**3**	**4**	**5**	**Total**
Eastern Cape (EC)	27.3%	24.7%	19.6%	17.0%	11.4%	100%
Free State (FS)	20.5%	20.9%	22.4%	20.8%	15.4%	100%
Gauteng (GP)	**14.1%**	**14.7%**	**17.9%**	**21.9%**	**31.4%**	**100%**
KwaZulu-Natal (KZN)	22.1%	23.2%	20.2%	18.7%	15.8%	100%
Limpopo (LP)	28.2%	24.6%	24.2%	14.9%	8.0%	100%
Mpumalanga (MP)	23.1%	24.1%	21.5%	17.7%	13.5%	100%
Northern Cape (NC)	21.5%	19.3%	20.7%	21.4%	17.1%	100%
North West (NW)	25.6%	22.3%	20.8%	17.6%	13.7%	100%
Western Cape (WC)	**8.6%**	**13.3%**	**18.4%**	**28.0%**	**31.7%**	**100%**
South Africa (SA)	20.0%	20.0%	20.0%	20.0%	20.0%	100%

Source: Adapted from White & van Dyk, 2019

It can be noted that in the Western Cape and Gauteng, over 30% of schools are in quintile 5, whereas in the rest of the provinces, between 8% and 15% of schools are in quintile 5. Figure 12 shows South Africa's nine provinces.

Figure 12
Nine provinces of South Africa



Source: South Africa Travel Online, 2023

1.7 NATURE OF THE STUDY: SOCIOTECHNICAL PARADIGM, ORIGINALITY, COMPLEXITY, AND INTERDISCIPLINARITY

The use of digital technologies for the teaching and learning of mathematics in secondary schools can be better understood using a sociotechnical perspective. The sociotechnical perspective is linked to activities that involve people, goals, processes, culture, digital technology, and infrastructure (Rowan & Brown, 2003). This study adopted a sociotechnical perspective as described by Davis and James (2013) and Markard et al. (2016) to investigate how teachers use digital technologies in the teaching and learning of mathematics in the secondary school context. Additionally, the research is claiming originality on the following grounds: (i) originality in the research data; and (ii) originality as "potentially publishable" (Cryer, 2006). Furthermore, this research depicts complex system characteristics due to the non-linear cause-and-effect relationships among school elements such as professional development of educators, teaching, and learning (Cochran-Smith et al., 2014; Hetherington, 2013). Moreover, this is an interdisciplinary study that seeks to obtain a holistic picture through the investigation of perspectives from mainly two disciplines, namely technology and education (Chavarro et al., 2014; Knight et al., 2013; Wang et al., 2015). This is a sociotechnical case study in which two cases are investigated, namely case study A (WCED) and complementary case study B (GDE).

1.8 SIGNIFICANCE OF THE STUDY

The purpose of this research is to explore approaches to shifting digital transformation in secondary mathematics education beyond the early stage. It seeks to examine and analyse the views of key actors (teachers, principals, district officials, local economic development agency (LEDA) representatives, academic experts, and independent experts) with regard to four dimensions of the study, namely the digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital experience.

This study is aligned with the DBE's initiative to promote the use of technology for teaching and learning by initially introducing the White Paper on e-Education (DBE, 2004) and, more recently, the Professional Development Framework for Digital Learning (DBE, 2018c). This study will show that the digital skills of educators, leadership at all levels, school digital infrastructure, and digital teaching experience are critical for successful technology integration in secondary education. Additionally, the study will show that transformational ways of teaching and learning using technology have the potential to improve learners' matriculation results, thus giving them access to tertiary institutions for science and engineering careers.

This study seeks to contribute to a narrow area of digital transformation, which is digital transformation in secondary mathematics education. The findings of this study will help secondary mathematics teachers, principals, policymakers, and academics to understand that the digitally supported teaching of secondary mathematics is a complex and interdisciplinary phenomenon that requires an ecosystem approach. The study offers insights to secondary mathematics educators and mathematics specialists in the DBE and to teacher professional development (TPD) programmes at universities.

1.9 LIMITATIONS OF THE STUDY

The study draws data from only 24 actors in the education sector, including mathematics teachers, principals, district officials, academic experts (mathematics and digital transformation), and independent experts who are closely involved in the use of technology for teaching mathematics in secondary schools in South Africa. These actors are based in the Western Cape and Gauteng. The study focuses on investigating approaches to shifting digital transformation in secondary mathematics education beyond the early stage i.e., transformational ways of teaching and learning mathematics in South African high schools. Some delays in research were experienced as a result of gatekeepers such as personal assistants, COVID-19 restrictions, and some participants' inadequate online digital skills when using the virtual platforms, among others.

Furthermore, information that is not credible is another possible limitation that the study mitigated by gathering information from various sources (triangulation). The researcher minimised the study limitations by interviewing critical informants, using careful design, and corroborating the interviews with observations and document analysis. Therefore, the results of this study will reflect the findings mainly from document analysis, observations, and interviews, meaning that the study involved data triangulation. The design framework will provide a basis for future research and further development.

1.10 DEFINITION OF KEY TERMS

This section provides an explanation of the key concepts and phrases used in this research.

Dynamic geometry environments (DGEs), also referred to as dynamic software applications or digital tools or tools: DGEs possess transformational affordances that allow the user to receive feedback, drag, measure, and trace (Hojsted, 2020) during digital teaching and learning. DGEs are a dynamic mathematics tool for visualising and exploring geometry and algebra. The drag mode allows the user to drag the points of a given sketch, for example, and the diagram will change according to the new position of the dragged point, while all the geometrical relations used in the construction are preserved. DGEs are also referred to as dynamic software applications or tools for the teaching and learning of mathematics from high school to university or college level i.e., GeoGebra, Geometer's Sketchpad, and Desmos, amongst others.

Digital transformation levels or levels of technology integration: Puentedura's (2006) substitution-augmentation-modification-redefinition (SAMR) model provided four different degrees of classroom technology integration, namely substitution, augmentation, modification, and redefinition. Substitution and augmentation constitute enhancement, while modification and redefinition constitute transformation (Puentedura, 2006). Transformation is also linked to the affordances of DGEs, namely, feedback, dragging, measuring, and tracing (Hojsted, 2020). Enhancement is equivalent to the early stage of digital transformation in this study.

Learning-centred approach: This approach acknowledges that both learner-centred and teacher-centred pedagogy can be effective, but teachers must consider the local context, including the number of students in the class, the physical environment, and the availability of teaching and learning materials, among others, and thus calls for teachers to be flexible and carefully adapt their pedagogical approaches based on the school environment (Learning Portal, 2019).

Digital pedagogy: This "[i]s precisely not about using digital technologies for teaching and, rather, about approaching those tools from a critical pedagogical perspective. So, it is as much about using digital tools thoughtfully as it is about deciding when not to use digital tools, and about paying attention to the impact of digital tools on learning" (UToronto, 2022). In this study, optimised digital pedagogy is the sweet spot reached when a learning-centred approach is adopted, a transformational stage is used (exploitation of dynamic software application affordances i.e., feedback, dragging, and measuring), and intermediate and advanced digital skills are available during the digital teaching and learning of mathematics in secondary schools.

1.11 CHAPTER OUTLINE

Chapter 1 discusses the context and challenges of digital transformation in secondary mathematics education. It provides perspectives on the role of secondary mathematics education in the science, technology, and innovation (STI) system in South Africa.

Chapter 2 provides the literature review and a discussion of the concepts, frameworks, and theories that underpin the theoretical analytical framework of the study.

Chapter 3 discusses the research design and methodology. It also provides an overview of the data collection and analysis process in the chapters that follow.

Chapter 4 presents and discusses the research findings from case study A: Western Cape Education Department (WCED).

Chapter 5 presents and discusses the research findings from case study B: Gauteng Department of Education (GDE).

Chapter 6 discusses the use of digital technologies for teaching secondary mathematics espoused by government policies and independent experts.

Chapter 7 provides the analysis and synthesis of data as the foundation for developing new dimensions for digital transformation in secondary mathematics education.

Chapter 8 provides the conclusion and recommendations. It sets out the thesis statement, the summary of findings, and practice-oriented recommendations.

1.12 CHAPTER SUMMARY

This chapter is the introduction to the study. It provides the study's research problem statement, the purpose statement, the research questions, and the aims and objectives. It also provides the rationale for the research problem statement. It focuses on the current state of digital skills, leadership, technology trends, school digital infrastructure, and trends in secondary mathematics education. It also highlights the nature of the study, which is sociotechnical and fulfils the requirements of originality, complexity, and interdisciplinarity. This chapter further provides the context, the study's contribution, the limitations, and the definitions of key terms. Chapter 2 presents an overview of the literature on the key sociotechnical theories that underpin the study, namely the digital transformation (DT) ecosystem, DT in secondary mathematics education (SME), including the SAMR model, the actor-network theory (ANT), and the social construction of technology (SCOT) theory.

Chapter 2: Literature Review and Theoretical Analytical Framework: Framing Early-Stage Digital Transformation in Secondary Mathematics Education

2.1 INTRODUCTION

The previous chapter provided the context and challenges associated with early-stage digital transformation in secondary mathematics education, in other words, technology integration or the use of technology (dynamic software applications) in the teaching and learning of mathematics in secondary schools in South Africa. The use of technology for teaching and learning mathematics promotes higher learning gains, but an improvement in matric results has not been widely seen in the country. According to Puentedura's (2006) substitution-augmentation-modification-redefinition (SAMR) model, technology can be used in an enhancement manner in teaching and learning, referred to in this study as early-stage transformation (substitution or augmentation), or in a transformational manner. The SAMR enhancement level (substitution or augmentation) has limited learning gains (Hojsted, 2020). This study proposes that shifting digital transformation in secondary mathematics education beyond the early stage (i.e., using technology at the transformation level of the SAMR model) requires an improvement in the digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experiences.

The purpose of this chapter is to discuss and analyse the body of knowledge with the ultimate goal of determining approaches to shifting digital transformation in secondary mathematics education beyond the early stage. The study therefore investigates approaches to professional development that can advance the digital skills of educators for effective curriculum design and delivery of secondary mathematics lessons, and determines the role of leadership (at the provincial and district levels) in promoting or impeding (intentionally or unintentionally) the implementation of digitally supported teaching of secondary mathematics in schools. The study also examines strategies for ensuring adequate internet connectivity, sufficient bandwidth, availability of devices, applications, and content in schools, and investigates the role of digitally supported teaching in improving the teaching experience and outcomes in secondary mathematics education. Figure 13 is a flow chart for Chapter 2.

Figure 13
Chapter 2 flow chart

Chapter 2

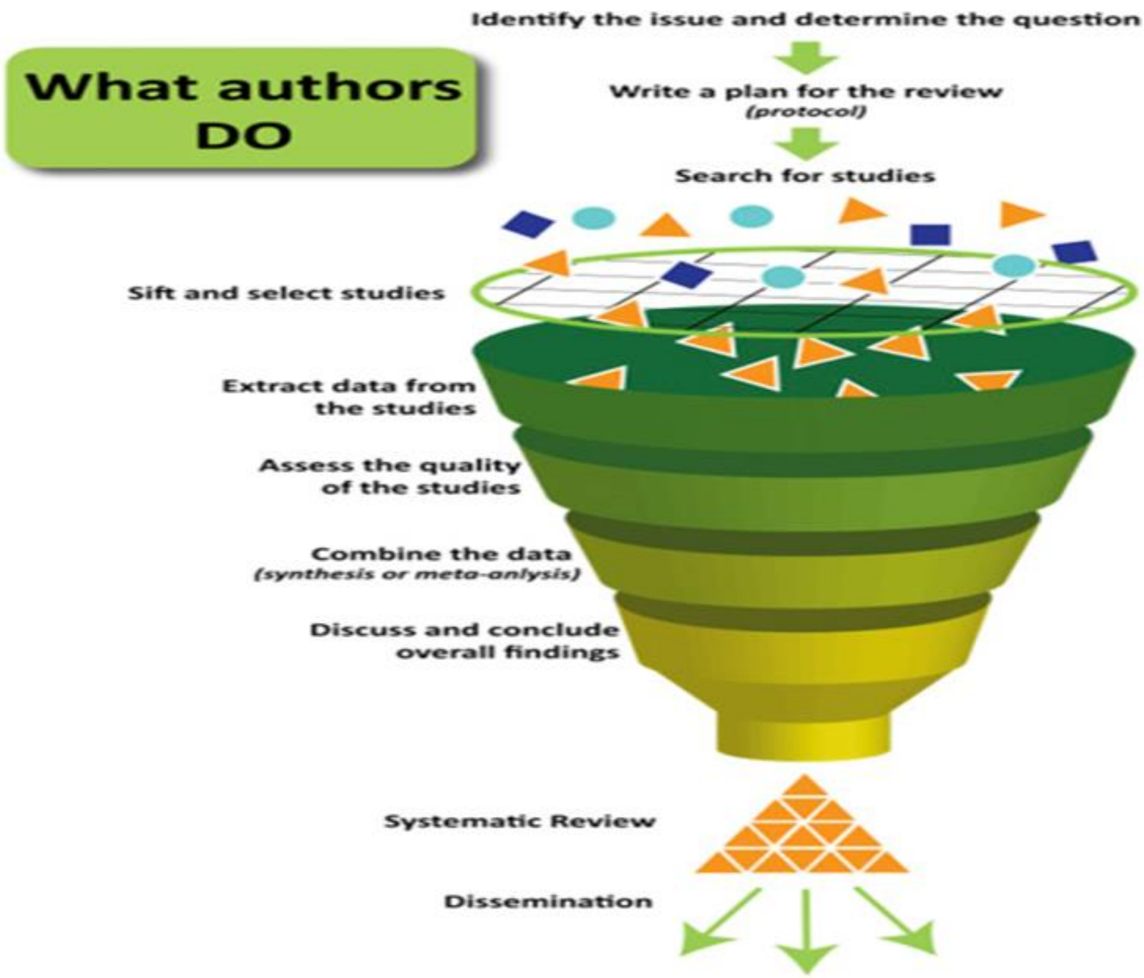
2. Literature review and theoretical analysis framework: Framing early-stage digital transformation in secondary mathematics education
2.1 Introduction
2.2 Overview of the systematic literature review of the study
2.3 Understanding the digital transformation concept
2.4 Key socio-technical theories and frameworks used in digital transformation in secondary mathematics education
2.5 Dimensions connected to digital transformation in secondary mathematics education
2.6 Analytical theoretical framework of the study
2.7 Chapter summary

This chapter consists of six thematic sections with relevant sub-sections. The first section provides an overview of the systematic literature review approach that was used in this study. The next section discusses the digital transformation concept. The third section discusses what other researchers say about relevant sociotechnical theories and frameworks that informed the development of the analytical theoretical framework of the study, namely the digital transformation ecosystem; the SAMR model; the technological pedagogical content knowledge (TPACK) framework; the actor-network theory (ANT); and the social construction of technology (SCOT) theory. The fourth section discusses the dimensions connected to digital transformation in secondary mathematics education. The next section discusses the development of the analytical theoretical framework of the study, the DT-SME 2022 framework, noting that the analytical framework proposes four dimensions for shifting digital transformation in secondary mathematics education beyond the early stage, namely digital skills of educators, leadership in the implementation of digitally supported secondary mathematics teaching, school digital infrastructure, and digital teaching experience. Finally, the chapter provides a summary of the chapter and outlines the focus of Chapter 3.

2.2 OVERVIEW OF THE SYSTEMATIC LITERATURE REVIEW OF THE STUDY

The study conducted a systematic literature review that spanned over nine years to assess studies that are related to digital transformation in secondary mathematics education or the use of technology in the teaching and learning of mathematics in secondary schools. A systematic literature review is a well-organised and complete synthesis of the literature centred on a well-formulated research question (Dewey & Drahota, 2016). Its goal is to find and combine scholarly research on a specific issue, including both published and unpublished works (CMU, 2019). According to CMU, "systematic reviews are conducted in an unbiased, reproducible manner to provide evidence for practice and policy-making as well as identify research gaps." The following databases were searched for relevant studies: GoogleScholar, ScienceDirect, SpringerLink, ERIC, and Wiley Online. Figure 14 depicts the design of the systematic literature review used in this investigation.

Figure 14
Overview of the systematic literature review



Source: Carnegie Mellon University (CMU), 2019

The study’s research questions guided the search for pertinent literature. The following search terms were used: “the role of mathematics in STI and the digital economy”, “digital skills”, “devices”, “digital teaching materials”, “global secondary mathematics education problems”, “digital policies”, “applications and content”, “digital tools”, “digital transformation”, “digital strategies”, “digital learning”, “digital delivery”, “digital transformation in education”, “education leadership”, and “teaching experience”.

The search closely followed the seven steps for conducting a systematic literature review provided by CMU (2019): (i) identifying the research question; (ii) defining inclusion and exclusion criteria; (iii) searching for studies; (iv) selecting studies for inclusion based on pre-defined criteria; (v) extracting data from included studies; (vi) examining the likelihood of bias in included studies; and (vii) providing results and evaluating evidence quality. The systematic literature review was conducted in four phases: the first phase focused on information and communication technology (ICT) in the educational setting; the second phase focused on determining the relevant sociotechnical theories; the third phase provided an update of the latest journal articles for the period 2019 to 2021; and the last phase searched for the most recent articles up to 2022.

The initial research focus changed from ICT in education very broadly to ICT in secondary mathematics education. The researcher, in collaboration with the supervisor, determined that early-stage digital transformation in secondary mathematics education should be the focus of this digital era. The researcher then derived research questions about the issue after examining some literature and observing that the use of digital technology in South African secondary schools is in its early stages. As mentioned in Chapter 1, the early stage is the enhancement stage of Puentedura’s (2006) SAMR model. As a result, the primary research question is: How can digital transformation in secondary mathematics education shift beyond the early stage?

Summary of the findings of the systematic literature review

The systematic literature review commenced in 2018 and therefore focused on articles that were published in the five-year period between 2013 and 2018. During phase 1, the researcher excluded articles that were not linked to digital technologies or ICT in education or did not address issues raised by the research search terms. The researcher included articles published between 2013 and 2018 that were connected to the use of digital technology in education, particularly secondary mathematics education. This phase yielded 200 articles; 119 were excluded because the literature dealt with broader issues of ICT in education or ICT in maths education, but not with specific elements of digital skills, digital leadership, digital infrastructure, and digital teaching experience, which were emergent dimensions in understanding the research problem. Also, 17 duplicates were discarded. This resulted in full-text assessment (n=64), books (n=2), online sources (n=22), and a dissertation (n=1).

In phase 2 on relevant sociotechnical theories, the researcher excluded papers that were not relevant to the sociotechnical perspective, as well as those that were not related to ANT and SCOT. The researcher used journal papers with a sociotechnical viewpoint as well as related theories like ANT and SCOT. Older journal articles were selected since critical publications on the sociotechnical approach were published before 2013. This phase generated full-text articles assessed (n=9) and books (n=1). Phase 3 updated the literature with recent articles for the period 2019 to 2021. This phase produced full-text articles assessed (n=9) and online sources (n=1). Phase 4 searched for the most recent articles up to 2022. This phase produced full-text articles assessed (n=9) and online sources (n=2).

Overall, the systematic literature review comprises a total of 86 articles, 25 online sources, three books, and one dissertation. Finally, the literature was recently updated in response to the examiners’ comments, to include literature on the TPACK framework and recent studies on technology integration in high school mathematics education by Makotjo and Mokhele (2021), among others.

2.3 UNDERSTANDING THE DIGITAL TRANSFORMATION CONCEPT

Digital transformation is associated with the use of digital technologies or the digitisation of certain key activities or functions in an organisation or institution. Digitisation is closely associated with the radical transformation of tasks and procedures, capabilities, and frameworks to take advantage of the changes and prospects of the combination of technologies and their societal impact in a planned manner, with current and futuristic mind shifts (I-SCOOP, 2019). It involves the complete or fractional digitisation of information, products, services, and processes (Hanna, 2016), and the incorporation of digital technologies in all aspects of an organisation (Hanna, 2016). The incorporation of digital technologies in all aspects of the organisation affects operations and value delivery to clients (The Enterprise Project, 2019). According to Reddy and Reinartz (2017, p. 11), digital transformation is:

> the use of computer and internet technology for a more efficient and effective economic value-creation process. In a broader sense, it refers to the changes that the new technology has on the whole; on how we operate, interact, and configure, and how wealth is created within this system …. [D]igital transformation has an obvious, lasting, even revolutionary impact, not only on the economic systems and commercial players, increasingly on the lives of individuals and society at large.

This definition of digital transformation reflects a sociotechnical perspective, specifically the ANT perspective, because all actors, both human (people) and non-human (infrastructure or technology), are considered, whereas the SCOT perspective is related to technology use (see section 2.4 below).

According to Nadeem et al. (2018), most research on digital transformation has focused on the automobile, finance, telecommunications, healthcare, oil and gas, and manufacturing industries. This research focuses on the public education sector, particularly secondary mathematics education. Additionally, digital transformation in secondary mathematics education is treated similarly to technology integration or the use of technology in the teaching and learning of mathematics in secondary schools, and these terms will be used interchangeably. However, the emphasis in the current study is on the levels of technology integration described using Puentedura's (2006) SAMR model, as indicated in Chapter 1. The SAMR model describes whether technology is used in an enhancement manner (early stage) or a transformational manner (beyond the early stage). Hojsted (2020) also describes the transformation level in relation to the affordances of dynamic software application, namely feedback, dragging, measuring, and tracing.

The COVID-19 pandemic was the impetus for digital learning in mathematics education because online education by schools expanded greatly following the coronavirus outbreak (Alabdulaziz, 2021). According to aus dem Moore (2019), the pace of digital transformation in the education sector will be driven by five key factors: (i) common accreditation standards for digital curricula and credentials; (ii) transparency around outcomes; (iii) data privacy regulations and IP rights; (iv) building and strengthening digital capabilities at all levels; and (v) efficient setup and deployment of secure IT infrastructure and devices. Education systems worldwide have invested in various initiatives for the implementation of digitally supported teaching and learning to derive the high learning gains demonstrated in some studies.

2.4 KEY SOCIOTECHNICAL THEORIES AND FRAMEWORKS USED IN DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION

This section discusses the different theoretical frameworks used as lenses for guiding researchers when investigating digital transformation broadly, and technology integration (using dynamic software application) in mathematics teaching and learning specifically. Details are presented on Hanna's (2016) digital transformation ecosystem, Puentedura's (2006) SAMR model, Chai et al.'s (2013) TPACK framework, Orlikowski's (2010) ANT model; and Pitch and Bijker's (1984) SCOT theory.

2.4.1 Digital transformation ecosystem

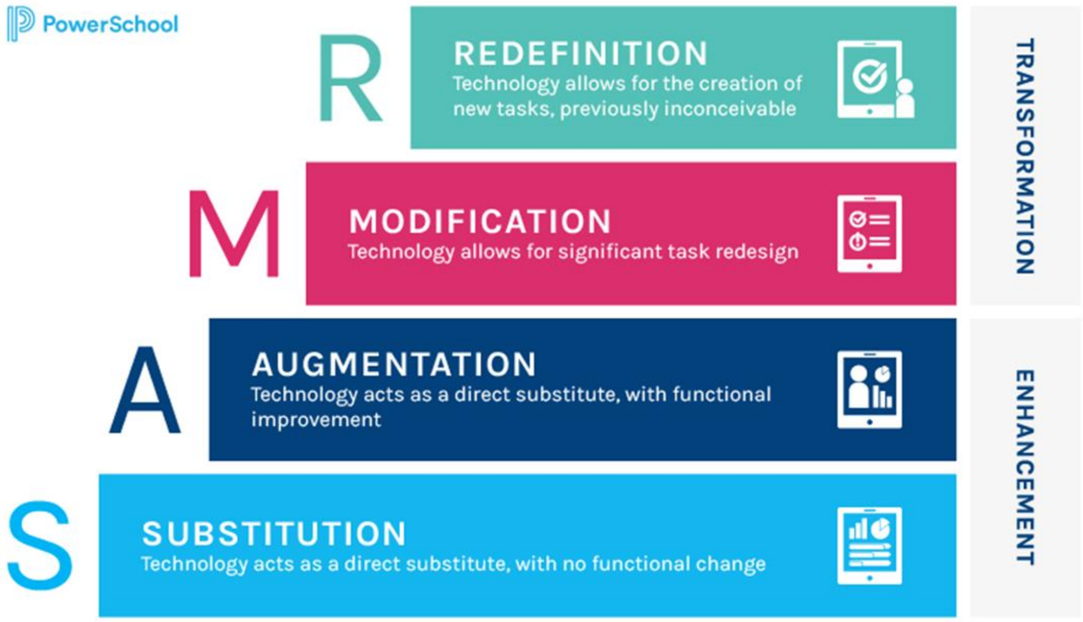
Investigating the use of digital technologies for the teaching of mathematics in secondary schools requires an understanding of the main issues involved. In this study, the issues are organised around four dimensions, namely the digital skills of educators, leadership in the implementation of digitally supported teaching of secondary mathematics, school digital infrastructure, and digital teaching experience. Hence, the analytical framework of the study is based on Hanna's (2016) digital transformation ecosystem framework with five dimensions, namely (i) policies and institutions; (ii) human capital; (iii) the ICT industry; (iv) ICT infrastructure; and (v) digital transformation. Policies and institutions refer to the enabling environment for the supply and use of digital technologies by organisations and broader society. According to this framework, "human capital" refers to the capabilities for developing and using digital platforms; "ICT industry" refers to the technology activities, local content production, and global partnerships; "ICT infrastructure" refers to an accessible, affordable, and reliable internet connectivity infrastructure, both fixed and mobile broadband; and "digital transformation" refers to digital applications and complementary investments in institutional capabilities to transform key digital technology users' sections of the economy. Additionally, the author argues that this holistic digital transformation is a foundation for the development of sector-specific strategies such as e-government, e-education, e-business, and e-society, among others. Furthermore, with regard to e-education, the author advises that during the adoption of an ecosystem approach, policymakers should be mindful that elements of e-education are handled by different parts of government and, therefore, consultation and coordination are necessary. Moreover, the author notes that the e-education strategy must be guided by a holistic vision that prioritises the needs and reform agenda of the education sector to meet the demands of the competitive innovation economy and inclusive information society, and it should be driven by a coherent education strategy and clear pedagogical philosophies.

Therefore, the digital transformation ecosystem is important for this research since it serves as the framework for establishing digital education-related strategies. While the digital transformation ecosystem is broad, it contains the major components of the current study, which will be modified for digital transformation in the secondary mathematics framework. The digital transformation ecosystem was chosen because of its holistic approach to digital transformation, which is the approach that this current study seeks to adopt through the study's four key dimensions, namely, the digital skills of educators, leadership in the implementation of digitally supported secondary mathematics teaching, school digital infrastructure, and digital teaching experience, as previously mentioned.

2.4.2 Substitution-augmentation-modification-redefinition (SAMR) model

Puentedura's (2006) SAMR model was used in the adaptation of Hanna's (2016) digital transformation ecosystem, resulting in the DT-SME framework, which is the study's analytical theoretical framework. Because this study will focus on the use of digital technology to teach mathematics in secondary schools, the SAMR model's two main transformation levels, enhancement and transformation, will be used. The digital transformation levels of the SAMR model are shown in Figure 15.

Figure 15
SAMR model

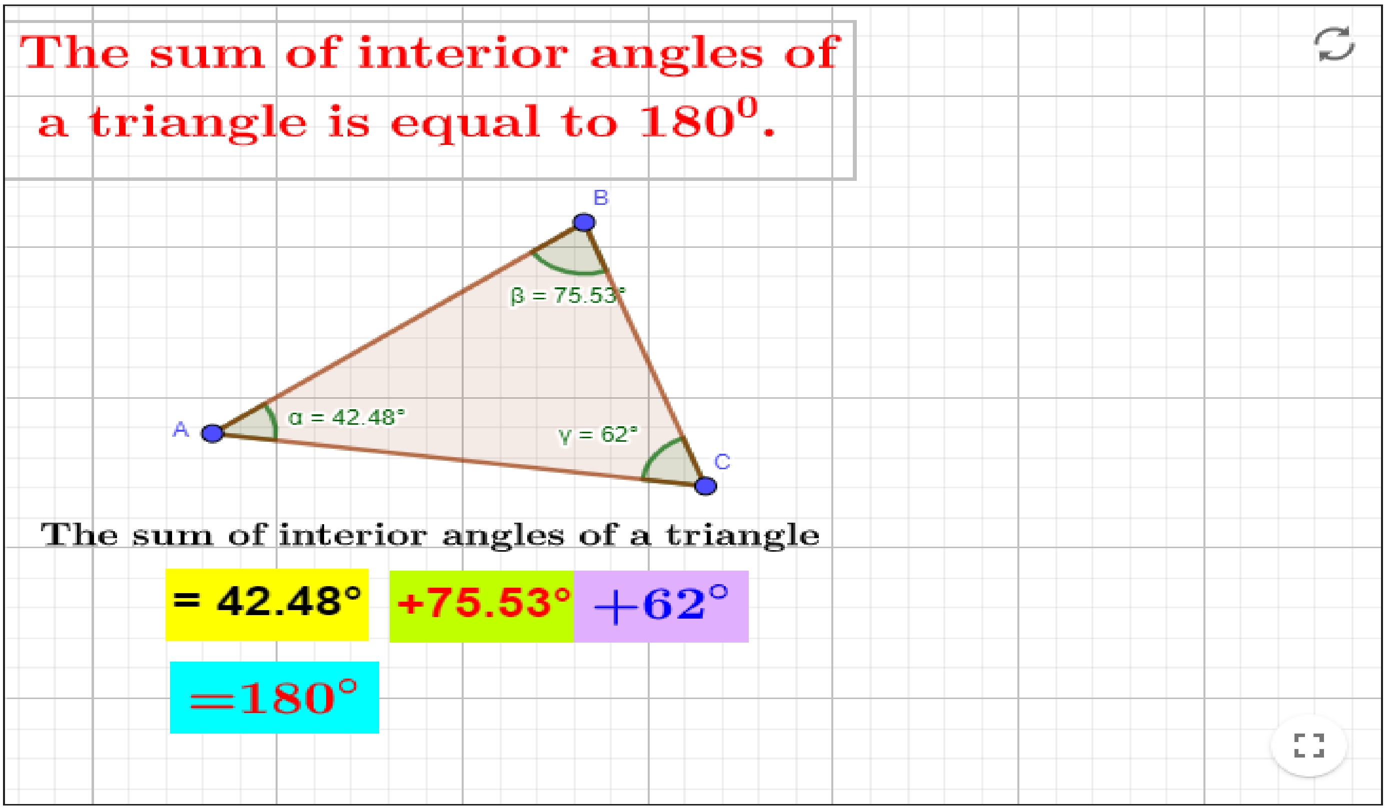


Source: Puentedura, 2006

The substitution stage (when technology is used as a direct substitute with no functional improvement, such as an e-book) and the augmentation stage (when technology is used as a direct substitute with functional improvement, such as an e-book with links) constitute enhancement. Transformation, on the other hand, comprises the modification stage (when technology allows for considerable work redesign) and the redefinition stage (when new activities are created, which would have been impossible without technology).

Furthermore, affordances such as feedback, dragging, measuring, and tracing, as stated in Hojsted (2020), are closely related to transformational methods of teaching secondary mathematics using dynamic software applications. These affordances generate dynamic visual imagery during manipulation and are associated with deep conceptual understanding for improved educational outcomes. Moreover, several transformational dynamic software programs allow learners to cooperate and inspire creativity while solving mathematics problems (Granberg & Olsson, 2015) and provide video analysis graphs or functions (Bray et al., 2013). Figure 16 shows an example of a preconfigured GeoGebra applet for showcasing that the sum of the interior angles of a triangle is equal to 180 degrees. In this example, points A, B, or C can be moved and it can be observed that the angles change but the sum remains 180 degrees (to access the GeoGebra applet, visit https://www.geogebra.org/m/mxfs8whu).

Figure 16
GeoGebra applet – Dragging and feedback affordances



Source: https://www.geogebra.org/m/mxfs8whu

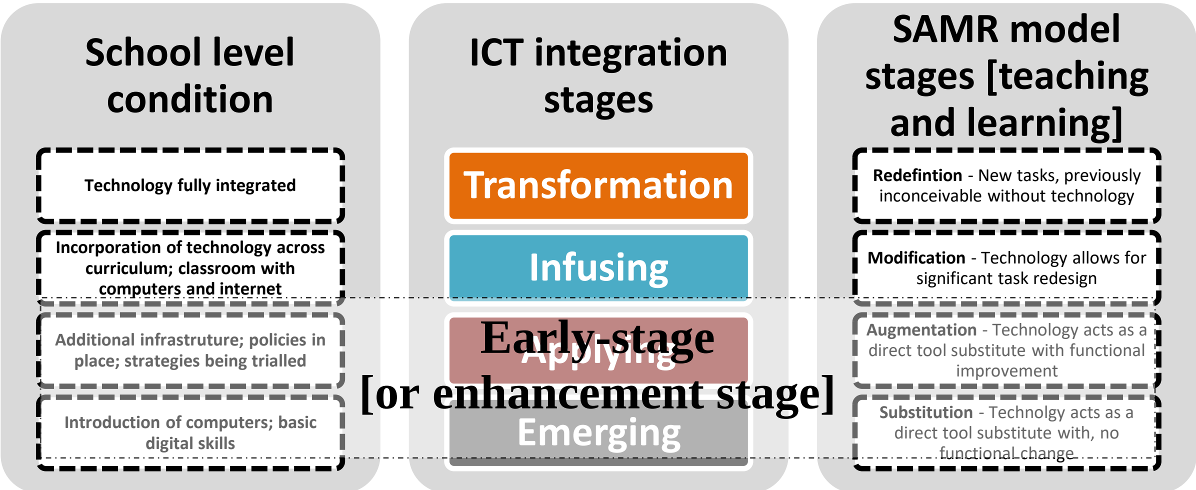
The stages of the SAMR model will be used with caution, only to define the kind of technology integration level happening in class, and being cognisant of the theoretical limitations of the model. Hamilton et al. (2016) note three challenges associated with the use of the SAMR model, namely (i) the model is not context-based; (ii) it emphasises products over processes; and (iii) it is rigid. The authors suggest the consideration of contextual factors such as appropriate learning outcomes, learners' needs, school and societal expectations, the dynamic nature of teaching and learning with technology, and the use of a certain tool that may be appropriate to the targeted motivational and learning objectives. Additionally, Granberg and Olsson (2015) make suggestions about how to overcome the challenges associated with using dynamic software applications or digital tools through successful class interaction with learners, the promotion of dialogue, and providing an environment that encourages creative reasoning (avoiding imitative reasoning). The digital skills of educators for teaching secondary mathematics using dynamic software applications is one aspect being explored in this study. Other aspects are leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience.

Schools also go through various stages when trying to integrate technology. These stages are connected to school-level conditions, including the availability of resources and the skills of teachers as key actors. According to UNESCO (2010), schools evolve across four stages in their technology integration journey, namely emerging, applying, infusing, and transformation. The emerging stage is where schools start to introduce computers, teachers possess basic digital skills, and a few teachers begin to explore the potential of digital technology in class; the applying stage is where the school has acquired additional school digital infrastructure, national digital policies are in place, several strategies are being trialled, educators use technology for professional purposes, and educators pay more attention to improving subject-matter teaching using several applications (Bray & Tangney, 2017; Maftuh, 2011; Peer & van Petegem, 2015). The infusion stage is related to the incorporation of technology across the curriculum, and classrooms have computers and the internet; the transformation stage is where technology is fully integrated into teaching and learning in schools. Furthermore, the emerging and applying stages are linked to educator-centred teaching methods (Zain, 2013).

The mapping of the school-level conditions associated with the ICT integration stages onto the SAMR model stages (see Figure 17) was undertaken to allow the researcher to gain an understanding of the corresponding digital transformation level and its corresponding school-level condition. In this study, the early stage of technology integration is associated with the emerging stage (introduction of computers, basic digital skills) and applying stage (additional infrastructure, etc) that correspond to the substitution and augmentation stages of the SAMR model. Figure 17 maps the school-level conditions and the four stages of ICT integration onto the SAMR model stages.

Figure 17

Mapping of the school-level conditions and four stages of ICT integration onto the SAMR model stages



Source: Adapted from Bray & Tangney, 2017; Puentedura, 2006; UNESCO, 2010

It can be noted that basic digital skills are associated with the early stage (the enhancement stage, particularly substitution or augmentation) whereas the transformation stage is linked to technology being fully integrated (redefinition or modification).

2.4.3 Technological pedagogical content knowledge (TPACK) framework

According to Zhang and Tang (2021), the TPACK framework comprises three major knowledge components that are its foundation and four components that address how these three bodies of knowledge interact, constrain, and afford each other. Additionally, TPACK is the concept that summarises the integration of technology into the teaching and learning situation (Chai et al., 2013).

Zhang and Tang (2021) state that the TPACK framework comprises three major knowledge components which form the foundation of the TPACK framework as follows:

(i) **Content Knowledge (CK)** refers to any subject-matter knowledge that a teacher is responsible for teaching.

(ii) **Pedagogical Knowledge (PK)** refers to teacher knowledge about a variety of instructional practices, strategies, and methods to promote students' learning.

(iii) **Technological Knowledge (TK)** refers to teacher knowledge about traditional and new technologies that can be integrated into the curriculum.

The author further notes that the four components of the TPACK framework address how these three bodies of knowledge interact, constrain, and afford each other as follows:

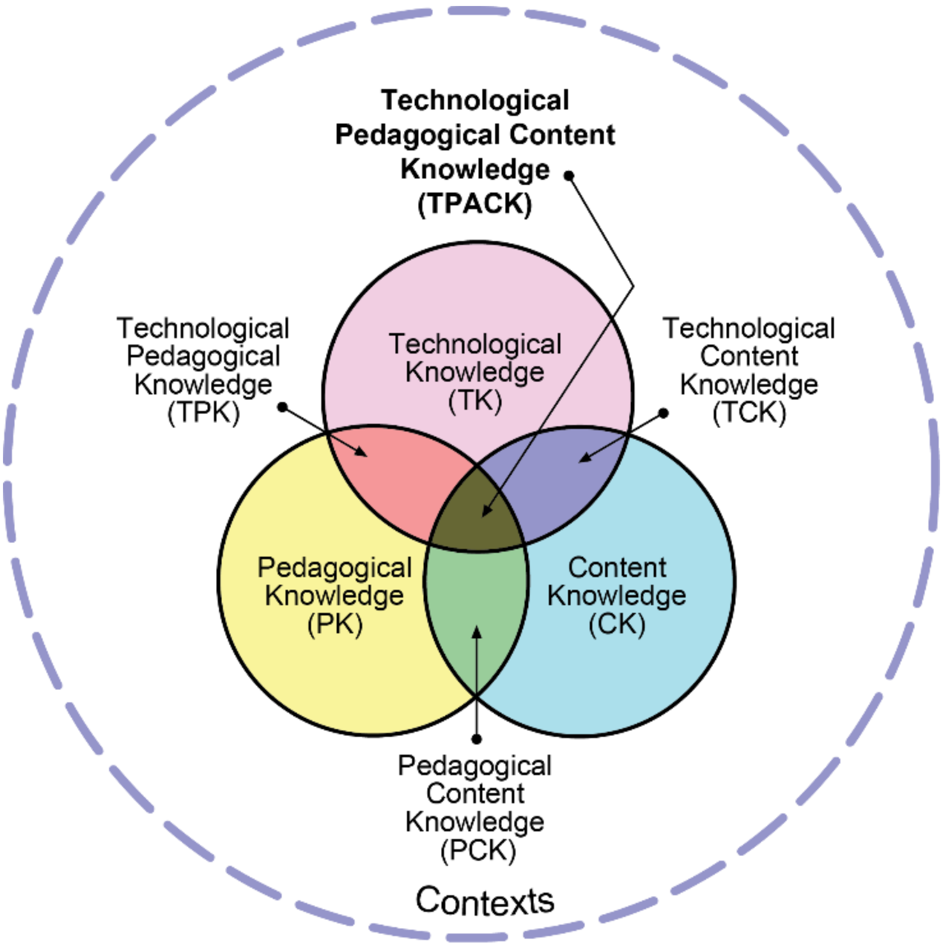
(i) **Technological Content Knowledge (TCK)** refers to knowledge about the reciprocal relationship between technology and content. Disciplinary knowledge is often defined and constrained by technologies and their representational and functional capabilities.

(ii) **Pedagogical Content Knowledge (PCK)** refers to an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction.

(iii) **Technological Content Knowledge (TCK)** refers to an understanding of how technology can constrain and afford specific pedagogical practices.

(iv) **Technological Pedagogical Content Knowledge (TPACK)** refers to knowledge about the complex relations between technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies. Figure 18 shows the TPACK framework.

Figure 18
Technological pedagogical content knowledge (TPACK) framework



Source: Chai et al., 2013

Koehler et al. (2013, p.102) state that "the TPACK framework suggests that teachers need to have deep understandings of each of the above components of knowledge to orchestrate and coordinate technology, pedagogy, and content into teaching." The authors add that "TPACK is an emergent form of knowledge that goes beyond knowledge of content, pedagogy, and technology taken individually but rather exists in a dynamic transactional" (Koehler et al., 2013, p.8).

There is a relationship between the TPACK and SAMR models. Adulyasas (2021, p.1704) investigated the TPACK and SAMR models, with the following aims to : (i) use learning community incorporating with lesson study for developing patterns in the integrated teaching of mathematics with the use of technology based on the TPACK and SAMR models and to determine pre-service teachers' levels of technology integration in their teaching; (ii) to examine the effects of the integrated teaching on students' achievement; (iii) to determine students' learning retention; and (iv) to measure students' level of satisfaction about learning. The study revealed that the pre-service teachers used technology in their teaching based on the concept of TPACK with a level four of technology integration (redefinition stage) in the SAMR model, which is the highest level.

An earlier study by Handal et al. (2013) investigated the integration of TPACK in the teaching of mathematics in secondary schools in Australia. The study found that PowerPoint and Excel constitute two TCK modal technological capabilities, while the TPK scores revealed teachers' lower capacity to deal with the general ICT goals across the curriculum, such as creating digital assessment formats. Additionally, the authors found that some technologies that are specifically for teaching, such as graphic calculators and interactive whiteboards, have not been widely adopted.

The dimensions of the present study are related to the TPACK knowledge areas, including the specific aspects that are being investigated in this study. For example, dynamic software applications or digital tools or just tools require TK, referred to here as the digital skills of educators that can be categorised into three levels, namely basic, intermediate, and advanced digital skills (ITU, 2017). Additionally, PK is linked to the three pedagogical approaches, namely the teacher-centred, learning-centred, and learner-centred pedagogical approaches. Furthermore, CK is related to secondary mathematics.

2.4.4 Actor-network theory (ANT)

The ANT perspective is important for mapping out all the actors (human and non-human) and understanding their equal role in the implementation of digitally supported teaching of secondary mathematics in schools. Actors are individuals, groups, or institutions acting within a system of interests that play an active role, as opposed to passive stakeholders (Future Learn, 2020), and they can be both language-bearing (human) and non-language-bearing (non-human); the roles and capacities of actors are not pre-determined but emerge as a result of negotiation, trade-offs, and compromises between them (Rowan & Brown, 2003). Mathew (2019) explains ANT as a theory that emanates from the fields of social science studies and technology studies; it dismantles barriers that exist between these fields, by engaging in a discussion about human and non-human actors equally, as they act amongst each other, in a constructing and deconstructing way. Furthermore, actors have no inherent qualities but acquire their form and attributes only through their relations with others in practice (Orlikowski, 2010). There are associations between actors, and they are defined by their location within the network, including their relationship with other actors (Waniak-Michalak & Michalak, 2019). Moreover, actors involved in the technology rollout provide more insights through their actions (Ochara, 2013; Latour, 1996). According to Binder et al. (2015), the ANT perspective has moved away from "the social", replacing it with the socio-material collective of humans and non-humans; design and design research must replace the "object" to focus on experimenting, prototyping, infrastructure, and travelling.

Two studies are highlighted to provide an example of the use of the ANT perspective: Chitanana (2020) and Sela et al. (2019). Chitanana (2020) analysed Web 2.0-facilitated collaborative design among undergraduate engineering students using ANT as a methodological and analytical framework to study the role of Web 2.0 technology in the collaborative design process. The study concluded that Web 2.0 technologies should not be viewed as simple tools for communication, as described in some literature, but as non-human actors that can mediate the collaborative design process and shape the way in which it is constituted and conducted in practice. The study mentions three categories of non-human actors in a network: non-human actors substituting for humans, non-human actors mediating humans, and non-human actors communicating with humans. Sela et al. (2019) adopted the ANT perspective in trying to understand the role of actors in the process of the financial inclusion agenda in Brazil. The study discovered that the financial inclusion agenda in Brazil has been a gradual process that involved a broad range of actors such as the government, the market, developers, scholars, and international actors. Also, the study noted the influential role of non-human elements, such as the Central Bank of Brazil, in the financial inclusion process.

ANT will be used in this study to treat all human and non-human actors and their interactions equally. However, ANT will not be used as the main theory i.e., the main theory is based on Hanna's (2016) digital transformation ecosystem framework and the resultant analytical framework prioritises the digital skills of educators and other elements (leadership in the implementation of digital teaching, school infrastructure, and digital teaching experiences). The ANT perspective will assist in analysing and mapping out all actors (human and non-human) and understanding their equal roles in the current research. Thus, teachers (human actors), with the help of leadership (human actors), must possess intermediate and advanced digital skills to provide a pleasant digital teaching experience that encourages the learning-centred pedagogical approach to enable the use of dynamic software applications or tools in a transformational manner or to exploit its affordances i.e., feedback, dragging, measuring, and tracing (non-human actors).

2.4.5 Social construction of technology (SCOT) theory

The SCOT perspective advocates the importance of following the actors involved because they can provide a better understanding of the evolution and use of technology in the classroom situation. The SCOT perspective is important for analysing the evolution of technology (Olsen & Engen, 2007) or the historical development of technology to understand how the technology in focus has changed based on the understanding of the several role-players involved (Sivamalia, 2013). Additionally, the SCOT perspective views technological evolution as the result of social interactions among related social groups (comprising those actors on a given artefact or technology which influences the process of innovation) and not automatically as an answer to the demands or opportunities of the market (Olsen & Engen, 2013). "The social environment shapes the technical characteristics of the artefact ...." (Howcroft & Light, 2010, p. 129) and the process for the development of the technological artefact is multi-directional and non-linear (Pitch & Bijker, 1984). Thus, the SCOT perspective is useful for analysing the evolution of technology, its use, and the role of social interactions among interest groups, including their different opinions on the problems and solutions. Additionally, the SCOT perspective is useful because it is inclined to address people's needs rather than market pressures. Furthermore, the SCOT perspective advocates the importance of following the actors involved as they can provide a better understanding of the use of technology in the classroom situation. Moreover, the actors involved must be identified as various components related to digital education, for example, they reside in different ministries in the government and private sector, including multinational organisations. Therefore, the SCOT perspective will be used in this study to analyse mainly technology use (enhancement or transformational) in the secondary mathematics classroom.

2.5 DIMENSIONS CONNECTED TO DIGITAL TRANSFORMATION IN SECONDARY EDUCATION

In this section, key concepts that form a foundation for developing the study's analytical theoretical framework dimensions are discussed. These concepts include digital skills, teacher professional development, leadership, digital infrastructure, and digital learning.

2.5.1 Digital skills in the economy – Mathematics as a foundation for advanced digital skills

Secondary mathematics, as part of the mathematics pipeline, serves as a critical basis for advanced digital skills-related engineering degrees in areas such as robotics, 3D printing, and coding, among others, which are critical for a country's national innovation system. Mathematics is at the heart of computerisation and can be found in a wide range of applications, ranging from science, technology, engineering, and mathematics (STEM) fields to non-STEM fields such as social sciences, finance, logistics, and risk analysis (Gravemeijer et al., 2017, p. 106). The national system of innovation comprises commercial and public scientific production institutions, such as universities, as well as government organisations that conduct or commission research (Lyasnikov et al., 2014, p. 536). Innovation is defined as "the process of developing a new product or service, a new technological process, a new organization, or improving an existing product or service, existing technological process, or existing organization" (Ramadani & Gerguri, 2011; Ramadani et al., 2013, p. 324). A strong and sustained foundational research and development infrastructure and a strong emphasis on education at all levels (OECD, 2004; Ramadani et al., 2013, p. 335) are some of the important enablers of innovation. Furthermore, innovation promotes economic growth (Ramadani et al., 2013, p. 335). Hausman and Johnston (2013) identify education as one of the main variables that contributes to innovation success and emphasise the critical importance of innovation in a country's economic well-being, using the United States (US) during the financial crisis period as an example. A strong mathematics pipeline helps to build sophisticated digital skills, which are critical for a country's innovation system and related economic spinoffs.

As indicated in Chapter 1, the world economy has changed from a fossil fuel-dominated to a digital innovation economy (Bloomberg, 2018). The digital innovation economy is defined as the proportion of total economic output derived from several broad "digital" inputs such as digital skills, digital equipment (hardware, software, and communications equipment), and intermediate digital goods and services used in production (Knickrehm et al., 2016). Furthermore, the authors claim that mathematics is both "pervasive and invisible" in the digital innovation economy, with the role of mathematics evolution equating to the function of technology, as mathematics lies at the heart of computer work. As a result, the role of mathematics in the broader national science, technology and innovation (STI) system can be viewed through a sociotechnical lens, allowing for the mapping of all the actors (i.e., leadership, teachers, etc.) involved and their interactions that contribute to success or failure in promoting transformational methods of digital teaching and learning of mathematics in secondary schools for improved education outcomes.

According to Lyasnikov et al. (2014), one of the "dissimulating factors" in the national innovation system is the "detachment of the scientific sector from the rest of the national innovation system". This is true for the South African education sector, where the sphere of influence of the Department of Science and Innovation (DSI) is limited to the production of accredited researchers in higher education, while the bottleneck occurs at the primary and secondary school levels due to an underperforming public education system, which should be of greater concern than higher education output due to its impact on the future scientific human capital base (Kahn, 2013; Sceri & Lastres, 2013). According to Hausman and Johnston (2013), governments aiming for innovation success can improve science and mathematics education by recruiting additional teachers and re-skilling existing teachers, among other things. Coordination between the public education sector and industry is required to train new and existing teachers in the use of digital tools to teach mathematics in a transformative manner that is related to deep conceptual understanding for improved results.

The digital skills of educators are important for leveraging digital technologies for teaching, particularly using dynamic software applications for teaching mathematics in secondary schools. The ability to use dynamic software applications in a transformational manner in a secondary mathematics classroom is linked to intermediate and advanced digital skills. Digital skills are important in enabling learners to study and in enabling educators to deliver lessons in class (Pirzada & Khan, 2013). The ITU mentions three types of digital skills, namely, basic skills, intermediate skills, and advanced skills (ITU, 2017). Basic skills include the ability to operate digital learning devices, whereas intermediate skills enable learners to make meaningful use of digital technologies to accomplish various tasks and engage in content creation. Advanced skills are usually relevant for professionals who develop computer programs, manage networks, and are involved in artificial intelligence (AI), big data, coding, cybersecurity, the Internet of Things (IoT), and mobile app development. Advanced skills are prevalent in innovation economies and are in demand worldwide. Furthermore, advanced skills such as robotics, coding, 3D printing, and AI, amongst others, are sometimes incorporated into the teaching and learning of mathematics to arouse interest in the related engineering and scientific fields. van Deursen and van Dijk (2010) categorised digital skills into four types of skills: operational skills – to operate hardware and software; informational skills – capacity to search, select, and process information; strategic skills – ability to use a computer and the internet to attain a particular goal; and formal skills – capacity to navigate in a hypermedia context.

While the four categories of digital skills from van Laar et al (2017) are important, the basic, intermediate, and advanced digital skills from the ITU will be the focus of this study due to their simple broad classification. Furthermore, digital skills are assumed to be closely associated with three activities during the digital teaching of secondary mathematics in schools, namely, content creation, content search, and content use i.e., Excel spreadsheets, GeoGebra and GSP applets that require intermediate and advanced digital skills. Moreover, basic digital skills are mainly for using available pre-configured tasks, whether GeoGebra or GSP, and are linked with the enhancement stage of digital transformation in secondary mathematics education.

Though digital skills are important to shift schools beyond the early stage of digital transformation in secondary mathematics education, the use of digital tools and the underlying pedagogical principles supported are also crucial. Additionally, analysing the digital skills of educators requires much greater attention to build a theory relevant to digital transformation in secondary mathematics education. Furthermore, the digital skills of educators are key for the successful implementation of digitally supported teaching of secondary mathematics.

2.5.2 Approaches to teacher professional development to promote digital skills – Pre-service and in-service teachers

Teacher professional development (TPD) is vital for ensuring that teachers possess the requisite digital skills i.e., intermediate and advanced skills in the case of the transformational digital teaching and learning of secondary mathematics. Countries must ensure that educators are equipped not only to prepare and deliver lessons, but also to exploit the affordances of digital tools for more visualisation, which is key for deepening the conceptual understanding of secondary mathematics concepts. Digital skills are the “capacity to respond pragmatically and intuitively to the challenges and opportunities in the manner that exploits the Internet’s potential” (Correa, 2015, p. 3, as cited in DiMaggio et al., 2004), the digital nature of occupations, and the skills and knowledge required for people to perform their jobs (Knickrehm et al., 2016). Additionally, there is a growing need for professional development to address the digital skills gap, as was discovered among lecturers in a certain German university (Bond et al., 2018).

The digital skills of educators are key for the successful implementation of digitally supported teaching of secondary mathematics. Two recent research articles are therefore reviewed to highlight some of the debates that are associated with TPD programmes to address digital skills for the digitally supported teaching of mathematics.

Hegedus et al. (2017) reviewed 40 papers emanating from prominent mathematics journals and the proceedings of several international conferences. The papers were organised around four perspectives related to TPD for integrating technology for teaching secondary mathematics.

The first perspective is made up of two views:

(i) **The institutional view:** The review concluded that only the National Council of Teachers of Mathematics (NCTM) is subject-specific i.e., the authors state that the NCTM standards emphasise teachers' awareness of the value of technology, the need for continuous updating of technology know-how and its use in teaching, and leveraging the power of technology in designing lessons. Other ICT standards such as the ISTE Standard-T and UNESCO ICT Competency Framework for Teachers are regarded as too general, not subject-specific, and not school-specific.

(ii) **The research point of view:** Teachers' knowledge and skills fall into three categories: (a) knowledge and skills to teach a particular concept (functions or algebra); (b) knowledge and skills to use a particular software (CAS or GeoGebra); and (c) general knowledge for supporting problem-solving in a digital space.

Thus, the Professional Practice: Applications of Dynamic Software for Secondary Mathematics Teachers (PP: ADS) short course is subject-specific for grades 8 and 9 mathematics and covers both algebra and geometry. This looks like a combination of the institutional (NCTM) view and the research view (use of a particular software – CAS or GeoGebra), which is progressive.

The second perspective is about the kind of knowledge and skills that must be developed in teachers. It seems that many TPD programmes fail to yield positive outcomes due to the gap between the needs of teachers and the TPD content (Hegedus et al., 2017). Additionally, there is a low level of research on TPD in the field of mathematics education. The current research seeks to contribute to this field of mathematics education.

The third perspective is about the types of theoretical frameworks informing the research in teacher education. The review uncovered a large volume of theoretical frameworks that are viewed as good for research. However, the authors point out that this creates a danger of what is termed "the framework compartmentalisation that could hinder the capitalisation of knowledge and its practical exploitation" (Hegedus et al., 2017, p. 30). The authors encourage the development of "an integrated theoretical framework" to promote the capitalisation of research on digitally supported mathematics education (Hegedus et al., 2017, p.30). This confirms the attempt by the present study to propose an ecosystem approach in addressing issues related to the digitally supported teaching of secondary mathematics in schools. Additionally, the development of a framework to select digital tools to be used in the TPD programme ensures objectivity driven by the desire to achieve teaching goals. Lastly, some skills, such as the ability to select appropriate digital tools and deciding when to use or not to use a digital tool, are underestimated.

Clay et al. (2016) conducted class observations on senior high school mathematics lessons to investigate the use of digital tools for teaching mathematics between October 2014 and January 2015. It emerged that digital tools were mainly used for demonstration (60%); by the teacher alone (70%); and not in conjunction with other resources (70%). The authors conclude that teachers remained in control of the digital tools and used them for demonstration. The authors also point out that many teachers know about digital tools, but have little personal experience with learning to use the tools and integrating them in the classroom as part of teaching. Furthermore, their annual review of the TPD programme revealed that teachers prefer short online recordings of lessons about digital tools that demonstrate key features and provide suggestions about how to incorporate the tools in various mathematics topics. Moreover, the authors found that when an optional introduction to the GeoGebra session was organised, about a quarter of the uptake of the course with high levels of satisfaction was reported.

The continual capacitation of teachers through various TPD initiatives is important in education. This is even more critical in the use of digital technologies because technology evolution is happening rapidly and teachers need to catch up or stay ahead. According to Avalos (2011, p. 10), "teacher professional development is about teachers learning, learning how to learn, and transforming their knowledge into practice for the benefit of their students' growth." There are two views regarding TPD, namely (i) traditional in-service or continuing or ongoing teacher education; and (ii) programmes that form part of a teacher's professional development journey, including pre-service training (Baustista & Ortga-Ruiz, 2015; Niemi, 2015). Traditional TPD programmes include seminars, talks, workshops, and conferences; these programmes are viewed as ineffective due to their sporadic and brief nature, passive participation, lack of feedback and follow-up support, and disconnection from classroom practice (Baustista et al., 2015). On the other hand, TPD programmes that are process-oriented are successful because they are not events but are specific, concrete, and practical, with ideas related to day-to-day classroom operations. Baustista et al. (2015) also note the common features of successful TPD programmes: (i) they are subject-specific (i.e., mathematics) – providing deeper understanding and pedagogical strategies to deliver content and knowledge of student thinking; (ii) they are tailored to teachers, depending on their prior knowledge and level of expertise, and coherent and responsive to their needs and interests, including alignment with the curriculum needs; (iii) they are voluntary, and (iv) their design features support active learning, collaboration, sharing, and continuous support beyond programme completion, among others.

Edmond and Burns (2005) mention three approaches related to TPD initiatives associated with the implementation of digitally supported teaching, namely (i) digital technologies as a delivery system for educators to improve their pedagogical skills and content mastery; (ii) as a focus of the study that facilitates the development of educators' capabilities in using specialised digital tools such as personal computers; and (iii) as a way of promoting new ways of teaching and learning such as collaboration, inquiry-inclined learning, and learner- or learning-centred learning. Additionally, the authors provide three categories of TPD programmes, namely (i) standardised; (ii) site-based; and (iii) self-directed. Furthermore, Svendsen (2020) found that newer approaches to TPD require (i) working with teachers to develop attitudes, beliefs, skills, and knowledge congruent with the shared objective; (ii) embracing a partnership (likely to be voluntary) approach between "actors" with different forms of expertise working towards a shared objective and with teachers working out the changes required in their contexts and for their students; and (iii) a bottom-up approach that treats teachers as professionals in situ solving pedagogical problems in their unique contexts, among others. Pournara and Addler (2021) argue for the revisiting of pre-service mathematics teacher education to address three areas of learning: (i) classroom time for teaching mathematics in schools; (ii) focus on mathematics teaching practices; and (iii) allowing teachers to learn about important ideas and results from the literature of mathematics studies.

TPD plays a crucial role in improving education outcomes, among others. The review conducted by Rosli and Aliwee (2021) on professional development programmes for mathematics teachers showed "that the mathematics teacher [professional development] programmes have been used to impact teacher attitudes and practices in classroom teaching practices, student learning outcomes and teacher knowledge and skills."

For TPD initiatives to bear fruit and translate to classroom practice, practitioners should take ownership. Postholm (2018) conducted a review of TPD in schools by examining its characteristics and influence on school improvement and found that teachers must develop learning processes that drive school improvement. The author further notes that "researchers should stimulate and sustain an extensive transformation process led by and owned by practitioners such as education leaders and teachers in the whole school" (Postholm, 2018, p.1).

It appears that research on the role of TPD in promoting digital skills has not been fully investigated by researchers. Skantz-Aberg et al. (2022) conducted a review to examine if and how the concepts of addressing teachers' professional digital competencies are defined or conceptualised in research. The review found that the concept of teachers' professional digital competence, or related concepts, was frequently mentioned in abstracts, keywords, and full texts, but, for the most part, it was rarely described in detail. Additionally, the review identified seven recurring aspects related to teachers' professional digital competence, namely (i) technological competence; (ii) content knowledge; (iii) attitudes to technology use; (iv) pedagogical competence; (v) cultural awareness; (vi) critical approach; and (vii) professional engagement, with the technological and pedagogical competences as the most prominent.

TPD initiatives appear to contribute to the improvement of the digital skills of teachers. Pongsakdi et al. (2021, p.1) investigated the impact of digital pedagogy training on in-service teachers' attitudes to digital technologies, and found that:

> Teachers who had low confidence in ICT use showed an increased ICT confidence level after the programme, while teachers who already had high confidence in ICT use showed no significant changes in their confidence level. Moreover, the results indicated that the need for ICT support was lower after the training for the teachers in the high confidence group, while there were no significant changes in the need for ICT support for the teachers in the low confidence group.

The TPD that was undertaken in the primary research site in the Saldanha Bay circuit in the Western Cape has similar features to successful process-orientated TPD programmes. It had a positive impact as teachers were engaged with online learning platforms during the COVID-19 lockdown period.

2.5.3 Leadership in the implementation of digitally supported teaching – Guidance through policies and strategies

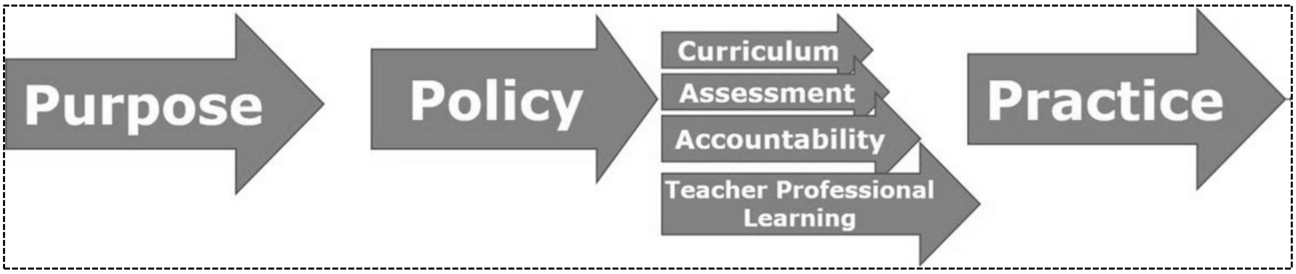
Support leadership, policies, and strategies are crucial not only for the development of policies and strategies during the implementation of digitally supported teaching of mathematics in secondary schools, but also for providing the necessary support in the form of resources, training, and infrastructure. There is a gap between policy design, development, and implementation in schools. According to Bates (2013), policy planning is dominated by the top-down approach in policy planning, which results in power inequalities that create a disconnect between policy planners and implementers, between complex plans and the reality of change, and between valued expert designers and poorly rewarded educators involved in policy implementation, reducing educators to a mere workforce and learners to statistics. Bates (2013) makes the following comment about the complexity associated with policy development and implementation:

> The price of the relentless focus on standards is an impoverished educational landscape, in which we lose sight of the whole child and have little time to connect to pedagogically important questions about the meaning of teaching and the significance of children in our lives. Paradoxically, policy-makers seem to spend a lot of time at the design board, abstracting and simplifying in an attempt to control the complexity that often defies centralised control. Teachers, on the contrary, have little time to draw away from "doing", from performing and "pushing" for targets, to reflect and to connect to the core purpose of teaching and caring for children. Education as a public service needs to be recognised by policy-makers and school leaders as a complex phenomenon that cannot be reduced to abstract measures without diminishing the humanness of the children that it has to serve. In the everyday life of a school, being of service signifies a moral obligation to care for and nurture children. It means acknowledging both the advantages and limitations of the synoptic view (Bates, 2013, pp. 51–52).

Technology integration requires all components of the education system to work together in a coordinated and coherent fashion (ecosystem approach), namely education policy, goals, and visions in conjunction with infrastructure rollout, teacher professional development, technical support, pedagogy, and curriculum change as well as development of the requisite content (Kozma, 2011). According to Maftuh (2011), countries whose industries are functioning at an emerging stage are at the beginning of their development and implementation of digital policies. Figure 19 depicts the key elements of policymaking alignment in education.

Figure 19

The key elements of policymaking alignment in education



Source: Butler et al., 2018

According to Bush (2007, p. 391), "[t]here is also increasing recognition that schools require effective leaders and managers if they are to provide the best possible education for their learners. Schools need trained and committed teachers but they, in turn, need the leadership of highly effective principals and support from other senior and middle managers." Table 4 shows the distinction between leadership and management concerns.

Table 4

Overview of the distinction between the focus or concerns of organisational leadership and management

Leadership concerns	**Management concerns**
Vision	Implementation
Strategic issues	Operational issues
Transformation	Transactions
Ends	Means
People	Systems
Doing the right thing	

Source: Day & Sammons, 2013

Miller and Rowan (2006, pp. 219–220) define two main theories of leadership, which are transformational and pedagogical or instructional leadership, that are seen as a best fit with the perceptions of the types of combined leadership which are inevitable in schools of the 21st century as:

> … a shift away from the conventional, hierarchical patterns of bureaucratic control toward what has been referred to as a network pattern of control, that is, a pattern of control in which line employees are actively involved in [making] organisational decision[s] [and] staff cooperation and collegiality supplant the hierarchy as a means of coordinating work flows and resolving technical difficulties.

According to Day and Sammons (2013, pp. 10–11), "transformational leadership is closely related with four core sets of leadership practices, namely: Building vision and setting directions; understanding and developing people; redesigning the organisation; and managing the teaching and learning programme." The authors note that pedagogical or instructional leadership "has emphasised the importance of establishing clear educational goals, planning the curriculum, and evaluating teachers and teaching. It sees the leader's prime focus as responsible for promoting better outcomes for students, emphasising the importance of teaching and learning and enhancing quality.” On the other hand, New Leaders (2020) define instructional leadership generally as the management of curriculum and instruction by a school principal.

Day and Sammons (2013, p. 40) conclude that while effective leadership is important, it is not a sufficient condition for successful schools. The authors add that instructional or pedagogical leadership has been shown to be important for promoting better academic outcomes for students, it is concluded that the two forms of leadership are not mutually exclusive. Furthermore, the authors argue that school leaders, especially principals, have a crucial role to play in providing guidance and generating an encouraging school culture, including the hands-on school mindset, and supporting and enhancing staff motivation and the commitment needed to foster improvement and promote success for schools in difficult situations. Moreover, the authors mention six key instructional leadership actions or practices that will promote learning in schools:

(i) **Setting a vision for ambitious instruction:** Having a shared vision for the rigour and quality of instruction serves as a rudder for teachers, students, and families, simultaneously empowering them to do their part and holding them accountable to the learning outcomes. The most effective vision statements articulate both the “how” and the “why” of a school’s instructional approach and will enable students to achieve more.

(ii) **Upgrade curriculum and resources:** A strong curriculum is both evidence-based and culturally responsive. Instructional leaders need to create systems and structures to continually analyse and adapt instructional materials, so they are relevant, timely, and high-quality. Working with teacher teams, a school leader can vet classroom-level resources to better support teachers’ preparation for delivery, build stronger alignment around best practices, and increase student voice and agency.

(iii) **Create systems for data-driven instruction:** Data – not perception – is the driving force behind instructional and school improvement. Using consistent data protocols, schools can quickly analyse disaggregated data, identify key trends, and unite around a common goal for improving student learning. A school principal who creates a collaborative culture in which teachers use data and student work to inform, adapt, and monitor instruction in their classrooms will fuel a sense of collective efficacy and accelerate school improvement.

(iv) **Provide equitable access for interventions:** Individual interventions, like tutoring, were implemented nationally in response to the pandemic. Ensuring equitable access to this support is a key responsibility of instructional leaders. Successful models include the use of data and student work to identify students who are most in need and then ensuring that students receive tutoring support multiple times every week from the same tutor, ideally a former teacher or a pre-service teacher.

(v) **Develop systems for professional development and collaboration:** When teachers are engaged in professional development and trusted to make instructional decisions that can create impactful changes for students, they are more likely to stay in their jobs. Strong instructional leaders listen intentionally to teacher needs, protect time for teacher collaboration, and provide various job-embedded supports, like coaching, that can inform instructional delivery over a sustained period of time and enable teachers to immediately apply their learning in their classrooms.

(vi) **Offer coaching to teachers:** Schoolwide systems for observation, coaching, and actionable feedback are often synonymous with instructional leadership and student gains. Two key ingredients are (a) a targeted focus on rigorous instructional strategies and delivery; and (b) systems that enable principals to monitor teacher practice over time and assess the impact of coaching on student achievement. Student achievement is the end goal. The Wallace Foundation found in a landmark report on educational leadership that “[i]t is difficult to envision an investment with a higher ceiling on its potential return than a successful effort to improve principal leadership”. Multiple independent evaluations have also proven that in schools led by a New Leaders principal, students perform better in reading and mathematics and gain additional months of learning. When principals are developed as strong instructional leaders, student learning trajectories can be changed.

This study assesses the current digital education-related policies, strategies, and the role of leadership in promoting or hindering the implementation of the digital teaching and learning of mathematics in secondary schools. Most of these issues are the subject of the current study and will be investigated under the leadership element from theory derived from Hanna's (2016) digital transformation ecosystem, as explained earlier in this section. Based on the SCOT perspective, national, provincial, and local leadership are key actors involved in the implementation of school-level policies.

Poor implementation and utilisation of policies for digital education emanate from a lack of communication, and lack of structured policy support from districts, resulting in the national policy being invisible in schools; there is also a lack of visionary leadership and know-how to drive the implementation of digital learning in schools (Mingaine, 2013; Vandayar, 2013). In addition, unclear educational policies that contradict day-to-day instructions and responsibilities and a lack of commitment from the state education department in providing adequate digital infrastructure and associated professional development (Albugami & Ahmed, 2015) result in teachers fearing to operate digital equipment and trying to avoid damaging equipment, which prevents the innovative use of digital infrastructure (Mingaine, 2013).

Leadership in the implementation of digitally supported teaching is a human actor that is critical during policy creation and implementation. National leadership is instrumental in designing and implementing digital education policies. The idealistic policies created through benchmarking exercises appear to be well-crafted, but become very difficult to implement due to the lack of participation of key stakeholders through a formal governance structure, the non-availability of related resources, and poor communication, among others. This study seeks to identify these and other issues and will offer modest recommendations.

2.5.4 School digital infrastructure – Internet connectivity, bandwidth, devices, applications, and content

Eickelmann et al. (2017) investigated the school level factors that play a role in supporting and hindering the use of ICT in the teaching and learning of mathematics in secondary school lessons. The study compared five countries, namely Australia, Germany, the Netherlands, Norway, and Singapore, as these countries are established in technology integration in teaching and learning. The study revealed that Norway has the highest use of computers in mathematics lessons, and, in the Netherlands, more than 80% of learners use computers in mathematics lessons. According to Goeman et al. (2015), 98% of learners have access to internet-connected devices in the Netherlands.

This can be contrasted with South Africa, where the use of technology for teaching and learning is low. Padayachee (2017) investigated the extent of ICT usage in South African schools, and found that the uptake remains low and that teachers are unsure about the enforcement of e-education while faced with poor infrastructure and lack of skills. The chief barriers were found to be lack of infrastructure or the inadequacy of the available infrastructure, no internet access, or none of the required tools such as a data projector. Ismail et al. (2015) argue that teachers need to be supported by providing the resources appropriate for lesson planning and there should be no limitations on accessing the internet, data projectors, and other visualisation tools.

Teachers need to have fully equipped classrooms to enable the successful use of technology for the teaching and learning of mathematics in secondary schools. According to Stols et al. (2015, p. 10), educators would prefer:

> … to be placed in a fixed and secure classroom, equipped with technology and stable internet connections. In their view, such resources and safe classrooms could save time and provide an environment where it would be easier to provide technology-assisted teaching.

Mura and Diamantini (2014) investigated the uses, perceptions, and representations of ICT among primary and secondary school educators. The study discovered widespread technology diffusion among teachers but a low level of technology integration in lessons. Additionally, teachers range from highly skilled users of ICT to insecure users of ICT, and all highlighted the need for additional professional development on technology usage.

The use of digital technologies for teaching and learning secondary mathematics requires investment in the rollout of related school digital infrastructure, including training and technical support, among others. According to Stols et al. (2015), some countries have invested large sums of money in school digital infrastructure (non-human actor) with little evidence of the effectiveness of these digital technologies for teaching and learning. Furthermore, “schools, despite the large investment, in many countries have not yet taken advantage of the potential of technology in the classroom …” (Butler, 2018, p. 474). The rollout of infrastructure in schools should be accompanied by the relevant training of teachers and should include maintenance and support to ensure adoption and usage, as indicated earlier.

Internet connectivity has positive effects on learner achievement. Amponsah et al. (2022) explored the use of the internet and its impact on the academic performance of senior high school students in Ghana. The study revealed that students have access to the internet via ICT labs, mobile phones, internet facilities for families, and public internet cafes. Furthermore, internet access influences academic standards among students, as those with internet access showed a greater improvement in academic performance than those without. Similarly, the presence of several sources of internet connectivity does not guarantee immediate access to all of them. It was also recommended that, to support student research, the schools’ ICT laboratories should be well equipped with internet facilities and students should be taught how to use search engines to search for academic materials. This is vital because the provision of school internet facilities plays a very important role in enhancing academic performance.

The researchers make the following recommendations:

(i) Heads of institutions should liaise with other stakeholders and management to provide internet facilities, which are crucial in supporting academic performance.

(ii) The schools’ ICT laboratories should be well equipped with internet facilities to assist student research and study.

(iii) Students should be taught how to search for academic information or materials online.

(iv) Students need to be effectively supervised by teachers and parents when using the internet so that they do not solely concentrate on social media.

Ghosha and Upadhyay (2023) conducted an analysis of literature on the impact of internet use on academic achievement and found that the internet has a significant impact on students’ academic performance as it enables them to access publications and articles that are otherwise unavailable in libraries. The study concludes that internet use was very helpful in enhancing learning results. However, the study also identifies the detrimental effects of internet use, such as distraction, as people spend more time on social media instead of studying. Therefore, the study suggests that authorities issue directives to assist students in addressing some of the difficulties encountered when using the internet.

The authors further argue that the internet has had a profound and multifaceted effect on students’ studies. Its vast availability of information and resources has empowered students to conduct research, access educational content, and explore diverse subjects like never before. The interactive and personalised learning experiences offered by online platforms have made studying more engaging and effective. Additionally, the internet’s capacity for global connectivity has facilitated collaboration and knowledge sharing among students, promoting a deeper understanding of subjects, and fostering essential communication and teamwork skills.

However, while the internet presents numerous benefits, it also poses challenges that students must address. The abundance of information requires students to develop critical thinking and digital literacy skills to identify reliable sources and avoid misinformation. Managing the distractions of social media and other online activities is crucial for maintaining focus and productivity in studies. Emphasising digital literacy education can equip students with the necessary tools to navigate the online world responsibly and effectively.

The quality of internet connectivity is one of the main challenges of countries or schools in their initial stage of implementing digital learning if broadband internet is not available at school and home (Choppin et al., 2014). Lack of access to hardware and software applications is another challenge for schools (Maftuh, 2011). Furthermore, the wide use of mobile devices can be hindered by limited network capacity and reliability as these devices rely heavily on internet connectivity, limited facilities and resources, digital resources not being current, restricted access, diverse and varying model platforms, alignment with specific content, and pedagogies that stifle digital learning (Groff, 2013).

A wide range of devices are available on the market for digital learning, including desktops, laptops, tablets, and smartphones, which are key to facilitating digital learning activities by accessing e-books and digital content online and offline, at school and at home (Choppin et al., 2014; Lin et al., 2017). Strategies such as universal service obligations (USOs) can be imposed on regulated telecom operators to ensure that broadband rollout in schools is prioritised in terms of availability, accessibility, and affordability (Haryadi, 2018; Nucciarelli et al., 2013). Therefore, limited internet connectivity, poor quality of internet connectivity, and lack of devices, applications, and content can contribute to schools not evolving to the desired transformational stage. Previous studies provide limited evidence on how education systems can move beyond the early stage of their digital transformation journey and do not specifically address the challenges in secondary mathematics education.

Grant et al. (2015) investigated the use of mobile devices (mobile phones, smartphones, and tablets) in secondary schools and found that while some teachers used their own devices, most teachers use school-issued devices that are mainly controlled on how they are used in class. The study found that the main challenge was technical network capacity and network reliability due to dependency on internet connectivity. Newhouse (2014) argues that the use of mobile devices (laptops, tablets, smartphones, wireless networking, voice or stylus input, and plug and play peripheral devices) are key for learner-centred learning situations that support the constructivist paradigm that empowers learners.

De Vita et al. (2014) reviewed literature on the use of interactive whiteboards in mathematics lessons and found that despite the potential of interactive whiteboards to improve conceptual understanding, many teachers resist using whiteboards as a lesson delivery tool. The study notes that the resistance emanates from pedagogy associated with the use of whiteboards.

Pfeiffer (2017, pp. 294–301) found that the use of GeoGebra facilitated a deeper understanding through “transformations of functions, circle geometry and general solutions of trigonometric equations” and that students developed a higher order of abstraction that is credited to the “visual, potentialities and enablement” of GeoGebra. The author adds that GeoGebra made teaching and learning mathematics enjoyable and promoted collaboration, amongst others. The author further cites some of the challenges of using GeoGebra, which include language rules, writing instructions, adaptation to the new teaching methods, and the inability of some learners to see the purpose of the lesson. Moreover, Eickelmann et al. (2015, p. 1545) noted that the use of digital technologies in “mathematics teaching was statistically highly significant” in only one out of five countries investigated. Educators also need to adapt their educational methodologies to match the current realities of using digital technologies (Camilleri & Camilleri, 2017). It is clear from the limited literature that the availability of digital infrastructure alone does not guarantee its adoption and usage; indeed, there may be minimal exploitation of its transformational potential.

Bhagat and Chang (2014) also investigated the impact of using GeoGebra on grade 9 learners’ geometry achievements and found that GeoGebra is an effective tool for teaching and learning geometry. The use of dynamic software applications in teaching and learning mathematics is more effective than traditional teaching (Chan & Leung, 2014; Mushipe & Ogbonnaya, 2019).

Grandberg and Olsson (2015) investigated how GeoGebra supports learner collaboration and creative reasoning during mathematics problem-solving. The study found that GeoGebra supports collaboration and creative reasoning by providing learners with a common workspace, visualisation, an interactive environment, and feedback from learners’ creative reasoning. Bray and Tangney (2017) categorised this study as representative of the modification level of the SAMR model. Hamilton (2017) argues that teachers need to move from substitution and augmentation (the enhancement level) to modification and redefinition (the transformation level).

On content knowledge, Shulman (1987, p. 8) lists seven categories of knowledge base:

(i) general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organisation that appear to transcend subject matter;

(ii) knowledge of learners and their characteristics;

(iii) knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures;

(iv) knowledge of educational ends, purposes, and values, and their philosophical and historical grounds;

(v) content knowledge;

(vi) curriculum knowledge, with a particular grasp of the materials and programmes that serve as the "tools of the trade" for teachers; and

(vii) pedagogical content knowledge, which is that special amalgam of content and pedagogy that is uniquely the province of teachers, and their own special form of professional understanding.

Content knowledge includes knowledge of the subject and its organisational structures, while curricular knowledge includes the full range of programmes designed for the teaching of subjects and topics at a given level. Pedagogical content knowledge is defined by Shulman (1986, p. 9) as:

> The most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the most useful ways of representing and formulating the subject that make it comprehensible to others. ... Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons.

According to Koehler et al. (2013, p. 102), the TPACK framework by Mishra and Koehler (2006) was framed by building on Shulman's (1986) "characterization of teacher knowledge to explicitly consider the role that knowledge about technology can play in effective teaching". As indicated earlier in section 2.4.3, "TPACK refers to knowledge about the complex relations among technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies." The authors add that the TPACK framework suggests that teachers must have a deep understanding of all the knowledge elements to successfully organise and direct technology, pedagogy, and content into teaching approaches. The authors further note that this results in an emergent new form of knowledge that goes far beyond the individual knowledge areas.

2.5.5 Digital learning – Digital pedagogy and social constructivism

According to Dublin City University (DCU, 2018), "digital learning is any form of learning that is facilitated by digital technologies or by an instructional practice that makes effective use of technology." Watson et al. (2014, p. 4) define digital learning as follows:

> Digital learning is any instructional practice in or out of school that uses digital technology to strengthen a student's learning experience and improve educational outcomes. Our use of the term is broad and not limited to online, blended, and related learning. It encompasses a wide range of digital tools and practices, including instructional content, interactions, data and assessment systems, learning platforms, online courses, adaptive software, personal learning enabling technologies, and student data management systems to provide timely and rich data to guide personalized learning.

Watson et al. (2014, p. 176) add that "digital learning is replacing previous reference to online and blended learning." In other words, digital learning is an all-encompassing term for all teaching and learning activities that use technology tools and resources. Additionally, digital learning involves the use of technological devices (smartphones, tablets, and computers), users, learning contexts, learning processes, and learning facilitators (Hager, 1998; Sousa, 2018). Furthermore, digital learning is designed to enhance the learning experience rather than replace traditional methods altogether (Ifenthaler et al., 2014; Wheeler, 2012). Moreover, online-based learning is linked to the promotion of visualisation, simulation, illustrations, and computerised testing (Kreijns et al., 2013), as well as learning analytics for tracking online learner habits for educational decision-making (Ifenthaler et al., 2014).

Lin et al. (2017) investigated learners' opinions of digital learning and found that it has more positive effects on learning motivation than traditional teaching does, and contributes positively to learning gains, among others. Lin et al. (2017,

p. 3558) also comment that "digital learning is attractive because there is no restriction on time and space for learning to take place. Lin et al. (2017, p. 3555), citing Keane (2012), further note that digital learning comprises four main components:

(i) **Digital teaching materials:** Learners can learn by extracting digital teaching material content. The digital teaching material content refers to e-books, digitalised data, or content presented using other digital methods.

(ii) **Digital tools:** Learners can proceed with a learning activity using digital tools, such as desktop computers, notebook computers, tablet computers, and smartphones.

(iii) **Digital delivery:** Learners' learning activities can be delivered through the internet, e.g. intranet, internet, and satellite broadcasting.

(iv) **Autonomous learning:** Learners can engage in online or offline learning activity by themselves.

Moreover, Lin at al. (2017) provide nine advantages of digital learning over traditional learning approaches, namely:

(i) **Learning no problem**: Unlike traditional learning, digital learning allows learners to select the time and location for online learning. Time and space do not present any obstacles as the instructors are online.

(ii) **Rich network resources**: The internet offers rich and diverse information and learners can acquire data simply by using key words. When a digital learning platform is able to organise relevant resources for the use or connection of learners, network resources can be effectively applied through digital learning, and instructors or learners can obtain better information beyond the teaching materials in the curriculum to enhance the learning effect.

(iii) **Digital learning contents and tailored learning schedule**: Learners are all treated the same in traditional teaching: all learners have the same teaching schedule and content, regardless of their level. However, the availability of digital learning content means that learners can freely select different courses and teaching material, according to their level and preference, to achieve a tailored learning outcome.

(iv) **Complete records of learners' learning history**: A good digital learning platform should be able to accurately record learners' learning history so that instructors can understand learners' learning conditions and learners can easily identify the level or learning outcome for adjustment and improvement.

(v) **Interactive learning**: Digital teaching materials should include more media pictures, sounds, or images than traditional teaching materials in order to be more attractive and engaging. Moreover, digital teaching platforms should provide interactive functions like chat rooms and discussions for more two-way communication between learners and instructors and between learners.

(vi) **Reduction of teaching costs**: The teaching materials used on a digital teaching platform should be kept as digital files so that the materials can be used again. In other words, the teaching materials developed by instructors can be used repeatedly, thus reducing teaching costs.

(vii) **Effective accumulation of knowledge**: The digital learning mode can accurately record all online teaching materials and learners' learning history. For learners, this can improve personal knowledge. For instructors, the teaching material can be effectively organised and accumulated on a digital learning platform and rapidly delivered to learners for effective knowledge management.

(viii) **Enhancement of learning interests**: Instruction that uses various media can be more engaging for learners, making learning more efficient and improving learners' performance.

(ix) **Simultaneous new technology learning**: Digital learning emphasises the learning of new technologies (computers, network, digital tools) to promote the use of information technology.

However, several challenges are associated with the implementation of digital learning in schools. Schoology (2018, p. 12) identified the top five challenges that are faced by educators during the implementation of digital learning in schools: (i) learners' access to technology; (ii) lack of time during normal school time; (iii) multiple digital tools being used for teaching or learning; (iv) lack of a digitised curriculum; and (v) lack of parent or guardian involvement or understanding.

Private and public secondary schools also differ with regard to classroom practice. Hameed and Butt (2018) argue that private school educators encourage a collaborative environment, provide individual attention, promote small group discussions, encourage learners, engage learners in problem-solving, and practise computational skills, whereas public school teachers believe that the textbook is an essential teaching tool, and promote drill or rote learning to solve complex problems. It is important to note the existing challenges related to the teaching and learning of mathematics, and that the integration of digital technologies is adding another dimension of complexity which this study seeks to unpack.

This study is closely linked to the social constructivist theory. According to Hoy et al. (2013, p. 19), constructivist theories, including the social constructivist theory, are concerned with how individuals make meaning of events and activities; hence, learning is seen as the construction of knowledge. Constructivism assumes that people create and construct knowledge, rather than internalise it from the external environment.

Pedagogy is also important in the teaching and learning environment. Koehler et al. (2013) refer to PK as "teacher knowledge about a variety of instructional practices, strategies, and methods to promote students' learning". Learning Portal (2019) refers to pedagogy as the "interactions between teachers, students, and the learning environment and the learning tasks." Westbrook et al. (2013, p. 9) note that educators can use four pedagogies, namely (i) teacher-centred learning; (ii) learner-centred learning; (iii) teacher-guided learning; and (iv) critical pedagogies. Moreover, Learning Portal (2019) mentions another type of pedagogy, called learning-centred pedagogy, which takes into consideration the local context, class size, the physical environment, and the availability of teaching and learning materials, among others.

Agrahari (2016) investigated the traditional teacher-centred teaching approach and the modern learner-centred approach in India, and found that the modern approaches develop more active learners who have a propensity to develop problem-solving skills, independent thinking, and autonomous learning skills.

On the other hand, digital pedagogy is likened here to techno-pedagogical knowledge, which is associated with teachers' knowledge of the different technologies involved in teaching and learning, and which enables them to associate tools with specific educational tasks (Bachy, 2014, p. 22). Further conceptualisation of digital pedagogy is provided in Chapter 8.

Table 5 provides a summary of the theoretical schools of thought that underpin the different pedagogical approaches.

Table 5
Broad theoretical schools of thought and associated pedagogies

Broad theoretical school of thought	**Associated pedagogy**	**Examples of pedagogy in developed countries**	**Examples of pedagogy in developing countries**
Behaviourism	Teacher-centred learning 'Performance', visible pedagogy	Whole class teaching, working together as a collective (Japan, the Pacific Rim) Focus on mastery of skills in a particular sequence	Lecturing, demonstration, direct/explicit instruction, rote learning, choral repetition, imitation/copying, 'masterclasses' (e.g., learning music or dance)
Constructivism	Child-centred learning 'Competence' or invisible pedagogy	Project work, individual activity, experiential, Montessori, Steiner, Pestalozzi in the US and Europe	Activity-based learning in Tamil Nadu

			Bodh Shiksa Samiti schools in India
Social constructivism	Teacher guided Learner/student-centred learning	Reciprocal teaching of reading in US, communicative learning, co-operative learning, group work element in national strategies, England	Small-group, pair, and whole-class interactive work, extended dialogue with individuals, higher-order questioning, teacher modelling, showing, problem-solving, inquiry-based, Nali Kali in India, the thematic curriculum in Uganda
Behaviourism and social constructivism	Learning-centred pedagogy Flexible and adaptable Digital pedagogy/techno-pedagogy		Considers the local context, class size, the physical environment, the availability of resources, among others

Source: Adapted from Bachy, 2014; Learning Portal, 2019; Westbrook et al., 2013

Even though technology integration is highly regarded by educators, less use thereof might be due to large class sizes and inadequate training. Bretscher (2021) investigated the association between mathematics educators' technology integration and found that teachers are more inclined to use teacher-centred approaches when using digital tools such as IWB software, PowerPoint, MyMaths and some websites.

ICT use in a whole-class context is more strongly associated with teacher-centred approach than in contexts in where students are given direct access to technology. Regarding training, Perienen (2018, p. 1) investigated factors that significantly contributed to technology use by mathematics educators and found that while educators perceive digital tools to be useful in enhancing mathematics teaching and learning, few educators used technology in class. Educators cited inadequate training in the "pedagogical integration of Information and Communication Technology (ICT)".

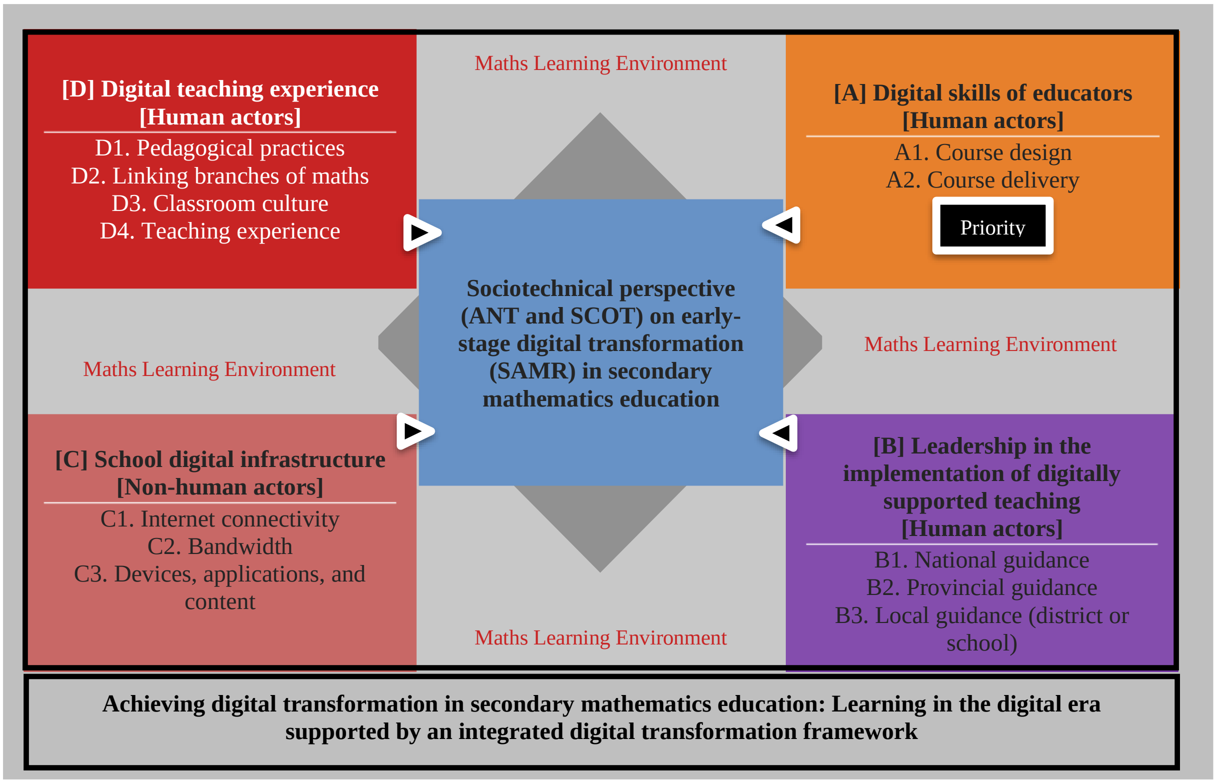
2.6 ANALYTICAL THEORETICAL FRAMEWORK OF THE STUDY

Coral and Bokelmann (2017) note that analytical frameworks are useful and provide an accessible language that is used to develop explanations of the relationships between concepts and terms that are used in a theory. The Center for Teaching and Learning (2017) notes that a theoretical framework provides the theoretical assumptions for the larger context of a study, is the foundation or 'lens' by which a study is developed, and helps to ground the research focus under study within theoretical underpinnings and to frame the inquiry for data analysis and interpretation. Hence, the analytical framework is a theoretical lens for this study and has a strong sociotechnical perspective that will be used during the data collection and analysis stages. The main foundation of this study's analytical framework is drawn from Hanna's (2016) digital transformation ecosystem.

Hanna's (2016) digital transformation ecosystem is a broad holistic framework comprising five interdependent elements: (i) policies and institutions; (ii) human capital; (iii) the ICT industry; (iv) ICT infrastructure; and (v) digital transformation. For this study on secondary mathematics education, the researcher has adapted four elements from Hanna's (2016) framework, in the following sequence: human capital (digital skills of educators); policies and institutions (leadership in the implementation of digitally supported teaching); ICT infrastructure (school digital infrastructure); and education-sector specific activities (digital teaching experience), as the key enablers to achieve digital transformation in secondary mathematics education. Figure 20 depicts the analytical framework for investigating the evolution of digital transformation in secondary mathematics education.

Figure 20

The study's analytical framework: The DT-SME framework



Source: Adapted from Hanna, 2016

2.6.1 APPLICATION OF THE DT-SME FRAMEWORK

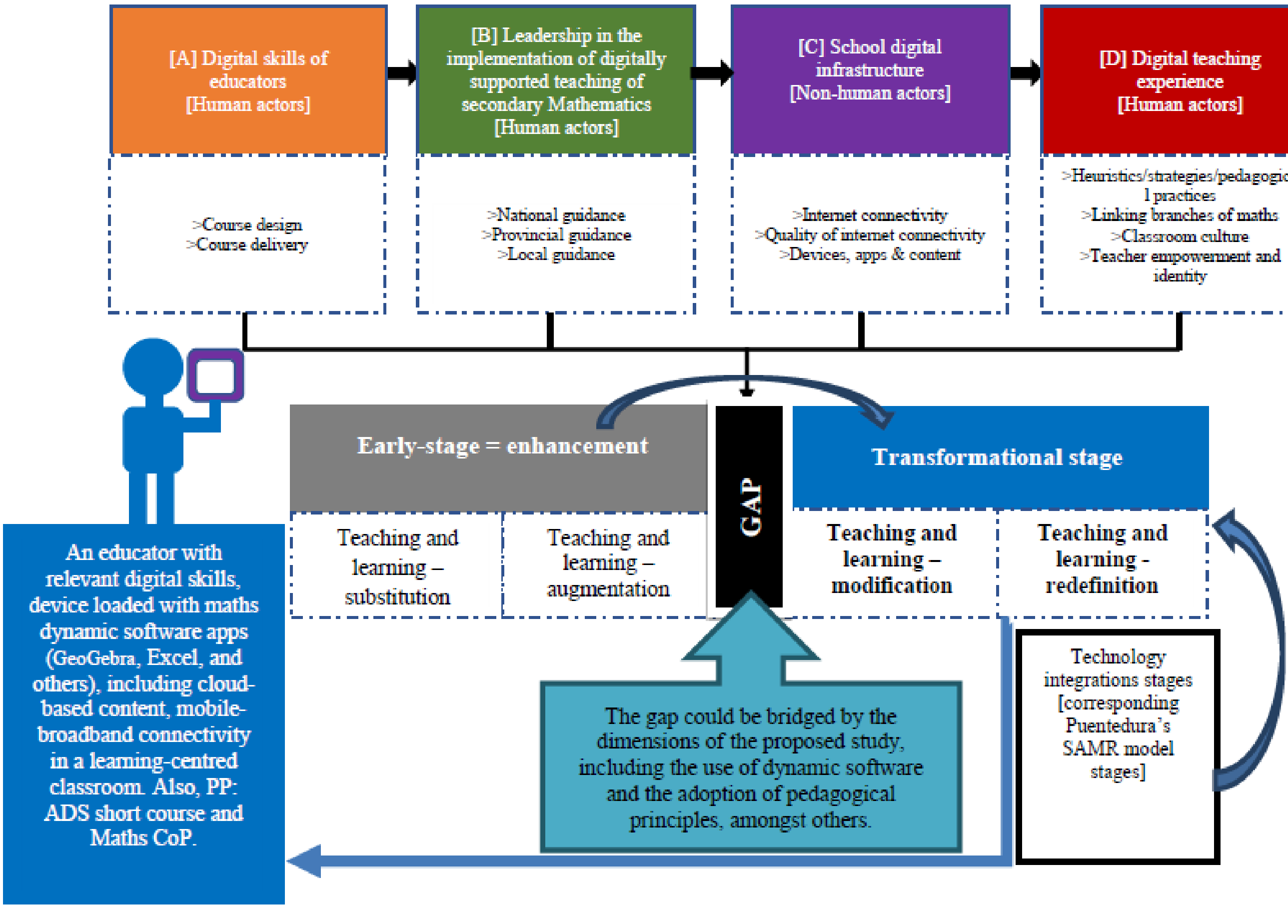
The adaptation introduces the sector-specific dimension of digital teaching experience, which is effectively represented in the form of Puentedura's (2006) SAMR model, into the analytical framework for this study. ANT will provide a sociotechnical data analysis tool applicable to all four dimensions, concerning understanding human and non-human actors. The SCOT theory will provide a sociotechnical data analysis tool applicable to the use of technology, relevant to how human action shapes technology. The study utilises a sociotechnical DT-SME framework with four dimensions: (A) digital skills of educators; (B) leadership in the implementation of digitally supported teaching of secondary mathematics; (C) school digital infrastructure; and (D) digital teaching experience i.e., a socio-technical (ANT and SCOT) DT-SME (SAMR) framework with four dimensions.

The theoretical lens for this study prioritises digital skills of educators because teachers are highly influential in the current classrooms of the "early stage" phase of transformation, and the other three elements (leadership, infrastructure, and digital teaching experience) will be considered as they relate to digital skills, within the broader frame of digital transformation. Shifting digital transformation in secondary mathematics education beyond the early stage or achieving a mature digital transformation ecosystem for digitally supported secondary mathematics education (see Figure 21) can be conceptualised as bridging the gap between the enhancement and transformation stages of Puentedura's (2006) SAMR model, through the proposed analytical framework, which will result in improved matriculation results.

The literature review identified a gap in the use of digital tools such as simulation programming, learning toolkits, and dynamic software tools in a transformational manner for mathematics teaching (Bray & Tangney, 2017). The adapted analytical framework proposes that the digital skills (intermediate and advanced) of educators are crucial for the successful implementation of the digitally supported teaching of mathematics in secondary schools. Also, leadership in the form of provincial and district officials is important for the rollout and use of school digital infrastructure, as well as training and support on digital skills. Furthermore, a constructive and enjoyable digital teaching experience can lead to the attainment of teaching goals. The interaction of dimensions A to D will contribute to the main element of the study, which is early-stage digital transformation in secondary mathematics education. This study investigates each of these dimensions and the nature of their relationship to each other in the context of secondary mathematics education, to address the knowledge gap identified. Figure 21 depicts some of the components related to achieving a mature digital transformation ecosystem for digitally supported secondary mathematics education.

Figure 21

Achieving a mature digital transformation ecosystem for digitally supported secondary mathematics education



Source: Author

It must be noted that the body of theory relating to digital transformation in secondary mathematics education is broadly organised but has been framed using mainly Hanna's (2016) digital transformation ecosystem.

2.7 CHAPTER SUMMARY

This chapter discussed the relevant literature to determine which approaches can be used to shift digital transformation in secondary mathematics beyond the early stage. The discussion of the literature revealed that the digital transformation concept is researched mostly in the automobile, finance, telecommunications, healthcare, oil and gas, and manufacturing industries (Nadeem et al., 2018). Digital transformation in the education sector, specifically secondary mathematics, is associated with Puentedura's (2006) SAMR model to describe whether technology is used in an enhancement manner (early stage) or in a transformational manner (beyond the early stage), including Hojsted's (2020) transformation-related dynamic software application affordances, namely feedback, dragging, measuring, and tracing.

While the literature confirms the positive benefits of technology integration in the teaching and learning of mathematics (Makotjo, 2021), there is no clear evidence of the SAMR transformation level that is key for the radical improvement of learning gains. A study by Hojsted (2020) found that the SAMR enhancement level was prevalent in Danish schools. Key sociotechnical theories have also been discussed, namely Hanna's (2016) digital transformation ecosystem and its adaptation to the DT-SME framework, including the adoption of transformation levels (enhancement and transformation) from Puentedura's (2006) SAMR model. The chapter also discussed the TPACK framework (Mishra &

Koehler, 2006), which is a popular framework for technology integration and its knowledge areas which are similar to some of the dimensions of the study's analytical framework. Also discussed were ANT and the SCOT theory from Orlikowski (2010) as a tool for analysing the role of actors and technology-use respectively i.e., the SCOT theory assists in understanding technology use whether it is at the enhancement or the transformational level (Puentedura, 2006). In Chapter 3, the literature discussed is used to prepare a research design and methodology that supports the interpretative social constructivist case study.

Chapter 3: Research Design and Methodology: Inter-disciplinary Social Constructivist Case Study

3.1 INTRODUCTION

The previous chapter discussed early-stage digital transformation in secondary mathematics education, which is equivalent to technology integration at the SAMR enhancement level in the teaching and learning of mathematics. The chapter also provides the foundation for the development of the study's analytical framework, which is the DT-SME framework, and which is suggested to be key in shifting digital transformation in secondary mathematics education beyond the early stage. This chapter will describe, justify, and discuss the research methodology of the study, which includes the research philosophy, the research approach, and the research design that are appropriate for addressing the aims and objectives of the research study, including a description of the selected participants. The philosophical stance taken by this study and the justification for the qualitative research, including the units of analysis, data collection, analysis procedures, and triangulation, are discussed to build an understanding of approaches to shifting digital transformation in secondary mathematics education beyond the early stage. Validity and reliability, including ethical factors, are also considered to ensure that the results of this study are accepted as a meaningful contribution to the body of knowledge to be used by other researchers. Figure 22 outlines the flow of the chapter.

Figure 22
Chapter 3 flow chart

Chapter 3

3. Research design and methodology: Interdisciplinary social constructivist case study
3.1 Introduction
3.2 Research philosophy: Ontology and epistemology
3.3 The theoretical perspective: Interdisciplinary
3.4 Research methodology: An interdisciplinary social constructivist case study
3.5 Unit of analysis
3.6 Sampling procedure
3.7 Data collection
3.8 Data analysis
3.9 Triangulation
3.10 Difficulty of conducting interviews during the COVID-19 lockdown and loadshedding
3.11 The researcher's perspectives
3.12 Validity and reliability
3.13 Ethical considerations
3.14 Chapter summary

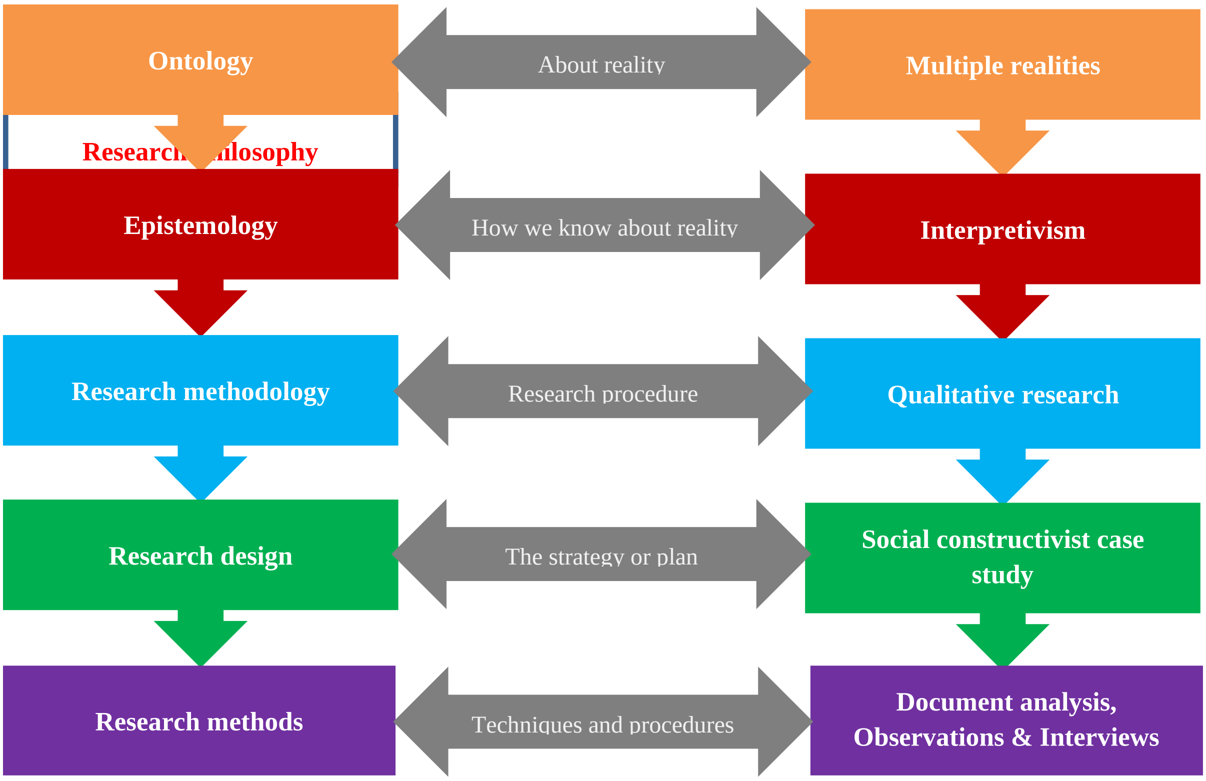
To guide the research study, the following research questions were formulated to address the elements of research specific to digital transformation in secondary mathematics education:

- How does professional development for educators advance the digital skills of educators for effective curriculum design and delivery for mathematics teaching and learning (human actors)?
- How does the exercise of leadership (at the provincial and district levels) promote or impede (intentionally or unintentionally) the implementation of digitally supported teaching in schools (human actors)?
- What can be done to ensure that there is adequate school digital infrastructure (non-human actors)?

- How can digitally supported teaching improve the digital teaching experience in secondary mathematics education (human actors)?

The overall research design and methodology of this study are shown in Figure 23. These inherent linkages are explained throughout the research study. The important aspect among these various stages is the location of the study within the realm of social constructivism, which views reality as socially constructed and appearing naturally, as in the case of objectivism. Hence, the methods of collecting data and analysing data are rooted in the views of participants in the technology in the secondary mathematics education ecosystem.

Figure 23
Overall research design and methodology of this study



Source: Adapted from Cavana et al., 2001; Cresswell & Poth, 2018

3.2 RESEARCH PHILOSOPHY: ONTOLOGY AND EPISTEMOLOGY

This research study is driven by the ontological and epistemological perspectives that provide an explanation and outline the researcher's conceptualisation of social reality and knowledge as it pertains to digital transformation in secondary mathematics education. This is important because researchers with a similar position on a subject do not often reach the same conclusion from their perspectives on their respective ontological and epistemological orientations.

3.2.1 Ontology – Multiple realities

Cresswell and Poth (2018, p. 20) state that ontology "relates to the nature of reality and its characteristics" and provides an answer to the question: "What is the nature of reality?" Ontology also describes what exists in the social world (Mouton, 1996). This is a qualitative research study which embraces the idea of multiple realities that can be confirmed by multiple sources of evidence presented by the different perspectives of individual actors (Creswell & Poth, 2018). Hence, this study is located within the realm of social constructivism that informs the epistemological and methodological stances.

As discussed in the previous chapter and in line with the scope of this research study, digital transformation or technology integration in mathematics teaching and learning is complex and involves various key actors, such as government, teachers, district officials, academics, the private sector, and civil society, among others. Therefore, a concerted effort is required to ensure that all role-players collaborate meaningfully to construct a social reality during the implementation of digitally supported teaching and learning in schools. Therefore, the use of technology in the teaching and learning of mathematics in secondary schools is located within the realm of constructivism, defined by Creswell and Poth (2018) as a branch of philosophy that asserts that reality is socially constructed and shaped by individual experiences.

3.2.1.1 Reflection on my journey in mathematics

Ontologically speaking, this research topic and scope are largely influenced by my personal experience and knowledge. My personal experience with mathematics education was a combination of working with concrete objects such as stones, bottle caps, and drawings of triangles in the lower grades. When I was in grades 8 and 9, a teacher facilitated an understanding of factorisation and encouraged us to have a rough work section to try various combinations of factors on the side. Although the pedagogy from the lower grades to high school was teacher-centred, teachers assigned group work, afternoon studies, and homework. I also remember practising and reworking examples to understand the problem-solving steps. During my university years at the University of Transkei (UNITRA), now Walter Sisulu University (WSU), in Mthatha, teaching practice reflected how I was taught (teacher-centred). While at UNITRA, I also enrolled in computer literacy classes, which proved valuable when I started teaching in 1996. Computer literacy allowed me to type exam papers on a computer for easy printing, while other teachers used typewriters and mechanical duplication, which was time-consuming and messy. After graduating from UNITRA, I taught mathematics to grades 11 and 12 (also physical science to grades 10, 11, and 12), using a chalkboard and a prescribed textbook.

The period during which I started working as a teacher coincided with the abolition of corporal punishment, and many teachers struggled with using alternative approaches to maintain discipline and motivation. When I resigned as a teacher in 1998 to pursue a Postgraduate Diploma in Engineering (PDE), specialising in satellite communications, at Stellenbosch University (SU), mathematics became very important for me in calculating engineering concepts related to radio communications. These include the delivery of television programmes via satellite systems, terrestrial (land-based) networks, and mobile communication systems. While I did well in mathematics under poor conditions, I was very concerned to hear in the media about the poor performance of the South African education system in general, and in mathematics specifically, which has resulted in a shortage of engineers and scientists. At one point, I attempted to purchase the Master Maths franchise after a few years of working in the telecommunications sector, to contribute to the improvement of results, particularly in rural settings.

This doctoral research on digital transformation in secondary mathematics education attempts to understand the issues related to the improvement of mathematics outcomes. My study will contribute to improving mathematics learning outcomes in the digital age by understanding four dimensions of this research, namely, digital skills, leadership in implementing digitally supported teaching, school digital infrastructure, and digital teaching experience. This research tackles these issues holistically using the digital skills ecosystem approach. There is evidence of the government attempting to roll out school digital infrastructure (in the form of tablets) in schools. However, the low levels of utilisation of digital infrastructure in schools point to the gaps in teacher professional development in addressing intermediate and advanced digital skills for content creation, search, and usage. The current exposure to the new pedagogical approaches, such as a learning-centred approach that emphasises the teacher–learner learning experience, allows engagement. The new pedagogical approaches are associated with inclusive design that will enable hand and brain coordination. This shift ensures that digital pedagogy leads content and that tools play a supporting role.

3.2.2 Epistemology – Interpretivism

Epistemology is related to providing an explanation and understanding of how researchers come to know what they know and entails being close to the subjects being studied to get their subjective experiences in their context (Creswell & Poth, 2018; Crotty, 2003; Schwandat, 2003). Klein (2005) defines epistemology as a branch of philosophy concerned with defining what constitutes knowledge, how it is developed, and its source, as well as its limits, with an emphasis on the scientific basis of knowledge, because speculation and wishful thinking do not constitute knowledge. According to Trivedi (2020), the credibility of knowledge can be ascertained in two ways, namely positivism and interpretivism. This study leans towards interpretivism which holds that knowledge is a matter of interpretation and that we need to interpret the meanings, purposes, and intentions (interpretations) that people give to their actions and interactions with others (Trivedi, 2020).

According to Cresswell et al.'s (2018, p. 21) epistemological assumption, carrying out a "qualitative study means that researchers try to get as close as possible to the participants being studied. Therefore, subjective evidence is assembled based on individual views." The authors also note that subjective evidence is obtained from participants in proximity. This study is therefore premised on knowledge gathered and sourced from a systematic engagement with participants in the education sector. The next section deals with the methodology of the research study that is informed by and aligned to the ontology and epistemology of the study as discussed in this sub-section.

3.3 RESEARCH METHODOLOGY – QUALITATIVE STUDY APPROACH

The methodology is "the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of the methods to the desired outcomes" (Crotty, 2003, p. 3). The methodology section seeks to answer the questions: "How do we attain knowledge? How do we ensure that we reach our research goal?" as suggested by Mouton (1996). There are mainly two research approaches, namely qualitative and quantitative. A qualitative study is defined by Cavana et al. (2001) as a research approach where a human being is an instrument for data collection and analysis, with the researcher intervening through talking and actions to understand the meaning of the respondent's attributes to the phenomena being studied. On the other hand, quantitative research values objective observation, precise measurements, statistical analysis, and verifiable truth (Cavana et al., 2001).

These are the characteristics of qualitative research (Babbie & Mouton, 2016, p. 270):

- The research is conducted in a natural setting of social actors.
- The process rather than the outcome is focused on.
- The actor's perspectives (the "insider" or "emic" view) are emphasised.
- The primary aim is in-depth ("thick") descriptions and understanding of actions and events.
- The main concern is to understand social action in terms of a specific context (idiographic motive) rather than attempting to generalise to some theoretical population.
- The research process is often inductive in its approach, resulting in the generation of new hypotheses and theories.
- The qualitative researcher is seen as the "main instrument" in the research process.

This study uses the qualitative research approach as the study seeks to answer the "how" question, aimed at improving understanding by closely examining individuals' words, actions, and records (Cavana et al., 2001; Maykut & Morehouse, 1994). A qualitative research approach is known to focus on non-numerical data and the research information or data that are gathered from occurring phenomena. This qualitative study seeks to explore approaches to shifting digital transformation in secondary mathematics beyond the early stage.

3.4 RESEARCH DESIGN – SOCIAL CONSTRUCTIVIST CASE STUDY

A research design is described as the overall approach that is chosen to integrate all the different components of a research study in a "coherent and logical way, thereby ensuring you will effectively address the research problem; it constitutes the blueprint for the collection, measurement, and analysis of data" (USC, 2023). It is a plan of action for how the research study is communicated. It is a critical aspect of the research process as it serves as a guiding tool for the analysis and reporting of the research findings.

This research study used a case study research design. According to Creswell and Poth (2018, p. 96), a "case study is a qualitative approach in which the investigator explores real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audio-visual material, and documents and reports) and reports a case description and case dimensions." The researcher considered two case studies – case study A: Western Cape Education Department (WCED) and case study B: Gauteng Department Education (GDE) – which are complementary. The perspectives of participants from case study A were complemented by those from case study B to enrich the findings on the dimensions of the study, namely the digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience.

According to Leedy and Ormrod (2015, p. 272),

> [a] case study may be especially suitable for learning more about a little-known or poorly understood situation. It can also be appropriate for investigating how an individual or program changes over time, perhaps as the result of certain conditions or interventions. In either circumstance, it tends to be most useful for generating or providing preliminary support for one or more hypotheses regarding the phenomenon being investigated.

The authors note that the major limitation of a case study, particularly in a single-case situation, is that no one can be sure that the research findings can be generalised in other situations.

This study uses a social constructivist case study to answer the research questions. Social constructivism is about trying to understand the world in which we live and work by developing subjective meanings of lived experiences towards objects through understanding language and actions (Creswell & Poth, 2018).

In this study, social constructivism arises in the knowledge constructed based on the insights from the in-depth investigation of the approaches to shifting digital transformation in secondary mathematics beyond the early stage in the teaching and learning of mathematics in secondary schools. The study explored and analysed the views of key education stakeholders such as teachers, principals, district officials, and academic experts on the study's analytical framework dimensions, which are viewed as critical for the shifting of digital transformation in secondary mathematics education beyond the early stage i.e., Puentedura's (2006) SAMR transformation level.

3.5 UNIT OF ANALYSIS

Researchers must be specific about the unit of analysis to be used for the population to be studied to determine what or who is being studied. Units of analysis can be individuals, dyads, or groups (Cavana et al., 2001), social interactions or social artefacts (Babbie, 2013), and objects that are examined to develop a summary description of all units involved to explain differences between them (Babbie & Mouton, 2001). For this research, the units of analysis in the case studies were mainly the individuals (teachers, principals, district officials, academic experts, and local economic development agency representatives). Case study A (WCED schools) was complemented by case study B (GDE schools) due to the COVID-19 lockdown, because remote interviews with WCED-based participants proved to be difficult. Table 6 depicts the units of analysis and the data collection plan.

Table 6
Unit of analysis and data collection plan

	Research questions	Unit of analysis	Data collection method
Case study A: Western Cape Education Department (WCED) schools	Interview guide (see appendix D)	Teachers (4)	Interviews
	Interview guide (see appendix E)	Local economic development agency representatives (3)	Interviews

	Interview guide (see appendix C)	Academic experts (3)	Interviews and observation
Case study B: Gauteng Department of Education (GDE) schools	Interview guide (see appendix D)	Teachers (3), principal (1) and district officials (3)	Interviews
Government policy documents and independent experts	Interview guide (see appendix D)	Documents (6) and independent experts (7)	Document analysis and interviews

The government policy documents and independent experts fell outside the two case studies. Independent experts are academics who were not part of the case study A short course.

3.6 SAMPLING PROCEDURE

The target population for the qualitative case studies was primarily teachers, district officials, principals, local economic development agency representatives, and academic experts who are involved in the implementation of digitally supported teaching and learning of secondary mathematics in WCED and GDE schools in South Africa. The research participants were purposively selected as they are viewed as most valuable or representative and it is also not feasible to study the whole population (Babbie, 2011). The sample that was purposively selected comprised mathematics teachers, principals, district officials, academic experts, and the local economic development agency representatives (see Table 6). These participants were selected based on their involvement in the implementation of digitally supported teaching of mathematics in secondary school in South Africa.

Yin (2014) is of the view that purposeful sampling seeks to help the researcher answer the research question. This research study sought to answer the main research question: How can digital transformation in secondary mathematics education be shifted beyond the early stage? Purposeful sampling allowed the researcher to select key actors (teachers, principals, district officials, academic experts, independent experts, and local economic development agency representatives), whose valued information, involvement, and insights allowed the researcher to gain valuable information to answer the study's research question.

3.7 DATA COLLECTION

Cresswell and Poth (2018) state that qualitative research has four basic types of data, namely observations, interviews, documents, and audio-visual material. In this study, semi-structured interviews, observations, and document analysis were used as data collection strategies to answer the key questions of the study. Some of the interviews were recorded (where consent was granted) and then transcribed. The researcher was a participant observer. Key government policy documents were obtained from relevant websites and were analysed.

3.7.1 Document analysis

Document analysis is a systematic way of reviewing and evaluating documents that include adverts, agendas and minutes, media statements, and public records (Bowen, 2009). Document analysis is an important data collection instrument in a case study, particularly if the research design includes interviews or observation (Rule et al., 2011). The documents in a case study normally include written reports or documents applicable to that particular phenomenon (Owen, 2014). The use of document analysis is deemed to be appropriate in situations where some aspects of the research have not been addressed appropriately by other methods of inquiry. This study's document review focused mainly on seven key government policies and strategies from the education sector and the ICT sector. The policy documents included (i) the *White Paper on e-Education Policy* (DBE, 2004); (ii) the *Guidelines on e-Safety* (DBE, 2018a); (iii) the *Professional Development Framework for Digital Learning* (DBE, 2018c); (iv) the *Mathematics Teaching and Learning*

Framework (DBE, 2018d); (v) the *National Broadband Policy* (DoC, 2013); (vi) the *Professional Learning Communities* (DBE, 2015); and (vii) the *Draft Curriculum and Assessment Policy Statement (CAPS) Grades 7-9: Coding and Robotics* (DBE, 2021a). Document reviews focused on gauging the availability or lack of availability of the four dimensions of the study, namely digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience. This provided the researcher with information about what these documents say about technology integration, which refers to digital transformation in general as well as mathematics in secondary schools.

The researcher used the documents to gauge the gap between what the documents say and classroom practices concerning the study's analytical framework dimensions, namely the digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience.

3.7.2 Observations

Observation is a way of collecting data in qualitative research by noting a phenomenon in the field via the researcher's five senses (sight, sound, touch, smell, and taste), and by making notes and recordings based on the research purpose and questions (Creswell et al., 2018). People can be observed in their natural work setting, their work activities, behaviours or actions, and a range of other demeanours (movements, work habits, facial expressions, statements, among others) recorded (Cavana et al., 2001).

In this study, observations were carried out during the activities associated with the short course that was designed and delivered by academics from SU and Wits (see Chapter 4 for an overview). The short course was about applying dynamic software to teach algebra (module 1) and geometry (module 2) secondary mathematics topics. The researcher was a participant observer. Saunders et al. (2003) state that being a participant observer involves the researcher attempting to "participate fully in the lives and activities of subjects and thus becoming a member of their group, organisation or community". The researcher observed the teaching and learning activities of teachers using dynamic software applications in case study A. The observation took place during both physical and virtual classes, including course orientation and design sessions, i.e., module 1 (16–20 March 2020, physical sessions) and module 2 (27 August to 26 November 2020, virtual sessions, once a week in the afternoon for two hours, due to the COVID-19 pandemic). An observation guide (see appendix C) was developed to guide the researcher in making descriptive and reflective notes.

3.7.3 Semi-structured interviews

Creswell and Poth (2018) suggest that an interview is a social interaction that is based on a conversation that results in knowledge creation and enables an understanding of the world from the participant's point of view by revealing their real world lived experiences. Interviews provide a special occasion for unearthing rich and complex data from a person (Cavanna et al., 2001). Semi-structured interviews are a more flexible research technique as they enable discussion and negotiation (Cresswell et al., 2018). Saunders et al. (2003) suggest that during semi-structured interviews, qualitative researchers follow a list of topics and questions to be asked, even if these may vary from interview to interview. Semi-structured interviews also allow research participants to express themselves freely in their own words about the research topic and even talk about issues that the researcher may not have considered, but may be important for understanding the phenomenon being studied. The semi-structured interview is popular in qualitative research due to the freedom it allows researchers to explore topics and follow up on questions with few limitations.

In this study, interviews were arranged in advance with the cooperation of research participants. The interviews were scheduled for at least 60 minutes. The interviews were conducted in a comfortable place preferred by the participants. The key informants were selected in consultation with the supervisor, including the districts and schools, which were included in the letters requesting permission to research the provincial education departments. The researcher prepared an interview guide (see appendices D and E) that served as a direct discussion. The interviews were recorded (where consent was granted; see appendix B for the informed consent form) and transcribed (Creswell & Poth, 2018), and the transcribed data was given a reference number to ensure the anonymity of the participant. The interviews were recorded using both a mobile phone and a voice recorder as a backup. These recordings, including field notes and transcripts, were stored on a password-protected laptop. Field notes were critical during the interviews where interviewees did not grant permission for recording. The researcher therefore took note of any ideas that were of interest and made sense of the data.

Semi-structured interviews were conducted face-to-face and virtually with key secondary mathematics education actors (teachers, principals, district officials, academic experts, and local economic development agency representatives). In case study A, interviews were conducted virtually between September 2020 and December 2022. In case study B, interviews were conducted physically and virtually between September 2020 and September 2022, as well as with independent experts, who were academics who were not part of the two case studies (see Table 6 above).

The semi-structured interviews were relevant for this study because they assisted in answering the research questions of the key actors' understanding and interpretation of the study's four dimensions, namely digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience.

3.8 DATA ANALYSIS

The data collected from documents, observations, interviews, and voice recordings were recorded where permission was granted. The recordings were listed and transcribed for data analysis. The process of analysing qualitative data is a continual one in which a researcher strives to learn how participants interpret a given phenomenon. The overall goal of qualitative data analysis, according to Cavana et al. (2001), is to comprehend the phenomenon being examined by interpreting what has occurred. Furthermore, qualitative data includes non-numerical data such as interview transcripts, notes, video and audio recordings, photographs, and text documents (Creswell & Poth, 2018). In addition, the researcher examined the transcribed data and field notes numerous times to gain a first impression of the data. The interpretative paradigm allows for the investigation to gain a deeper understanding of the research participants' perceptions, experiences, and opinions regarding approaches to shifting digital transformation beyond the early stage, which is the study's goal. The data obtained from secondary mathematics teachers, principals, district officials, and academics via semi-structured interviews, observations, and document analysis were analysed. Additionally, the documents were explored using the interview technique: the documents were treated like research respondents by asking interview questions and highlighting the answers in the text (O'Leary, 2014).

The analysis will use inductive reasoning to draw a general conclusion from the data (Saunders et al., 2023), and counter-inductive reasoning to explore other ways of explaining a phenomenon, or "taking the way things are within our experience as a guide to how they will not be outside our experience" (Oxford University Press, 2023). The data was obtained from 17 key stakeholders through semi-structured interviews, observations, and document analysis. Erlingsson et al. (2017) provide three steps for content analysis, which this study followed. The first step entails reading the data thoroughly and then transcribing the data, while keeping in mind the aim of the study. In this step, it was essential to break the text into small and meaningful units. The second step was to code the meaningful units. These codes helped the researcher to reflect on the data in new ways. The final step was to group the codes into categories or themes. Sutton et al. (2015) state that theming is the drawing together of codes from different transcripts of participants to present the findings of qualitative research in a coherent and meaningful manner.

Although the qualitative research programme ATLAS.ti 9 was useful for data manipulation, a significant amount of researcher interpretation was present.

3.9 TRIANGULATION

Cohen et al. (2007, p. 141) define triangulation "as the use of two or more methods of data collection in the study of some aspect of human behaviour". Triangulation is a form of verification that is used by qualitative researchers to ensure that the research study "reflects the evidence, they have checks on their evidence and interpretations" (Cavana et al., 2001, pp. 135–136). Cohen and Manion (1989) suggest three types of triangulations: first, research-subject corroboration that involves cross-checking the meaning of data between the researcher and the respondents; second, confirmation from other sources about the specific issues or events; and third, the use of two or more methods of data collection and comparison of resultant interpretations. The study employed observations, document analysis, and semi-structured interviews as research instruments for data collection, which allowed the researcher to explore approaches to shifting digital transformation beyond the early stage from various viewpoints. The research could explain the participants' views on the dimensions of the study's analytical framework dimensions. Data triangulation made it possible for the researcher to examine the seven government policy documents.

3.10 DIFFICULTY OF CONDUCTING INTERVIEWS DURING THE COVID-19 LOCKDOWN AND NATIONAL LOADSHEDDING PHASES

The researcher faced two main challenges while conducting interviews: the unforeseen COVID-19 lockdown and the national loadshedding crisis, which are discussed below.

(i) **Relationship-building:** Conducting research is not only about asking a stranger questions and hoping to get answers; it is about building trust so that people can freely share their views and experiences. The researcher was faced with difficult challenges in obtaining the correct information in order to contact district officials, principals, and teachers. In fact, in one district the researcher was advised to simply go in and that he would still be taken to schools during the COVID-19 restrictions, although the regulations would be observed. This proved useful as it became clear that meeting stakeholders in these institutions via MS Teams would be impossible as internet connectivity and the skills for using the virtual platforms were inadequate. Schools should not abandon offline teaching and learning tools and should rather adopt a blended approach as part of the technical architecture. The pandemic exposed the weaknesses in the education department as most officials, teachers, and school-based leadership struggled to connect remotely.

(ii) **Alternative power sources:** Schools need to invest in renewable energy sources to mitigate the effects of loadshedding, including modern eco-friendly classroom design that allows for natural ventilation and lighting.

3.11 THE RESEARCHER'S PERSPECTIVES

The researcher's view is that a holistic approach and long-term planning will ensure that the dimensions from this study are optimised for shifting digital transformation in secondary mathematics education beyond the early stage. The sociotechnical perspective adopted by this study must be followed to not only look at the deployment of infrastructure, including appropriate devices (laptops), but also to address the realities, which include the lack of intermediate and advanced digital skills, data availability (school and home), and the school environment (rural–urban disparities). Additionally, studying mathematics should be a rallying point for the current generation; they are immersed in technology at the consumption level but are not motivated to be creators or inventors due to the lack of role models and career guidance to inspire them to pursue engineering and science degrees. Furthermore, the digital divide has shifted from access to the quality of internet connectivity; connectivity should be available both in school and at home, including data plans. The rural and peri-urban environments are not attractive to telecoms companies; hence, a different approach should be adopted to ensure that these environments are also connected.

Teachers becoming discouraged is another issue, as there is no follow-through with many digital initiatives i.e., training with no appropriate devices, limitation related to internet connectivity, lack of exposure to or availability of digital tools, and lack of digital pedagogies, among others. The PP: ADS short course was conceptualised to deal with these sensitivities i.e., intermediate and advanced digital skills training was offered alongside the integration of digital tools for the teaching of secondary mathematics; teachers were supported via a community of practice; and teachers were exposed to a broader digital innovation system so as to inspire learners to pursue advanced digital skills related to engineering and science degrees.

3.12 VALIDITY AND RELIABILITY

Validity is the extent to which data collection method or methods accurately measure what they were intended to measure, and the extent to which research findings are really about what they profess to be about (Saunders et al., 2017). The research uses triangulation, which is the use of multiple data sources (document analysis, observations, and interviews) and methods to "confirm the validity or credibility or authenticity of research data, analysis and interpretation" (Saunders et al., 2017, p. 218). Reliability is the extent to which the data collection technique or techniques will yield to consistent findings, similar observations would be made, or conclusions reached by other researchers, or there is transparency in how sense was made of the data (Saunders et al., 2017). The researcher collected all the data personally using one-on-one interviews and guaranteed anonymity to ensure that participants provided positive answers. Constant feedback from the supervisor on the writing of this thesis also contributed to the validity and reliability of this study as weaknesses were pointed out and resolved during research consultations.

3.13 ETHICAL CONSIDERATIONS

The Wits Human Research Ethics Committee (HREC) (Non-Medical) granted an ethics clearance certificate which permitted data collection for this study (see appendix A). This study involved people, hence the privacy, confidentiality, and anonymity of participants' information were guaranteed. Saunders et al. (2003) encourage researchers to adhere to ethical issues such as privacy, confidentiality, and anonymity by seeking consent, not using the names of participants, and protecting the identity of participants. Hence, the study treated all information provided as confidential. The names of the research participants are not used and are not linked to the data collected for the research. Hence, individual participants were not identifiable in any manner in the study report. The interviewees were presented with a consent form at the beginning of each interview session and invited to ask any questions. In all cases, participants did not provide their names and used pseudonyms to ensure privacy, confidentiality, and anonymity.

3.14 CHAPTER SUMMARY

This chapter discussed the research philosophy of the study. This was followed by the discussion of the research methodology is qualitative in nature and the research design is a social constructivist case study whose data collection techniques included participant observations, document analysis, and semi-structured interviews. The chapter also highlighted the difficulties encountered when conducting research during the COVID-19 pandemic period, the researcher's perspectives, and how ethical issues were addressed. Chapter 4 presents and discusses the research findings from case A.

Chapter 4: Case Study A: Western Cape Education Department – Exploring the Use of Digital Technologies for Teaching Secondary Mathematics in WCED Schools

4.1 INTRODUCTION

The previous chapter stated that the data collection strategies included participant observations, which took place only in this case study, and semi-structured interviews. The purpose of this chapter is to report on the data that was collected from case study A in order to answer the study's research question, which seeks to determine the approaches that can be used to shift digital transformation in the teaching of secondary mathematics beyond the early stage. The interpretation could inform the aim of this study. Case study A took place in Saldanha Bay, where grade 8 and 9 teachers were trained on how to use dynamic software applications (GeoGebra and Geometer's Sketchpad) to teach mathematics in the Professional Practice: Applications of Dynamic Software for Secondary Mathematics Teachers (PP: ADS) short course. The short course was offered in two modules: module 1 (algebra) and module 2 (geometry). In keeping with the design of the case study, the study interviewed key actors (academic experts, teachers, district officials, principals, and local economic development agency (LEDA) representatives). Structurally, this chapter consists of four thematic sections with related sub-sections. The first section provides the context of and background to the case study. The next section is a data presentation of participant observations that were made during this case study. In the third section, the perspectives of the key actors are presented. Finally, a summary of this chapter and the focus of the next chapter is provided. Figure 24 shows the flow chart for Chapter 4.

Figure 24
Chapter 4 flow chart

Chapter 4

4. Case study A: Western Cape Education Department (WCED)
4.1 Introduction
4.2 Context and background: The transition of Saldanha Bay schools to using dynamic software applications for teaching and learning
4.3 Participant observations of the events that ensued in the conceptualisation, design, and delivery of the PP: ADS short course in the Saldanha Bay circuit
4.4 Perspectives of the key WCED actors
4.5 Chapter summary

To provide an informative interpretation, the context of and background to case study A is presented next.

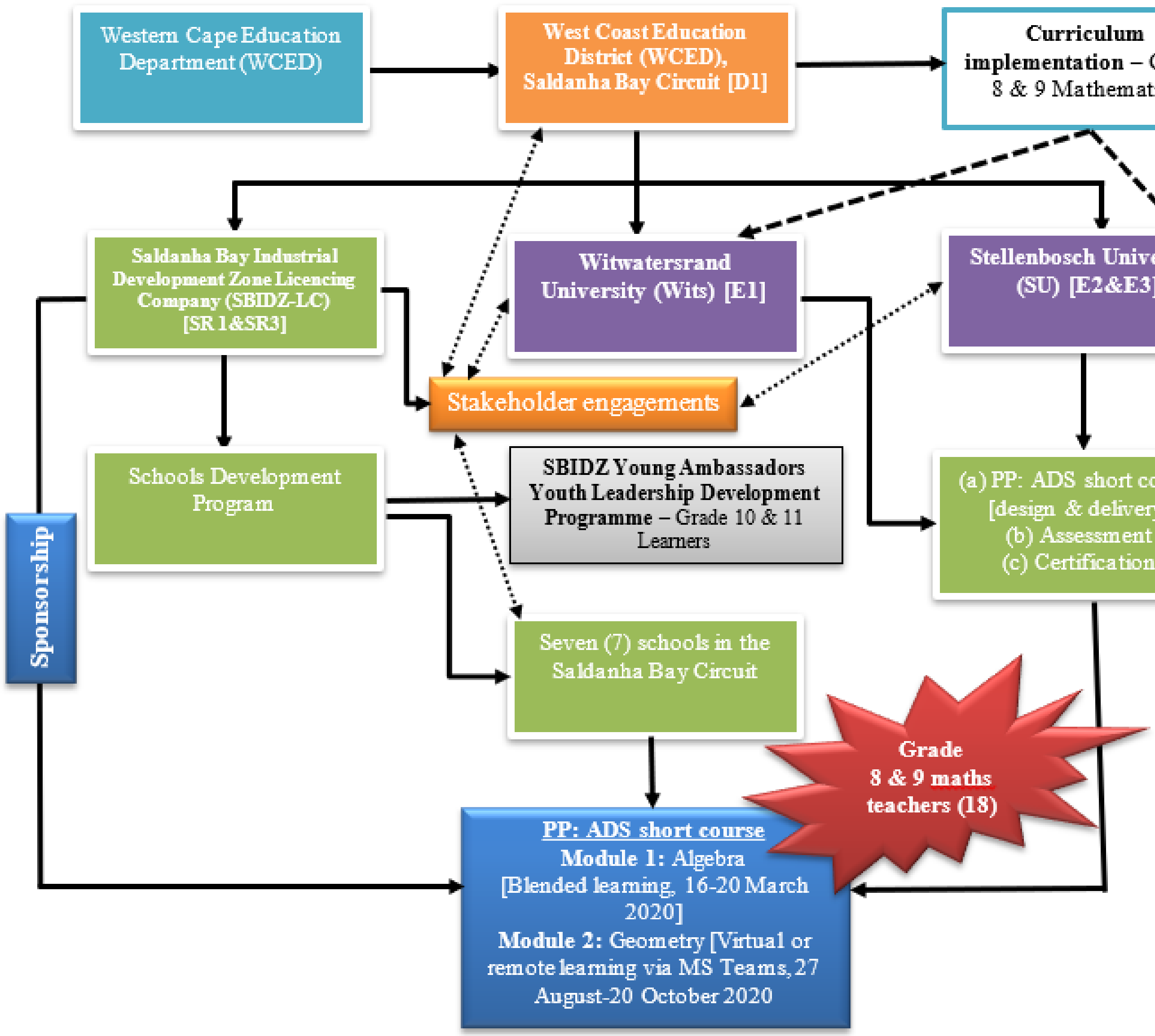
4.2 CONTEXT AND BACKGROUND: THE TRANSITION OF WCED SCHOOLS TO USING DYNAMIC SOFTWARE APPLICATIONS FOR TEACHING AND LEARNING

In case study A, a teacher professional development (TPD) initiative aimed at training grade 8 and 9 mathematics teachers in Saldanha Bay was conceptualised, designed, and delivered by mathematics education academic experts from SU and a digital transformation academic expert from Wits. The TPD initiative, which became known as the Professional Practice: Applications of Dynamic Software for Secondary Mathematics Teachers (PP: ADS) short course, is pitched at NQF Level 5. The West Coast Education District, with the approval of the Western Cape Education Department, provided guidance for curriculum resequencing to allow for the linking of different topics in a single lesson and the Saldanha Bay Industrial Development Zone Licencing Company (SBIDZ-LC) sponsored this two-week short course.

The study uses the analytic framework to investigate approaches to shifting digital transformation in secondary mathematics education beyond the early stage. The researcher conducted participant observations during the activities around the PP: ADS short course. The short course became a vehicle to observe teachers and academic experts from SU and Wits. Figure 25 provides an overview of case study A and its components (artefacts and key actors).

Figure 25

Overview of case study A: Western Cape Education Department (WCED) schools

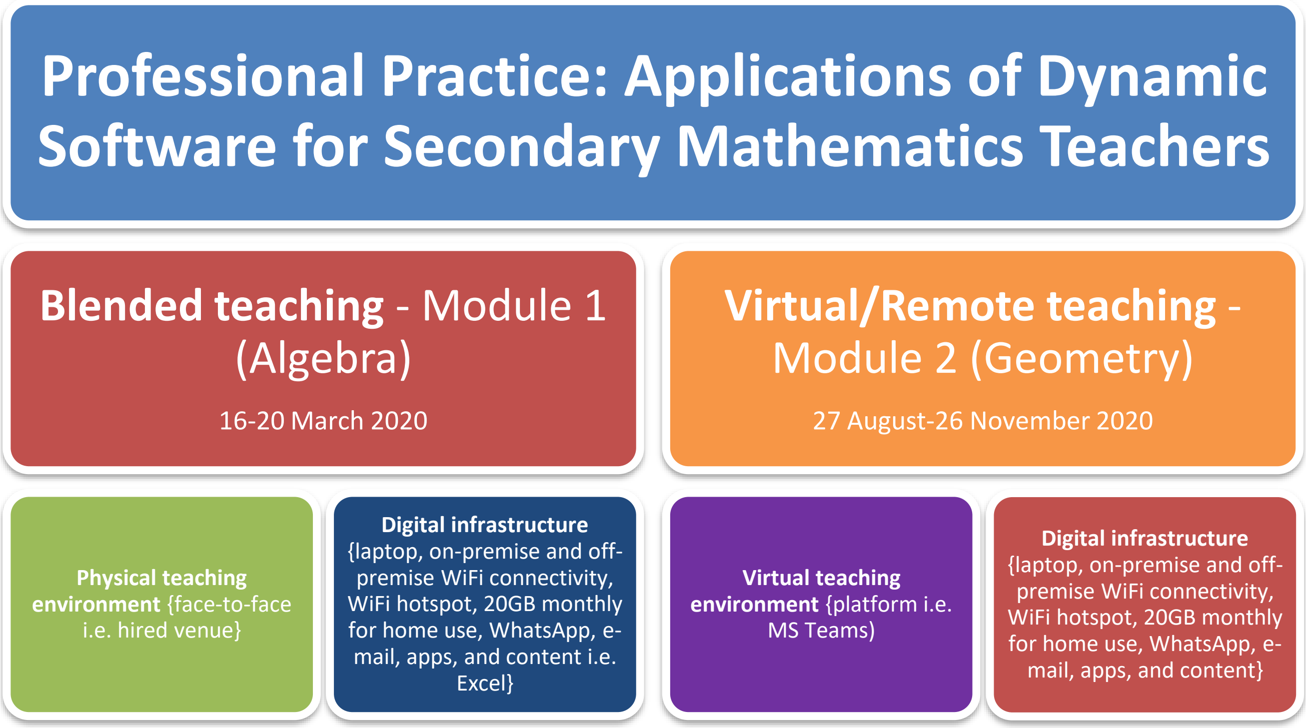


Source: Author, 2021

The PP: ADS short course was developed to run over two weeks, with the first module (algebra) offered in the period 16 to 20 March 2020, and the second module (geometry) from 23 to 27 March 2020. However, due to the emergence of the COVID-19 pandemic, the second module had to be virtual and took place from 27 August to 26 November 2020, accounting for 13 weeks. Eighteen teachers from seven schools (four high schools and three primary schools) attended the course. District officials also attended from time to time, which showed some digital leadership. Figure 26 provides an overview of the components of the PP: ADS short course.

Figure 26

Overview of the components of the Professional Practice: Applications of Dynamic Software for Secondary Mathematics Teachers short course



Source: Author, 2021

This two-week partly-online, partly-physical course was offered to grade 8 and 9 mathematics teachers from several schools in the Saldanha Bay region (Lakabane, 2021, p. 10). Lakabane (2021) further notes that the PP: ADS short course aims to equip educators with a combination of strong pedagogical knowledge, digital skills, technical skills, and leadership skills.

The research participants (human actors) provided an actor-network theory (ANT) perspective on human-related attributes such as the digital skills of educators, leadership, and digital experience, and non-human-related resources (school digital infrastructure) and the social construction of technology (SCOT) perspective assisted in analysing technology usage. The interviews in case study A were conducted virtually due to the COVID-19 restrictions. All interviewees were involved in the PP: ADS short course. Table 7 below shows the participants (human actors) and the pseudonyms used in this case study.

Table 7

Participants (human actors) in case study A

Date	**Pseudonym**	**Role**	**Location**
30 September 2020	E1	Expert [digital transformation]	Virtual
28 October 2021	E2	Expert [mathematics education]	Virtual
5 November 2021	E3	Expert [mathematics education]	Virtual
17 December 2021	LEDA1	Local economic development agency representative	Virtual

26 January 2022	LEDA2	Local economic development agency representative	Virtual
11 February 2022	LEDA3	Local economic development agency representative	Virtual
20 February 2022	WT1	Teacher	Virtual
28 February 2022	WT2	Teacher	Virtual
2 March 2022 (SMS)	WT3	Teacher	Virtual
9 September 2022	WT4	Teacher	Virtual

Source: Author, 2023

W/WCED stands for Western Cape Education Department

WT 1-N represents teachers; WP 1-N represents principals; WD 1-N represents district officials ; LEDA 1-N represents local economic development agency representatives; E 1-N represents experts involved in case study A

Eighteen teachers from seven schools (four high schools and three primary schools) participated in this TPD programme, which was sponsored by the SBIDZ-LC as part of the school's engagement programme. Table 8 below depicts the seven (7) schools.

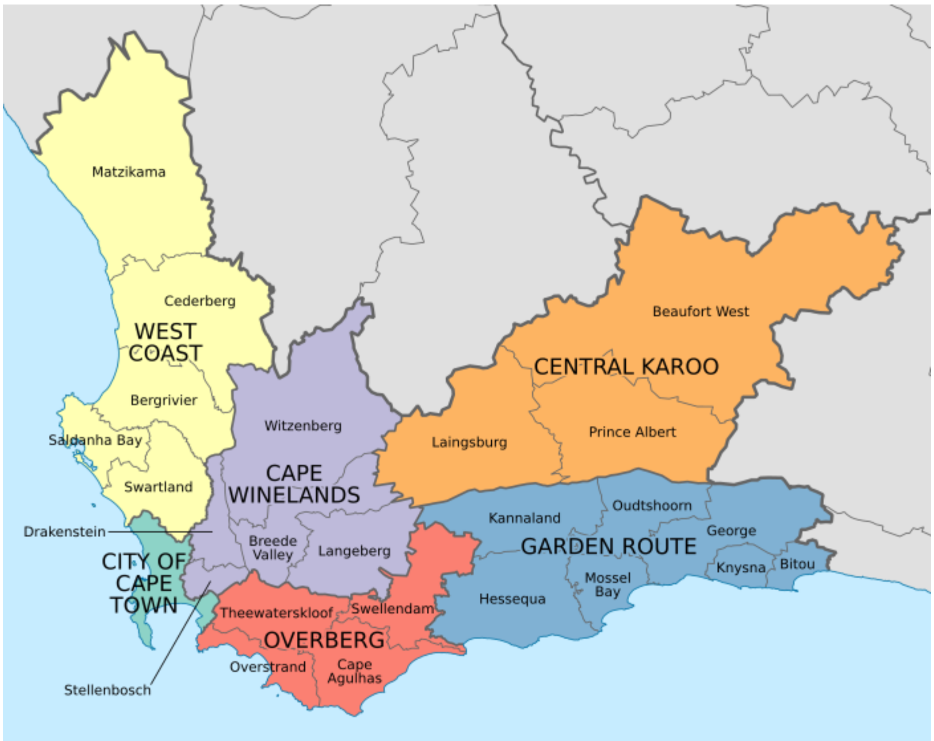
Table 8
Saldanha Bay schools that participated in the TPD programme

Name of School	School Fees	Section 21 School	Teachers	Learners
(i) Diazville High School	No		44	1235
(ii) Weston High School	No		58	1410
(iii) Louwville High School	Yes		41	926
(iv) Velddrif High School	No		35	455
(v) Hopefield Primary School	No	Yes	26	798
(vi) Jurie Hayes Primary School	Yes	Yes	19	583
(vii) St Helena Bay Primary School				

Source: Adapted from Student Portal, 2020

Hopefield Primary School and Jurie Hayes Primary School are Section 21 schools. Section 21 schools are allocated finances by the WCED and are responsible for ordering stationery and textbooks, for paying their water and electricity accounts, and for undertaking their own maintenance, including deciding what subjects the school can offer and also what sports and other extra-mural activities the school can offer (Student Portal, 2020). In contrast, a school that is not a Section 21 school has its budget administered by the district office (Student Portal, 2020). There was no information available for St Helena Primary School. Figure 27 shows the Western Cape District map.

Figure 27
Western Cape district map



Source: Western Cape Government, 2020

In 2020 the Western Cape Government made the following statement about the economic disparities in this region that have resulted in a high proportion of no-fee schools.

> The proportion of no-fee schools remained 52 percent from 2017 to 2019, indicating, that, given the tough economic climate, schools have been reporting an increase in parents being unable to pay their school fees. In a effort to alleviate some of the funding challenges the Western Cape Department of Education (WCED) offered certain fee-paying schools to become no-fee schools. This means that almost two-thirds of the schools in Saldanha Bay, 52 percent, are registered with the Western Cape Department of Education as no-fee schools (Western Cape Government, 2020, p. 7).

The Western Cape Government further provides the following statistics: electricity connections are about 96.8%, the learner-teacher ratio is 32:1, 52% of schools are no-fee schools, and several schools have libraries (15 out of 23). It is encouraging to note the high rate of electricity connections in the Saldanha Bay area as digital teaching and learning of secondary mathematics require this resource. However, continued loadshedding might present another complication.

4.3 PARTICIPANT OBSERVATIONS

This section focuses on the participant observations of the research investigation. “Participant observation (PO) is a research methodology where the researcher is immersed in the day-to-day activities of the participants” (UToronto, 2022, para 1). This section describes the chronological order of events that took place in this case study and highlights key dimensions that emerged that are related to ways of shifting digital transformation in secondary mathematics beyond the early stage. The emergent dimensions are organised and discussed according to the analytical framework dimensions, namely, digital skills of educators, leadership in the implementation of digitally supported teaching of secondary mathematics in schools, school digital infrastructure, and digital teaching experience.

Observations played a significant role in shaping case study A through orientation sessions, course design sessions, in-class sessions, virtual or remote sessions, and assignments, among others. In addition, about ten key stakeholders were interviewed; they included experts (E) in the conceptualisation, design, and delivery of the PP: ADS short course, the LEDA representatives, and West Coast education district teachers (WT). Table 9 provides an overview of the chronological order of 21 observation instances that were captured in case study A.

Table 9

Overview of the chronological order of observed events of case study A: Participant observation instances during the conceptualisation, design, and delivery of the PP: ADS short course

Category	**Date**	**Event**	**Town**	**Involved**
Orientation session observations	6 August 2019	1. Meeting at WCED Offices	Paarl	WCED, SBIDZ, SU, and Wits
	7 August 2019	2. Meeting at Saldanha Bay Industrial Development Zone (SBIDZ) Offices	Saldanha Bay	SBIDZ and Wits
		3. Vredenburg High School visit	Saldanha Bay	Wits
		4. Weston High School visit	Saldanha Bay	Wits
Course design session observations	8 August 2019	5. Course design session	Saldanha Bay	Wits
		6. Abbreviated curriculum and grade 8 and 9 mathematics curriculum	Saldanha Bay	SU and Wits
	31 August 2019	7. Course design session	Johannesburg	SU and Wits
	1–2 September 2019	8. Course design session	Johannesburg	SU and Wits
	30 January 2020	9. Principals and deputies' engagement	Saldanha Bay	SBIDZ, SU, Wits, school principals, and deputies
	31 January 2020	10. Course design session	Saldanha Bay	SU and Wits
	12 February 20220	11. Teacher engagement	Vredenburg	SBIDZ, SU, Wits, and schoolteachers
	13 February 2020	12. Course design session	Somerset West	SU and Wits
In-class observation	16–20 March 2020 (blended teaching)	13. Memo 1 – PP: ADS short course module 1 (algebra)	Saldanha Bay	SU, Wits, and schoolteachers
Assignment for module one	30 March 2020	14. Module 1 – Applying dynamic software tools in algebra group assignment		SU and Wits

Course design session observations	9 August 2022	15. Correspondence about online course modalities and purchase of data for teachers		Wits and SBIDZ
Virtual observation	27 August–26 November 2020 (virtual teaching)	16. Memo 2 – PP: ADS short course module 2 (geometry)	Virtual or remote teaching	SU, Wits, and teachers
Assignment for module two	12 November 2020	17. Assignment instruction for module 2 (geometry)	Virtual	SU, Wits, and teachers
Virtual observation	27 November 2020	18. SBIDZ School Project Meeting	Virtual	SBIDZ, SU, and Wits
Proposal	3 March 2021	19. Proposal and budget for Open Saldanha Secondary Mathematics PLC		SU, Wits, and SBIDZ
Video observation	21 April 2022	20. Professional Learning Community (PLC) for Maths – Using Learning Management Systems [Google Classroom]	Virtual or remote teaching or hybrid	SU and Wits
Video observation	19 May 2022	21. Maths apps and tangrams	Virtual	WCED, SU, and Wits

Source: Author, 2020

The participant observations during orientation sessions, including the school visits and the PP: ADS short course delivery, highlighted six categories of challenges.

4.3.1 Digital skills of educators

4.3.1.1 *Basic digital skills of educators*: Participants struggled to work with Excel and Geometer's Sketchpad, indicating limited or basic digital skills.

4.3.2 Digital teaching experience

4.3.2.1 *Digital pedagogy*: Participants expressed difficulties with their own learning, noting that it was difficult or impossible to provide for one-on-one engagement to address the use of Sketchpad and other dynamic software tools. It was not possible to provide for the facilitation of in-classroom activities. Teachers specifically reflected on the following: (i) during the pandemic, schools had only partial attendance or half-empty classrooms; (ii) teachers needed more time to practise using the software, on their own and in the classroom; (iii) it was difficult for teachers to use Sketchpad in the classroom, since only the teachers had the software, not the learners, but teachers could switch to using GeoGebra in the classroom; (iv) there were only a few laptops to be shared among teachers, and similarly among learners. and in some instances no laptops were available to learners; (v) 45-minute teaching periods were seen as being too short to convey the optimal mathematics learning experience and the particular benefits of using dynamic software. Building digital pedagogy needs to pay attention to all the above issues and many more.

4.3.3 Leadership in the implementation of digitally supported teaching of secondary mathematics in schools

4.3.3.1 *Creation of a community of practice*: The participants asked for support in their classrooms that goes beyond the scope of a short course offering. The website that was created for sharing tasks and reference material provided a preliminary community of practice environment. The website made it easy to share pre-configured

Excel worksheets, GeoGebra applets, lesson plans, and information related to secondary mathematics readings and events, among others. The academic team indicated that teachers would adopt teaching with technology only if they are shown by other teachers that the learning gains are worthwhile.

4.3.4 School digital infrastructure

4.3.4.1 *Technical architecture*: An issue of great importance is the absence of a technical architecture to resolve issues that are related to support, such as an intermittent internet connection, booting up time, security, software licences, and support. Hence, this study proposed a technical architecture for schools.

4.3.4.2 *Use of Excel*: All secondary mathematics teachers should be taught the basics of using Excel spreadsheets. For example, pre-configured Excel worksheets can be used for demonstrations by trainers, and for use by teachers during class exercises. Similarly, exercises that involve the creation of tables with patterns and subsequent plotting of related graphs, as well as the determination of equations of the plotted graphs, can provide an overall linking of these concepts. By using Excel, teachers will be better able to share data across subjects (such as data about experiments in science which can be shared with the maths teacher for mathematical analysis in his or her classroom).

4.3.4.3 *Access to devices*: Both teachers and learners need access to devices to address what is commonly referred to as the "digital divide". The maths teachers need their own devices, over and above the pool devices available at school. Learners can share devices initially. Maths teachers need to be able to practise, progressively transferring the teaching practice from the "chalk and talk" process to the use of dynamic software for each component of the curriculum, even if not for every lesson.

4.3.5 Risk factors

4.3.5.1 *Continuation of engagement with the community of maths teachers*: Leaving maths teachers on their own, after only very basic training, is a risk factor. Teachers asked whether the end of the course would mean the end of the engagement and expressed interest in continued collaboration. Building a maths teachers' community of practice in the Saldanha Bay circuit is one way of addressing this need for continuous engagement.

4.3.5.2 *In-class practice*: Over and above the facilitation of in-class teaching and learning sessions in early 2021, teachers need continual practice to build their knowledge of and capacity for the relevant software tools. The maths community of practice enabled knowledge-sharing among this initial group of teachers. Teachers in this circuit who did not attend the course were invited to participate in the community of practice. One specific issue raised was the need to have longer class periods (we deliberately do not call this a double period) for maths lessons. The ideal period would be 90 minutes, which could happen once or twice a month. The research understand that this is a highly contested issue but argue that it is necessary from a learning perspective, as 40 or 45 minutes is not sufficient time to understand the benefits of learning with dynamic software.

4.3.5.3 *Marginalisation*: Teachers in general, and in this case maths teachers, were generally marginalised from the economic and social activities that can validate their investment in teaching.

4.3.5.4 *Role of the district office*: The district office can make four main inputs, namely (i) hosting a get-together of principals of all schools in the circuit (online, if necessary) to mathematics teacher development and to create a collaborative engagement with principals and schools; (ii) ensuring that subject advisors advance their knowledge of dynamic software applications; (iii) ensuring that the IT staff at the school, circuit, and district levels give greater support to schools so that the available resources are used effectively; and (iv) preparing a three-year vision document for the transition to teaching maths with dynamic software that fits within the DBE's Professional Development Framework for Digital Learning, but makes it real and realisable for teachers in the Saldanha Bay circuit, or in the West Coast education district.

The next section provides the perspectives of key WCED actors.

4.4 PERSPECTIVES OF KEY WCED ACTORS

This section presents the qualitative results and findings obtained from key WCED actors, namely academic experts and teachers who were involved in the PP: ADS short course. The data was gathered via semi-structured interviews, and observations will be presented. The data will be analysed in Chapter 7. The first question probed the key actors about how they refer to digital transformation in the education sector. The second and third questions examined the digital skills of educators for course design and delivery respectively. The fourth question explored the digital teaching experience, while the fifth question was concerned with school digital infrastructure. The sixth question investigated the role of leadership during the implementation of digitally supported teaching. Each question will now be presented, along with the educators' responses, which will be discussed.

4.4.1 Digital transformation in secondary mathematics education

Digital transformation in the education sector [Question A0]: The following question was asked during the in-depth interviews: *How do you refer to digital transformation in the education sector (e.g., the use of digital technologies for teaching, learning, administration, other)?*

Below are some of the responses from academic experts and teachers.

E1 (2021): *Digital learning or digital enabled learning*

E2 (2021): *e-learning or online teaching, those are the terms we use*

E3 (2021): *Using technology for Mathematics education*

WT1 (2022): *e-learning "… textbook on the tablet"*

WT2 (2022): *… e-learning, yes e-learning*

It is evident from the above experts' responses that there is a shift towards the modern definition of technology use in education, while the teachers mainly used old terminology, despite the introduction of the Professional Development Framework for Digital Learning (DBE, 2018c). This implies that the framework developed by the DBE has not yet been implemented in schools.

4.4.2 Digital skills of educators

Digital skills for course design [Question A1]: The following question was asked during the in-depth interviews: *Which digital skills of educators should be developed for successful course design in schools, specifically for mathematics education? Please add any other influencing skills not mentioned above.*

Below are some of the responses from academic experts and teachers.

E1 (2021): *Teachers that we were engaged with in the schools in Saldanha Bay did not have highly developed digital skills and some of them didn't even have basic digital skills. And I mean when it comes to maths, I don't mean general digital skills like everybody has, you know everybody knows how to use a cell phone, how to search the internet, how to be on Facebook, I am not talking about that, because your question is about specifically for using technology for mathematics teaching and learning. And what we observed is that teachers did not have, some did not basic digital skills and some did not have advanced digital skills. But it seems that what they needed, even before the digital skills is these other skills that give them a level of comfort and a level of confidence to learn something new, to acquire skills of using technology because many of them lacked the confidence to even embark upon this new learning process.*

Now, using applets, you don't know how to do it, so you must learn, you have to practise and then you have to prepare your lessons and that will take more time. So, they need to learn to use applets, they need to create their own lesson plans and they need time to develop digital skills for that … subject advisors and/or district officials should also possess digital skills for course design, not only teachers … without input from subject advisors, principals, and district officials via circulars to encourage digital skills for course design will result in weak digital skills to design or redesign.

E2 (2021): *Teachers don't design lessons, they take their cue from the workplan which they like to call the curriculum and textbooks, so they would mostly select three or four problems to do and usually those are already available for download, or they copy it from textbooks, hardcopies. So now if you talk digital skills to do that, it is obviously very little. So, to be able to know what do to do make things interactive and then based on what you think you are going to get in the interactive session, what you design there, you then decide what should be done by learners in writing that should go to exercises or a worksheet. Now, the digital skills there would be as I said, I think in the first question, understand how that, what the affordances and constraint is of the mathematical software you work with.… stakes are low at the moment for teachers to become involved with teaching mathematics differently with digital tools. The stakes are low because they are not in exams, but the pressure of the exams is high.*

E3 (2021): *… the teacher with one computer and an overhead projector, data projector can change the whole context …*

WT1 (2022): *No, I wouldn't say they don't use. Like we have got a media centre and most of them, we have a system where you need to prepare your lesson plans two weeks in advance and that must be submitted to our deputy principal that handle[s] the curriculum. So, most of them are using computers to do that … Usually there is, on a yearly basis you get continuous training on ICT and eLearning within the classroom, but if you don't have the devices that skills are going nowhere.*

WT2 (2022): *I would say that it's a yes and a no. The yes would be according to using Word and Excel and all of that program to form a lesson, then yes, to form a lesson, to type up a physical lesson then that is fine. But the no would be using GeoGebra or Sketchpad because all teachers are not familiar on how to use the programs.*

WT1 (2022): *Look here I can say the younger teachers most definitely. From my experience is that they come equipped from university and they are doing it with electronic devices their lesson plans and everything. It's now the projector, the white board, and the computer and sometimes the tablets but I believe they are more equipped than the older teachers … So, most of them are using computers to do that.*

WT2 (2022): *Also, I acknowledge that I also don't know how to do everything but, especially the older teachers who have been teaching for a long time they don't like to change. So they don't want to adapt, so I would say it's a yes and a no.*

The evidence points to the general lack of digital skills for course design in the education sector. Teachers received lesson plans that were already prepared, and therefore there was no need to design lessons, particularly using technology (E2).

Digital skills for course delivery [Question A2]: The following question was asked during the in-depth interviews: *Which digital skills of educators should be developed for successful course delivery in schools, specifically for secondary mathematics education? Why? Comment on the current state of digital skills for course delivery, specifically for secondary mathematics education. Please add any other influencing skills not mentioned above.*

Below are some of the responses from academic experts and teachers.

E1 (2021): *For successful course delivery. I think that teachers need to be very comfortable with multiple software brands if I could call it that. They need to be comfortable to work with GeoGebra … I think that in terms of developing digital skills educators need to have a level of comfort to work with any software, that's my main thing so that they can easily use any software that they want irrespective of whether its Desmos, GeoGebra, Geometer's Sketchpad or something else … our experience was that the teachers did not have any skills, any digital skills for course delivery, they did not know Excel, they were not for many teachers it was their first time to use Excel. For many teachers, the one teacher told me that he had never used PowerPoint before, it was his first time to use PowerPoint and he was so happy coming on the course where he had been, where he had the opportunity to learn to use PowerPoint.*

E2 (2021): *I have seen many little videos that teachers make of themselves talking to the topic or with various tools often cell phones. So, they were quite keen to do that kind of a thing, I haven't seen many Excel spreadsheets, I have not seen GeoGebra applets often. As I say, I think the pressure for old style mathematics learning and because of the assessment it's just too high, teachers don't go for the nice things even if they think it's nice … I don't think the digital skills are so big.*

WT1 (2022): *What I am saying is that delivering the lessons with computer devices and electronic devices, technology devices, that is a challenge at my school.*

WT2 (2022): *Yes, because the thing with our school is all the classes don't have projectors. So, we cannot express ourselves with technology, like I can because I have a projector but nowadays because of Covid also we are so pressured to finish the work. You don't actually have the time to do that little bit extra according to technology. So, we should take into account that because you are pressured to finish the work and also you sit with learners who has a huge backlog of work, so you are trying to get them up to speed. So, for the technology part, I would say that we don't use it as we should, we are lacking in that … The class sizes because now you have a bigger variety of learners, there is learners that is a little bit advanced, there is your weaker learner and then there is a learner that is in the middle. So, you must balance your lessons so that you can like accommodate all the levels in the class. But we use the basic like we use PowerPoint to make it a little bit interesting, we use a video sometimes but to go with maths programs it's a bit difficult sometimes.*

It is evident that there is a lack of digital skills for course delivery due to schools mainly focusing on mathematics content delivery without also considering the use of technology. Traditional methods are still prevalent (chalkboard) due to limited time, large class sizes, and learners with different abilities (WT2).

4.4.3 Digital teaching experience

Digital teaching experience [Question A3]: The following question were asked during the in-depth interviews: *How are teacher-centred, learner-centred, and learning-centred teaching strategies working (or not working) in the early digital learning environment? [A3.1] What strengths and weaknesses do you experience in linking different branches of mathematics in a single lesson, or series of lessons? [A3.2] What obligations and expectations (school culture) will need to be met during digitally supported teaching? [A3.3] What is needed for greater teacher empowerment and building your collective identity as digitally enabled teachers? [A3.4] What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools? [A3.5] Please add any other teaching experience and expected outcome issues not mentioned in this list. [A3.6].* These questions are answered individually below.

How are teacher-centred, learner-centred, and learning-centred teaching strategies working (or not working) in the early digital learning environment? [A3.1]

Below are some of the responses from academic experts and teachers.

E1 (2021): *Definitely, teacher-centred … They don't have the experience of using digital technologies and dynamic software in the classroom.*

E2 (2021): *I think still teacher-centred. It depends on who judges. Even with the use of technology most of what I see is still exposition, just style it's not engaging learners.*

E3 (2021): *Yes, well absolutely it is so.… So, the teachers want control, they think that they are in control when they are making these pictures, you know exercise 2, exercise 3, exercise 4 and they are in charge, they are in control. But that is unfortunately one of the problems in control of what? They can never be in control of what children learn, so you know the whole teacher-centred approach is an effort to be in control of what children learn and that just cannot possibly be.*

WT1 (2022): *I think at the moment it's still teacher*-centred.

WT2 (2022): *I think the most common one is the teacher-centred because we are the ones who talk the most and the learners must listen, but I have tried to do the flip classroom, but it doesn't work in maths, it doesn't work because then they are supposed to do homework in class and classwork at home. But the thing is you must first explain the concept before the learner can do homework.*

WT3 (2022): *Teacher-centred approach still prevalent. The PP: ADS short course has shown me how to improve my teaching approach … to first probe learners about what they already know.*

WT4 (2022): *Teacher-centred approach common.*

It is evident from the above responses that teacher-centred approaches are still prevalent. Various reasons are offered for this, such as teachers needing to be in control of the classroom, large class sizes, and teachers wanting to have something accomplished or getting the work done, among others. There was knowledge about linking different branches of mathematics in a single lesson.

What strengths and weaknesses do you experience in linking different branches of mathematics in a single lesson, or series of lessons? [A3.2]

Below are some of the responses from academic experts and teachers.

E1 (2021): *But translating work that one might do in algebra to creating shapes and visualisations in geometry is very powerful, but my understanding is that currently that is not the case. Algebra is taught separately, and geometry is taught separately, they are even taught in different semesters … the impression I got is that the teacher says no, this semester we are teaching algebra or quarter, this quarter we are teaching algebra. We are only going to teach geometry in the third quarter and really that kind of, that doesn't indicate that mathematics is a unified area of thinking and application.*

E2 (2021): *Well, I think it's always important because understanding comes from making connections and understanding mathematics fully comes from making connections. It no use anymore today to teach the circle in circle geometry and to teach it in an analytical geometry or give a formula for the relation that's a circle and the two never meet. You know it's unfortunate it still* happens, *but it mustn't.*

WT2 (2022): *So, yes, I would say we do integration between different topics. Sometimes we try to do it with different subjects, but it doesn't always work. I would say the strengths is that when the learner understands the basic or the core of the topic, it would be easier for the learner to understand the next one. Because like I said if the learner has a good understanding about algebra, he will have no problem doing this problem solving, so I think this is the strength. And, I don't think that is the problem because it flows* *through so, I can just refer back to old work. I don't need to do a whole new topic so it's not time consuming.*

Weaknesses, there are weaknesses if the learner doesn't understand the algebra, we are going to sit with a huge problem with the problem solving because now I need to go back again. So, it's basically the other side of the string, I need to go back to the work. So now it becomes time consuming for me when the learner doesn't understand the basic the algebra in order to do the problem solving.

It is evident that the linking of different branches of mathematics in a single lesson is being actively practised in secondary mathematics teaching.

What obligations and expectations (school culture) will need to be met during digitally supported teaching? [A3.3]

Below are some of the responses from academic experts and teachers.

E1 (2021): *… the lesson periods are too short to teach mathematics in a 40-minute period. So, the culture of organising mathematics learning as a 40-minute period is not sustainable, cannot, cannot progress, cannot advance mathematics learning. Particularly if you are now introducing digitally supported teaching, dynamic software, presentations, you cannot very quickly. The nature of the teaching aids, software as a teaching aid or presentations as a teaching aid doesn't lend itself to some a time that is very short. You need time for the learners to digest the learning process, the technological adaptation to get comfortable with playing with the technology themselves and they don't have time to play with the technology in a 40-minute period, that is my main response.*

E2 (2021): *I want to say experiential learning of mathematics, there will be errors and mistakes, but they are the things to take up to learn from. If that culture isn't there then what's the use of having access to technology that can actually give you so many more opportunities to investigate, than you could have had on a piece of paper. So, the culture of learning means not regurgitating stuff but actually asking questions and looking for answers for them and representing mathematical concepts in different ways.*

WT1 (2022): *I think that the school actually would encourage it to a certain point, the challenge is now is do we, can we deliver to all our learners. For instance, my school is old, we a no fee school and we must also look at the context of our learners and, do our learners have the facilities and the devices and the, you know, is it typical in their context to deliver such an e-learning approach and you and I know that the disparity because the regions in this country is among the biggest or is the biggest in the world.*

WT2 (2022): *The school culture is definitely to be disciplined, because we can use technology, we can be digital but if the learner is not disciplined to stay, let's say I give them activity to do on the phone or multiple question on the phone, the learner must be disciplined to know, I am supposed to do this work and not go on Facebook … I would say to give training but we had the training with Sketchpad virtual but that wasn't nice for us, we would like interactive, so that we can physically sit and do so that they can help us and not just sitting and looking at what you are doing.*

The huge problem is the Wi-Fi because you can have all these nice things but now you come to school and the Wi-Fi is down … the learner must have access to the Wi-Fi and all of them don't, because they don't have data, or they don't have access to the school Wi-Fi.

It is evident from the above responses that a supportive culture that allows enough time for mathematics teaching and learning, allows learning by mistakes, and is responsive to the resource needs of teachers is absent.

What is needed for greater teacher empowerment and building your collective identity as digitally enabled teachers? [A3.4]

No response.

What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools? [A3.5]

Below are some of the responses from academic experts and teachers.

E1 (2021): *My main comment is that teachers must be given time. How, I don't know. Teachers must have time to use and learn these digital aids particularly the dynamic software on their own and as a mathematics community of practice. Whether that community of practice is at a school, so if there are five maths teachers at a school or seven maths teachers at a school, those five or seven maths teachers must regularly get together as a group to teach each other, learn from each other, share their knowledge, share their experience, that is really essential … So, the only way they can acquire these skills and build their skills further is to work in groups at the school level and then I would say at the circuit level because these schools in South Africa are organised in circuits. So there has to be a community of practice in each circuit in South Africa, each school's circuit.*

E2 (2021): *Get the teachers to have discussions with the learners about the mathematics, that must be changed that mathematics is something to talk about. Number two, start with the problem and use the technology available to investigate that problem. So those two things, start with the problem and have discussions, mathematical discussions with the learners which makes mathematics more than something to do, but which makes it something to think about.*

So, one thing I think that I can be specific about because I feel strongly about it and also that the, that comes with teaching mathematics with technology is to understand that there is a difference between doing a sum, getting an answer in mathematics which is, I have a single thing I get an answer, I can do a calculation it's over with, I can say it's right or wrong, versus making conjectures, so saying investigating and saying I think this is all thought, always through and then that kind of statement comes from usually comes from having explored with technology. But to make that conjecture and then to work offline to prove that your conjecture, whether your conjecture is true. That difference you've talked about the culture; I think that is another thing that we must get in the schools. So, you can learn to do structure, impose structure by working with a tool like that. Same in Geometer's Sketchpad or GeoGebra … if you say I think that angle is always a right angle it doesn't matter how the figure itself changes if I drag points, then you can actually use the sort of structure to say well let me construct a right angle right there and to use GeoGebra you must understand what it means to construct a right angle or a line perpendicular to another line. And then when you have constructed it you can drag again, and you can see how the data you have gathered in the beginning compared to what you have constructed. So, this whole notion of the outcome, the expected outcome for mathematics teaching must be to construct arguments, to construct, to impose structure that you can reason with and not just do sums for which you get answers.

WT4 (2022): *First probe learners what they already know … depend on prior knowledge. The PP: ADS short course helped use to improve the way we teach … showed us how to improve/approach things and to be open to new ways of teaching, including the language of mathematics. Also exposed to connect with like-minded people.*

It is evident that teachers need time and that a community of practice needs to be established in each district. Also, discussions with learners, constructing arguments or imposing structure and reasoning should be encouraged; the focus should not be on simply getting correct answers.

Please add any other teaching experience and expected outcome issues not mentioned in this list. [A3.6]

No response.

4.4.4 Leadership in the implementation of digitally supported teaching of secondary mathematics in schools

Please refer to or mention how national, provincial, and local (district/school) administrators provide guidance to schools to implement digitally supported teaching [Question B]: *In what ways is the national and provincial government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B1) In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B2) In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in your school? (B3)*

In what ways is the national government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B1)

Below are some of the responses from academic experts and teachers.

E1 (2021): *Yes, so national I think that the Professional Development Framework for Digital Learning is a very powerful document, very powerful document. That guidance has been given by the Department of Basic Education, but to my knowledge it is not being used in the schools in the same way that other templates are being used because teachers have to follow certain templates in the school ... And then one other thing I think is that they need to do a lot of communication … to my knowledge there is no teacher's guide to GeoGebra for South African schools. You can have a teacher's guide to GeoGebra and Desmos, it doesn't have to be restricted to GeoGebra. So how about national government DBE doing a teacher's guide to using GeoGebra and Desmos for secondary mathematics teaching, I think that is missing.*

E2 (2021): *Well, they publish guidelines like you have referred to right when we started the use of digital technologies guidelines that they have and white papers or whatever papers they publish that with a loud bang, but I don't think there is much support lower than that.*

WT1 (2022): *What I would have done or had love for them to do is that first start with the infrastructure. You cannot build a new school without the infrastructure of getting it to, say technologically advanced school, you still build a school as if it was still in the 1980s without the smart boards, without the projectors included in the building. If there are 40 classrooms, include 40 projectors, 40 computers, 40 whatever you want to do, then you give the framework and from there you give the training and from there we can implement, and you can monitor and then we can reflect on where are we now and then we can strengthen it. But we are sitting with a situation where we have a framework and you give a few things and then you expect from the teachers now to implement this framework or to work towards others, and I think this inequality thinking is that you are actually keeping this disparity between those schools that can implement it because of what advantages that they had previously and to those that really want to be and want to contribute but they can't because of the current situation and I think the funding plays a huge role. And there is also something that needs to be changed with the funding model and how schools are classified so that we can implement it at those schools.*

WT2 (2022): *I am gonna be honest, I am not 100% sure on what they are doing with helping us. I am just being honest; I am not sure … the world is changing we are becoming more technology based. So, I feel like the teaching methods should also change and not use the old school chalk and talk. So, I feel that a concern is that I feel that the Department or whoever must help us to do the switch or not to do the switch eventually but to come into the motion of doing it gradually to go into the technology.*

Oh, one thing that I can say they have helped us with, sorry, you can just add that, most educators have a school laptop. I am not sure if the Department gave it but it's a school laptop so they can use all the programs on it, but it is the schools. So that is something they are doing and also, they are giving Wi-Fi at schools, sorry I am just referring to the previous question. But the concern is I feel like that we *should be moving, we are not moving, I feel like we are standing in one place regarding teaching and all of that.*

But I know most educators do have the school laptops. But they do complain about when they work now, and they shut off and all the work is gone so they need to capture everything on the stick or something like that. I don't have that problem, but they talk about it especially with the Sketchpad then it's gone and then they need to install it again.

You see the one where I said I am not sure about the government and all of that? I was thinking now they also, they are providing a WhatsApp line where learners can like just to send the message to the number and its data free and then there is like a tutor that assists you with the maths for free. That I think it's the government that is providing that.

It is evident from the responses that national guidance is provided in schools in terms of documents such as frameworks i.e., Professional Development Framework for Digital Learning, laptop devices for teachers, and communication apps such as WhatsApp and related data, including support. However, the framework without the associated infrastructure is viewed not to be helpful.

In what ways is the provincial government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B2)

Below are some of the responses from academic experts and teachers.

E2 (2021): *So, provincial in my experience they also take it up mostly by a way of talking about it and say yes, you must do it, you must do it and they are too happy if external providers come in and offer them some course that they can say it starts here and it starts there and bang now the teachers must be able to do it. So, I am afraid it's also more window dressing than anything else.*

WT1 (2022): *Provincially there is something, and you can apply, and you can use some of your ... money towards that but I think that look here for a no fee school it is ... If you are in a wrong quota, you get an X amount of money you can just do so much but if you are in a school where there are paying fees like my previous school, I know there is some projects that the parents have funded, and the businesses have funded actually. And here is the other thing also, the other stakeholders in Education can also come up with some better initiatives as with what we are doing now at the moment.*

It is evident that the province does provide some limited guidance, coordinates stakeholders that want to work with schools, and provide approvals for the district to collaborate with external stakeholders, as is the case with the WCED, the SBIDZ, Wits and SU for the PP: ADS short course.

In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in your school? (B3)

Below are some of the responses from academic experts and teachers.

E1 (2021): *I think it is essential that all subject advisors and all managers of subject advisors for secondary mathematics must themselves, a course must be designed for them and they must attend that course so that they can provide guidance and leadership to teachers because those subject advisors are on the road almost every day, going to speak to or meet with teachers, mathematics teachers on a daily basis, and they are not conveying anything about digital skills, possibly because they do not have the knowledge of digital skills and digital software. And the local education district administration must take responsibility for that, for the education subject advisors being knowledgeable, being able to go to a school and find a teacher who says I was trying to use this applet, but I am struggling, can you help me.*

E2 (2021): *My experience is, either you have a champion in the school … and that must a headmaster or a head of mathematics that says my school is going to take this up and then really drives it and find support or you need a teacher that already can do it.*

E3 (2021): *…. it's the whole as you say the whole hierarchy, the whole everybody involved … So, this leadership at all levels is vital.*

WT1 (2022): *With the districts, you know, we have, we get support in terms of there is training, there is programmes and there are courses that our teachers can go to. I think we must stop talking, we must implement what we are saying and that for me it's a huge concern, like I said, I would love when the day come when a teacher gets to a school, he gets all his tools.*

WT4 (2022): *The district setup paper and memorandum.*

It is evident that local district support for schools does exist. However, the application of the policies, frameworks, and guidelines in schools is missing. Participants indicated that new schools need to be built in line with the infrastructure contemplated in the policies, accompanied by related training and support.

4.4.5 School digital infrastructure

Please mention or comment on the following issues related to school digital infrastructure [Question C]: *What kind of internet connectivity do you have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why? (C1) What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why? (C2) What type of devices, applications and content does your school have for digitally supported teaching of secondary mathematics? Why? (C3) Comment on any other relevant school digital infrastructure issue. (C4)*

What kind of internet connectivity do you have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why? (C1)

Below are some of the responses from academic experts and teachers.

E1 (2021): *Okay, so here the teachers did not have suitable internet connectivity either at school or at home to participate in the course to read or to use the application software that we were teaching as part of the course. And so, the SBIDZ licensing company had to buy data at the cost of around R11,000 a month, so that teachers could have the kind of internet connectivity that they could rely on to do the reading, use the software, do the group assignments and the individual assignments.*

E2 (2021): *Well once again, I have not been in a school that doesn't have internet connectivity. The teachers where I sat in, you know for an extended time in a staff room where teachers come in and out, they complain that it's slow today or so and I mean so it is for me, you know, we don't have the biggest bandwidth in the country, but they have connectivity.*

E3 (2021): *Yes, the technology available, I don't think that is a problem because as you know you can use it in many ways, some of my first remarks was all that I want is one computer and a data projector. So, if we talk about cost, then that is cheaper than every child having a computer or having a computer lab with 30, 40 computers in it.*

WT1 (2022): *We do have Wi-Fi at our school. For the teachers at home most of them is still using their own mobile data from what we have done research on, some do have Wi-Fi at home but it's out of their own pockets, it's nothing from school or like in this case, in this course they gave us a bundle and said you can use this at home whenever you do research or when you listen to the trainers or whatever the case may be. But that is not happening at the school.*

WT2 (2022): *At our school we have two different Wi-Fis, we have the WCG School Wi-Fi and that one is normally not working and then we have our school Wi-Fi itself and then that one only like connects at a certain range. So, from my class I do get it but it's very low, it's very weak and then at home most of us do have Wi-Fi ... it's our personal Wi-Fi [at home].*

WT3 (2022): *At this moment our school's lab is dysfunctional and digital teaching is minimised to the projector with poor Wi-Fi.*

WT4 (2022): *There is connectivity (Wi-Fi).*

It is evident that there is some form of internet connectivity in most schools.

What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why? (C2)

Below are some of the responses from academic experts and teachers.

E2 (2021): *Quality wise as I say, I think it's slow, it's in our country its insufficient bandwidth it's not just the problem for the schools so I think that is something that must be tackled at national level. But again, I don't think it's to complain about it, it can be done.*

WT1 (2022): *It's very slow and inconsistent.*

WT2 (2022): *Yes, very slow. Sometimes it's not working then we must ensure that we have our own data on our phone. Because there is lots of things that need to be done, we need to send totals, we need to do attendance online so there is lots of things happening, but the Wi-Fi is not always working with us.*

WT3 (2022): *At this moment our school's lab is dysfunctional and digital teaching is minimised to the projector with poor Wi-Fi.*

WT4 (2022): *The bandwidth is low, and no data supplied for home preparation.*

It is evident that internet quality and range (in most instances) is not adequate.

What type of devices (C3), applications (C4), and content (C5) does your school have for digitally supported teaching of secondary mathematics? Why?

Below are some of the responses from academic experts and teachers.

E1 (2021): *Okay, so my view is that as a minimum, the group of mathematics teachers in a school must have their own device, not a shared laptop for the whole school, not a pool laptop, but a laptop that is dedicated for mathematics teaching only, no other subject, no administration, only the teaching of mathematics, that's a minimum. The ideal would be that every maths teacher has their own laptop. Why? Because the teachers need to be able to overtime, over the school year, over multiple school years build up a database of material that they use, they need to have their own folders where they have the applets ready for teaching the lesson. They could have a folder for every lesson and in that folder is the lesson plan and the applets that they are using for that lesson. So, if they are teaching, I don't know, let's just say a hundred lessons for the year, they have got a hundred folders, each folder has got the lesson plan and the related applets and any other material that they need for that lesson, then they will have greater confidence in teaching that lesson using digital technologies.*

E2 (2021): *Well obviously, as our teachers have also clamoured and that was promised by the Education Department (WCED) that the teachers will get laptops, they clamour to laptops. Now laptops will make their lives easier if we want them to teach with technology. But I don't think it's indispensable. The* *schools that I visited had desk top computers but modern ones without the big box that they could easily take to the classroom and put up there. And then secondly, they obviously need a casting device. So, either an overhead projector or, you know something like that or it will have to be an overhead projector or a whiteboard, a digital whiteboard I think those are on their way out. So, they need those two things. What we are underestimating, I think is the use of smartphones. So GeoGebra is available on the smartphone, teachers can work on their smartphones, and they can project via bluetooth from the smartphones but that would then mean that they have access to the internet at the school and that they don't need to pay for their own data. But I don't think you need huge resources and especially if you are in a school where one of our three children have a smartphone. Hopefully now after Covid if their children can put their heads together literally again, we should make use of that. GeoGebra is on the smartphones.*

WT1 (2022): *Look here, we usually have the projector, the laptop, the smart board, that one and, what is the other one where we use the books, the visualiser, that is the main devices that we are using. Smartphones nowadays I see some of the teachers are using their smartphones also and tablets, but that is the main thing … apps, there is an app like photo math, now if you and maybe if you, you must write it down, you can go and look for it. But if you use photo math, you can take a photo of a mathematical problem and it will give you the answer … The questions arise now, must we teach the children to use this technology or must we teach the children to do the problem, and it's still the same question with calculators also. And the answer is clearly we must use both, you cannot say we cannot use this, but we must be cautious with regards to how we are using it. If we are using it just to get the answer, there is no benefit for us to use it … Our main concern was just that all the classes must have the devices, but when we do that, we need to have a ratio that is working with us. If we want to be learner-centred, we cannot work with 50 learners within a class.*

WT2 (2022): *… we have a media lab at school, there are computers, I am not sure where the school got the computers, there is printers but 95% of them don't work. There is like this morning I was in the media lab, there is only two computers that print, the rest works but you can't print. Now that you get a computer that prints it's not connected with the printer that prints because there is for instance four printers but only one work. So, it's very problematic for us not to get printing and stuff done. Then you need to go to the office, then you need to change all your Word documents to .pdf in order for you to print that stuff, then it becomes extra effort for us as educators.*

I am only using GeoGebra … I am aware of Sketchpad and GeoGebra and I normally use that to set up my papers to draw sketches and stuff. I tried to use like we got the training now from Luci and them, so I am going to try and incorporate it this year in my class when I get to that topic. Like I said there is some classes like that doesn't have the projectors.

WT3 (2022): *Currently we don't have a computer lab.*

WT4 (2022): *Laptop provided for teachers and learners with tablets.*

It is evident from the above responses that laptop devices for teachers and tablets for learners are available. GeoGebra is also available in some schools.

4.4.6 Social issues

Social issues affecting teaching and learning in schools [Question D]: *What kind of social issues are affecting educators in schools? Why? (D1) What kind of social issues are affecting learners in schools? Why? (D2) Comment on any other social issues affecting schools. (D3)*

Below are some of the responses from LEDA representatives and teachers.

LEDA1 (2022): *I think whether we like it, or we don't like it the issue of, I am not talking about the medical issue but the issues that Covid has relayed, has unpacked, has uncovered are quite in this thing and can't be ignored, particularly within working class communities, the issues of vaccination and not vaccination, the debates that proceeded from that in the spectrum, scientific debates, religious debates and all those kinds of things.*

LEDA2 (2022): *We know that there is massive inequality in Saldanha, that there is a sense of hopelessness for the youth, and you can see that evidently being played out in the high youth unemployment rates across the country. There are other issues and like just issues that you find in marginalised communities, young people are dealing with drugs, for example.*

WT1 (2022): *Look, in our case I will say the social economical context from which our learners are coming here, it places a barrier on using these devices. At the moment we have an influx of many learners that is coming to the West Coast and in most cases or some, let me not say most cases, what we have found is that in some cases these learners are sent from other provinces to come and live by with an uncle, or a nephew or cousin whatever the case may be or even they live on their own with a friend. Though the parent involvement is becoming minimised or get to a point where there is no parent involvement and now how do you control the use of technology within the house where there is no parental structure, or you know what there is nobody that is controlling how learners is using these devices.*

So, I would say that is our biggest challenge is the socio-economical situation currently at our learners' houses and I believe that a challenge now at home is not centred around learning, but it is centred around surviving now, to put bread on the table now is the most important thing for parents and even for most of our learners.

WT2 (2022): *Firstly, it is the use of drugs and cigarettes, all of that. Learners come to your class high as a cloud, but the things are they also smoke on school, we tried to like control it but it's difficult because when it is time for classes they normally go to the bathroom and smoke, now we can't be everywhere. So, when they come to class normally, they are not a problem they will just sit there. I can't identify always who is the one that smoked, sometimes you can see them, and we can send them back with the intervention letter and they will be suspended. Then also things that disrupt the class is fights, we have a lot of gang-related fights, yes. There was, like sometimes you are teaching and all of a sudden there is a fight outside. Like in the school yard, like learners fighting and everyone is running out. So, then you are losing like 10 minutes because you have to get everyone back. So, yes, we had cases at school where there was stabbing with the knife literally fighting and the learners are bleeding.*

WT4 (2022): *Gangs, drugs and alcohol are some of the social issues that must be addressed.*

E2 (2021): *There were no examinations for teaching and learning with technology as current assessment practices used pen and paper*.

The evidence points to social issues such as marginalisation, alcohol, drugs, violence, and lack of parental involvement that affect schools and learners negatively. Also, the issue low stakes due to no examinations of technology integration in mathematics teaching and learning in secondary schools was also raised.

4.5 PERSPECTIVES OF LOCAL ECONOMIC DEVELOPMENT AGENCY (LEDA) REPRESENTATIVES

This section presents the qualitative results and findings obtained from LEDA representatives who were involved in the PP: ADS short course. The data was gathered via semi-structured interviews will be presented here. The data will be analysed in Chapter 7. The LEDA representatives were asked the following questions: *Why did the SBIDZ-LC start the Open Saldanha Project? [Q1] Why did the SBIDZ-LC get involved in teacher development in general and in mathematics education in particular? [Q2] What short-term and long-term plans does the SBIDZ-LC have for* *engagement with the Open Saldanha schools, relevant to the innovation and development taking place at the SBIDZ? [Q3] How does the SBIDZ-LC envisage providing future support to the schools in the Saldanha Bay circuit to overcome the challenges related to internet connectivity, devices, and use of mathematics teaching applications, amongst others? [Q4] What are other issues relevant to the schools in the Saldanha Bay circuit that the SBIDZ is involved in addressing? Why? [Q5]*

Why did the SBIDZ-LC start the Open Saldanha Project? [Q1]

Below are some of the responses from LEDA representatives.

4.5.1 Interfacing with communities

LEDA1 (2021): *… how do we penetrate communities? They are very fractured those communities so various organs of social production and reproduction again not unlike other parts of South Africa have been completely undermined … In the meanwhile, what we are going to say is how do we make this intervention work most effectively? How do we penetrate communities? I think school are good apparatus to do that.*

LEDA2 (2022): *Okay, so why we started it [Open Saldanha Project] … is because for two reasons. Number one is the purpose of SEZs no matter what country you are in and what has been the purpose of the SEZ is to bring in investment and particularly we started with the foreign direct investment and to get the benefits of jobs … you want jobs, but you want it most successful when you have those local spill overs happening in knowledge, in technology exchange, in skills and in economic spill overs … So, skills development of school leavers, everybody outside of schools put it that way. But we knew that even to get deeper and understand and understanding our context in Saldanha is that we needed a programme that with school students, so learners, and that is why if you take that all into consideration, that is why we started with the Open Saldanha Programme because we knew that we need to make an intervention into schools to reap the benefits 20 years from now.*

LEDA3 (2022): *So, to my understanding the Open Saldanha Project was started by just looking at the mandate of the Saldanha Bay IDZ which is really to create this economic growth in Saldanha Bay and the West Coast and ultimately in South Africa. And there has been a number of projects that have happened in Saldanha Bay in the past and our communities have been left behind and so, really if you are looking at the Open Saldanha Project its looking at the, you are looking at the mandate of the Saldanha Bay IDZ and if this is our mandate which is to create the sustainable economic growth and make sure that the communities in the area are able to drive and take opportunities in the developments that are happening in the area, then we have to understand that the success of the SBIDZ would actually depend on us being able to make sure that the communities are able to have the necessary skills set that will be required for them to actually be able to take up those opportunities and so that is really how it came about. It's like how we can assist communities to be able to be part of this development and to drive this as well and to not be left behind like they have been in the past.*

The evidence shows that the overall objective of the Open Saldanha Bay Project is to interface with the surrounding communities via schools. This is to ensure that there is a strong mathematics pipeline in schools for future participation in marine engineering careers in the Saldanha Bay IDZ.

Why did the SBIDZ-LC get involved in teacher development in general and in mathematics education in particular? [Q2]

Below are some of the responses from LEDA representatives.

4.5.2 Human value

LEDA1 (2021): *Maths and science are important but so is singing important and so is art important, so many other things are important because all those things enable, they tangibles this determination for children and* *only embracing the humanity, the human value. And so I think that before you talk about maths and science or arts or anything else, we need to start by saying we have to engage a process that enables people to understand their individual value and the value of other people by this or that to renegade the fundamental proposition around human value … So, we designed a full programme, a five part programme, I will just share with you very quickly what the five components of that programme were. Two of the five had to do with curricula interventions and those were around mathematics and the natural sciences, and I will come back to why and I am the person who designed it, so I will come back to why I chose to design it that way … The fundamental struggle is for human value and whatever we design from those flows from there. So, our economic system of organisation can be designed in several ways and if its purpose is to serve the people of South Africa, if that's its purpose, then, we must somehow find a way of doing this differently … So, we've simply not been able to attract any funding for this …*

LEDA2 (2022): *So then, knowing our context and studying it because we did a community baseline survey in 2015 the research revealed that the schools are the most pragmatic and effective way of accessing school children and that long term view, sustainably, consistently maybe put it that way and so you should look then at what is happening in our schools and knowing that you have a 20 year mindset to say what are the skills that are needed in 20 years and the research is the evidence is that digital skills is the confidence to be able to work with a laptop and solve your own problems without learning or I would even say self-actualisation, you know. And what we chose then looking at the curriculums is that mathematics would be a good match for using digital tools but also in the vein of what the IDZ's industries are which is very much in 20 years it's going to be about solving very technical problems and I want to say its problem solving and mathematics gives that foundation for problem solving, no matter where you are in HR, in engineering, in finance, in corporate management, you know. So, that's why we decided to do a digital mathematics programme and then lastly, we decided that we needed to talk to the teachers because you need to teach those who are going to teach.*

LEDA3 (2022): *And so, with the study that was done looking at the communities in Saldanha Bay and the schools, the level of basic education is very low, and mathematics and physics just the pass rate is very low in the area as well. So how do you actually make sure that the students that come out of matric are able to go to university, go to technikons and be able to take subjects that are related to the sector, the energy and maritime sector. So, if the maths and the physics are very low then you are not going to be getting a lot of students that are coming out of Saldanha Bay actually being able to work in the IDZ. And that is how you have to create this maths programme and you have to start with the teachers because they are basically the ones that are teaching the kids. They are the ones that are motivating the kids, so if the teachers are able to have the confidence to teach digital mathematics, then it has to start with the teachers.*

This evidence shows that the dignity of the individual is an integral part of development. Teacher-development initiatives should be holistic in nature. Marine-related engineering degrees require a good mathematics result.

What short-term and long-term plans does the SBIDZ-LC have for engagement with the Open Saldanha schools, relevant to the innovation and development taking place at the SBIDZ? [Q3]

Below are some of the responses from LEDA representatives.

4.5.3 Partnerships

LEDA2 (2022): *The long-term plans for the Open Saldanha Programme are that it will likely sit within the innovation campus programme, with projects within the IDZ just for the governance arrangements to be suitable to access third party funding, donor funding and to get others on board. I think these figures, I think this thing will take a life on its own and we have limited resources and capacity to give it up between operating the IDZ and Open Saldanha programme if you consider the scale that it needs to go to. I* *mean nine schools of students of over a thousand each, you know teaching body you know 30, 40, 50 teachers per school. Like you know it's a big, massive programme and it needs to have a home of its own and I think that home will be within the innovation campus entity that we are going to be establishing which will likely probably be an NGO entity to make sense.*

4.5.4 Teacher support

LEDA3 (2022): *I would say the short-term goals, the work that we are doing right now with the teachers, so now we have had this programme with the teachers, and they are going to be graduating towards I would say possibly this month, then how do we continue from that? Like how we move forward because we need to be able to put this into the classrooms and how can we support the teachers. How do we give them the support for them to be able to integrate this into the classrooms? And sort of like what other opportunities can we introduce the teachers to? It does not have to just be the maths programme. Like for example last year we sort of like excited the teachers as well in Saldanha Bay by introducing them to drawing technology, and like what other programmes can we actually bring into the schools and I would say that the, one of the main short term goals as well is to be able to support the teachers and actually giving them that confidence and actually making them to understand that they are playing such a huge role and that is one of the things that we want to do is to provide these leadership skills to the teachers which I think are very important.*

4.5.5 Technologies in the curriculum

LEDA3 (2022): *And then the long-term goal I would say would be to just integrate 4IR technologies into the curriculum in schools. Being able to see like that schools in Saldanha Bay are, like doing like they are being taught 3D printing, robotics, coding, like all of those 4IR skills are actually being integrated, have been integrated into the school system in Saldanha Bay and being able to find partners who are, who see the vision and importance of this and are able to fund this. I think the energy and the maritime industry like looking at the picture it's going to be just a myriad of complicated jobs basically that are going to be so integrated with technology. So, just to be able to provide these are sort of like different teaching mechanism in the schools in Saldanha Bay is something that is going to need more than what the education system in Saldanha Bay or in South Africa is able to provide right now. It's going to need more creativity, and right now if you are looking at the Saldanha Bay Innovation Campus, I would say the most innovative thing that us as the Saldanha Bay IDZ at this moment, the most innovative things that we can do is to actually play a role in improving the school system in Saldanha Bay.*

The evidence shows that the short-term and long-term goals are to ensure the training of mathematics teachers and learners, including partnerships, support in class, and factoring in the evolution of technology trends. The long-term goal is to involve all the schools in the Saldanha Bay area.

How does the SBIDZ-LC envisage providing future support to the schools in the Saldanha Bay circuit to overcome the challenges related to internet connectivity, devices, and use of mathematics teaching applications, amongst others? [Q4]

Below are some of the responses from LEDA representatives.

4.5.6 Leadership development

LEDA1 (2021): *… Of course, confounded by the Covid-19 thing last year, this year, but so what we've decided in 2022 is we want to continue what I call an education colloquium … doing a leadership development programme with kids, with children from the high schools, the six high schools should develop a cadre leadership …*

4.5.7 Internet connectivity

LEDA2 (2022): *So, this was something that we thought that we going to have to tackle, or lead agitate for change but I am also very heartened by the fact that the municipality sees broadband connectivity, equitable broadband connectivity as, they call it the fifth utility. So, they have a broadband project that is rolling out that intends to provide fibre across to deepen and really strengthen the network that is already there that was established by the provinces to the schools but really provide that constant accessible connectivity to public institutions and to households. So, the fact that we have a partner that the local authority is taking a lead on that is really needs to be encouraged and we need to then co-plan with the municipality with their timelines and their milestones and their needs in order to ensure that the Saldanha Programme has a good fit then, that we aren't left scrambling for digital access and we try, you know on the curriculum that we are rolling out and the schools still don't have it, the kids still can't access the internet that is really going to ruin the reputation of the Open Saldanha Programme, and the trust in it.*

What are other issues relevant to the schools in the Saldanha Bay circuit that the SBIDZ is involved in addressing? Why? [Q5]

Below are some of the responses from LEDA representatives.

4.5.8 Collaboration

LEDA3 (2022): *I think like just from the work that we have been doing the past few years, since I would say we started this teacher training, for me it's just the realisation that I would say it is the realisation that it's going to take a lot of collaboration. Like we can't do it alone. So, it's a matter being able to provide the internet to the schools, it's a matter of finding people who see the vision and are willing to collaborate with us. In the matter of providing these 4IR technologies to the schools and making sure that the learners in Saldanha Bay do not see these things as something that is just so far away from you but are able to actually interact with them and say like wow, like this is something that I can actually do. It's going to take collaboration, it's going to take finding people who, they want to actually want to make a difference just like us. I think we are slowly finding those people and just the more we continue we are going to find more people, you know. And that is what actually is going to create that change.*

The evidence shows that there is a need for leadership development and collaboration, to embrace internet initiatives.

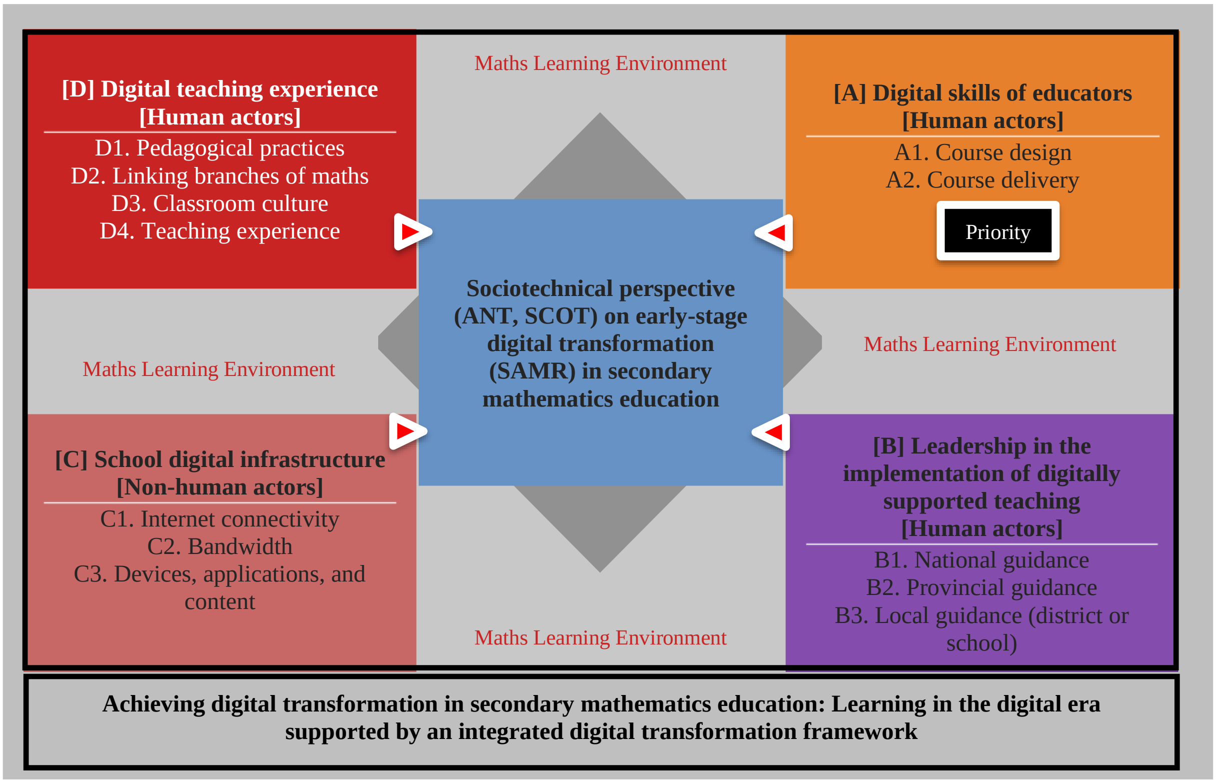
4.6 CHAPTER SUMMARY

This chapter provided data and interpretation to confirm the claim that the use of digital technologies for teaching secondary mathematics in schools is still at an early stage, which is equivalent to the enhancement stage (substitution and augmentation) of Puentedura's (2026) SAMR model. Based on the evidence from both participant observations and semi-structured interviews, there is a widespread lack of intermediate and advanced digital skills among educators; these skills are needed for content creation and advanced searches. There is also a lack of a formal governance structure to hold key role-players accountable during the design, development, and implementation of digital education policies. Further, there is a lack of a technical architecture to address the challenges of internet connectivity, the operation of devices and support, and power-related matters such as loadshedding. Lastly, there is the continued use of teacher-centred pedagogical approaches. These findings concur with the earlier findings in the literature review.

Furthermore, the inquiry about social issues revealed problems such as the use of alcohol and drugs that leads to violence on school premises. Moreover, the emergent low stakes dimension is related to the fact that there is no assessment of digital teaching and learning of secondary mathematics. In Figure 28 the red arrows show the limited contribution of the four dimensions to the shifting of digital transformation in secondary mathematics education beyond the early stage.

Figure 28

DT-SME framework for case study A – WCED



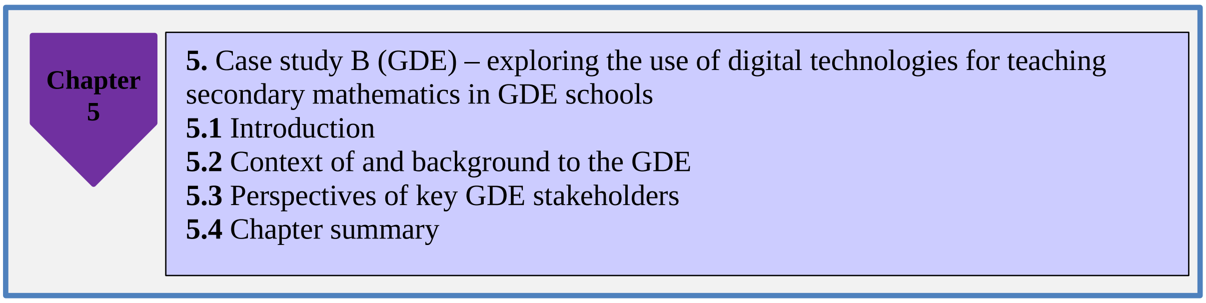
The collaboration between key actors (LEDA representatives, the WCED, the local education district, SU and Wits) demonstrated that the use of dynamic software applications for teaching mathematics in secondary schools can be transformational. While the initiative exposed several gaps in digital skills, leadership, infrastructure, and pedagogy, it also provided an opportunity for the partners to seek innovative ways of bridging those gaps. For example, a website was created for the course material and was complemented with a USB in case there was no internet connectivity. Also, during the COVID-19 lockdown, lessons were conducted remotely, and laptop devices and data were purchased for the participating teachers to ensure the completion of module 2 (geometry) of the PP: ADS short course. Chapter 5 presents and discusses the research findings from case study B – Gauteng Education Department (GDE).

Chapter 5: Case Study B: Gauteng Department of Education – Exploring the Use of Digital Technologies for Teaching Secondary Mathematics in GDE schools

5.1 INTRODUCTION

The previous chapter reported on the data that was collected from case study A (WCED) in order to answer the study's research question, which is to determine the approaches for shifting digital transformation in secondary mathematics education beyond the early stage. The purpose of this chapter is to report on the data that was collected from case study B (GDE) in order to respond to the research question. Case study B complements case study A. No course was offered in case study B. Structurally, the chapter consists of three thematic sections with relevant sub-sections. The first section also provides the context of and background to this case study. Next, the section presents the views of key GDE actors (teachers, district officials, and principals) pertaining to the four specific dimensions of the DT-SME framework (i.e., digital skills of educators, leadership in the implementation of digitally supported teaching of secondary mathematics, school digital infrastructure, and digital teaching experience). In conclusion, the chapter summary and the focus for the following chapter are provided. Figure 29 shows the flow chart for chapter 5.

Figure 29
Chapter 5 flow chart



Case study B complements case study A; a complementary study was needed because of the challenges experienced during the COVID-19 pandemic. Semi-structured interviews were administered to seven key GDE actors (district officials, teachers, and principals) who also provided an actor-network theory (ANT) perspective on human actors (digital skills of educators, leadership, and digital experience) and non-human actors (school digital infrastructure), with the social construction of technology (SCOT) perspective being used to analyse technology usage. Table 10 shows the actors (participants) and the pseudonyms that are used throughout this chapter for participants in this case study.

Table 10
Actors from the GDE case study

Date	Pseudonym	Role	Location
8 September 2020	GD1	District official (JWD)	Physical
8 September 2020	GT1	Teacher (JWD)	Physical
8 September 2020	GT2	Teacher (JWD)	Physical

17 September 2020	GP1	Principal (JWD)	Physical
22 September 2020	GD2	District official (ESD)	Virtual
22 March 2022	GT3	Teacher (JND)	Physical
10 September 2022	GD3	District official (ESD)	Physical

Source: Author, 2022

G/GDE stands for Gauteng Department of Education:

GT 1-N represents teachers; GP 1-N represents principals; GD 1-N represents district officials; JWD – Johannesburg West District; ESD – Ekurhuleni South District; JND – Johannesburg North District

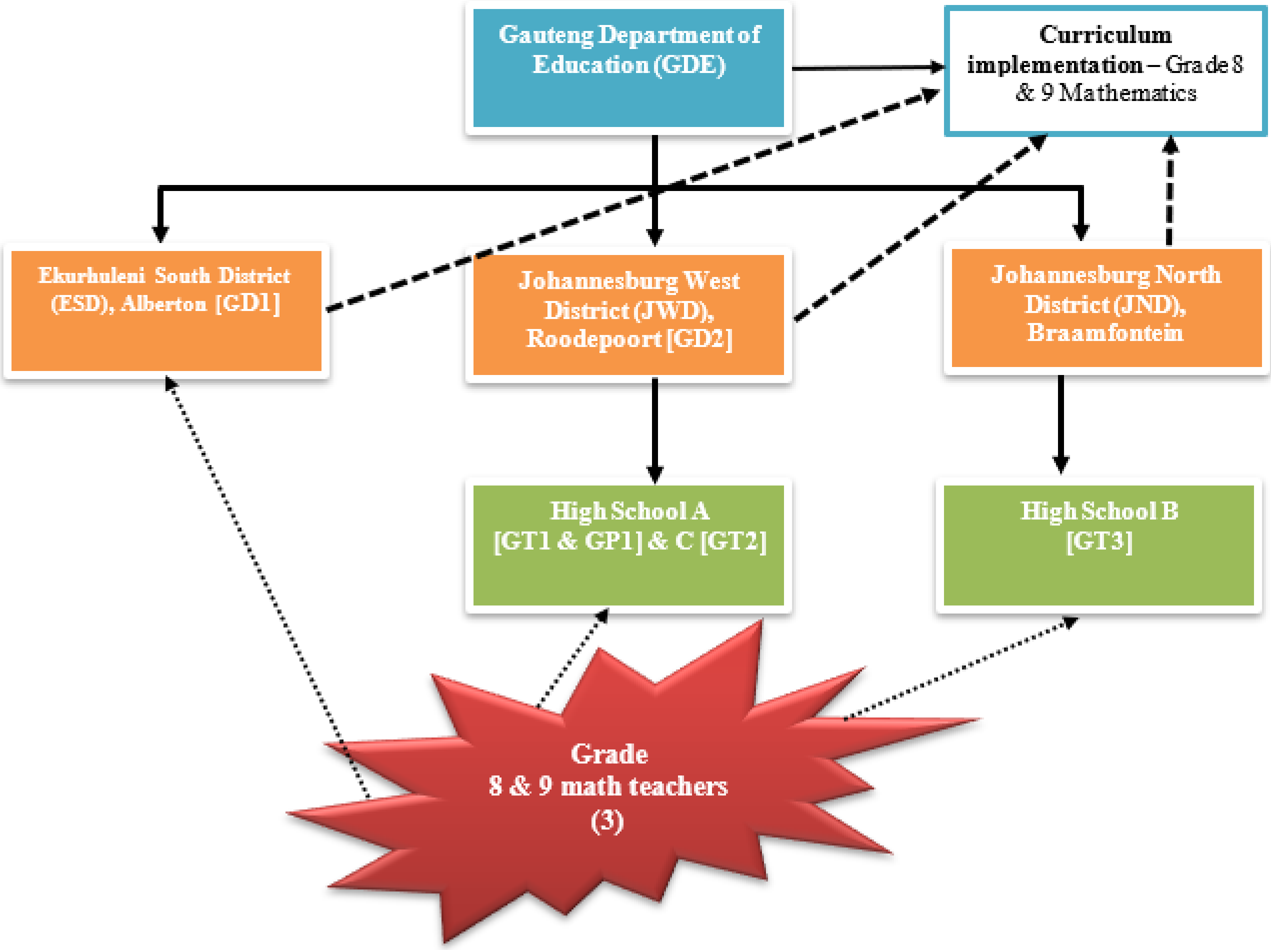
The study's analytical framework is used to organise the data. The context of and background to case study B are presented below.

5.2 CONTEXT OF AND BACKGROUND TO THE GAUTENG DEPARTMENT OF EDUCATION

Data collection for this case study was carried out in Gauteng, mainly in the Johannesburg West District (JWD) and was complemented by two other GDE districts, namely the Ekurhuleni South District (ESD) and the Johannesburg North District (JND). Figure 30 shows the three districts and the high schools that participated.

Figure 30

Case study B: Gauteng Department of Education – Overview of the research sites



Note: Case study B was added for complementary purposes.

Case B (GDE) was chosen to complement case A (WCED) due to the COVID-19 pandemic as the researcher was based in Gauteng to access participants closer yet from the DBE. Permission was granted by the Gauteng Department of Education (GDE) and the researcher interviewed managed to interview participant from three districts in Gauteng, namely Ekurhuleni South District (ESD), Johannesburg West District (JWD) and Johannesburg North District (JND).

ESD interviews were conducted virtually due to COVID-19 restrictions. Additionally, Johannesburg West District (JWD) interviews were conducted physically with strong adherence to COVID-19 protocols (masks, sanitising, and social distancing). Furthermore, Johannesburg North District (JND) interviews were conducted physically as most schools had fully vaccinated pupils and teachers, with strict observation of COVID-19 protocols.

5.2.1 The economy of Gauteng

According to Gauteng Online (2017), the Gauteng Province's total GDP for 2010 was R811 billion, making the province the single largest contributor to South Africa's GDP with a contribution of 33.8%, despite having only 1.4% of South Africa's land area. Gauteng generates approximately 10% of the entire African continent's GDP. Gauteng's unemployment rate was 33.7% in 2021 (Statssa, 2021). Figure 31 shows the Gauteng districts.

Figure 31
Gauteng district map

Note: The main research site, JWD, is in the West Rand District.

5.3 PERSPECTIVES OF KEY GDE ACTORS

5.3.1 Digital transformation in education from the case schools

This sub-section presents the responses from experts, teachers, principals, and district officials in the in-depth interviews. The following question was asked during the in-depth interviews [Question A0]: *How do you refer to digital transformation in the education sector (e.g., the use of digital technologies for teaching, learning, administration, other)?*

Below are some of the responses from teachers, principals, and district officials.

GD1 (2021): *E-learning … And that is what is called e-learning.*

GT1 (2020): *ICT.*

GT2 (2020): *Yeah, we call it e-learning.*

GT3 (2022): *ICT in education.*

GP1 (2020): *Yeah, I think mainly it's more e-learning … Because we use smartboard, laptops and then videos.*

GD2 (2020): *ICT and e-learning.*

The above participants' responses during the in-depth interviews include the use of the term 'ICT' in education, which is an old term that has been replaced by 'digital technologies' in education and variants such as digital learning.

5.3.2 Digital skills of educators

Digital skills for course design [Question A1]: The following question was asked during the in-depth interviews: *Which digital skills of educators should be developed for successful course design in schools, specifically for mathematics education? Please add any other influencing skills not mentioned above.*

Below are some of the responses from academic experts and teachers.

GD1 (2020): *Not in grade 8 and 9. Grade 8 to 9 they want lesson plans from other people … They don't want to do their own lesson plans, so they rely on whatever comes from head office.*

GT1 (2020): *Design classwork and homework at home so as not to waste time.*

GT3 (2022): *Create graphs and shapes using GeoGebra.*

GT2 (2020): *Teachers use their laptops to prepare for their lesson plans. Yes, they will need more training on computer applications to know how to play around preparing slides and all of that. I think most PowerPoint and mostly Excel as it is mathematics. So generally, Windows applications are what they need to be trained on. Yeah, they need to plot graphs and maybe they want to do analysis of their results or maybe help them to help the learners afterwards. They must be able to enter and to calculate the averages to calculate you know the levels and so on.*

GP1 (2020): *Chances are they're probably using PowerPoint … but I wouldn't say really if they are well versed in terms of that. But it's something that we are looking at with the ICT committee because one of the things we did was we went to one of the schools last week to go and check what are they doing. So, all they did was to incorporate Zoom.*

GD2 (2020): *There are some teachers who use ICT for course design, but most do not use … There are some gaps in the district. The younger teachers are more willing to use technology than the older generation who are reluctant, and the majoring are older.*

The above responses indicate that teachers have limited digital skills for course design. It seems that teachers receive prepared lesson plans from the DBE's head office. There is a strong indication that teachers need basic digital skills on programs such as Word, Excel, and PowerPoint.

Digital skills for course delivery [Question A2]: *Which digital skills of educators should be developed for successful course delivery in schools, specifically for secondary mathematics education? Why? Comment on the current state of digital skills for course delivery, specifically for secondary mathematics education. Please add any other influencing skills not mentioned above.*

Below are some of the responses from academic experts and teachers.

GD1 (2020): *Look, I tried the other day to show some of the teachers how to draw graphs … So, I tried showing them how to do it using Excel. There is an encouragement for teachers to use Excel. Advantages of using Excel include performing diagnostic analysis to zoom into every question and find out how learners performed in this question. And why they are performing so that the data is not just data but becomes information. Schools are still busy with mathematics content. Look at the moment you're still fighting with teachers regarding content delivery. The traditional way of doing things is still prevalent because teachers use chalk. The DBE provides teachers with already designed material.*

GD1 (2020): *No apps that are used.*

GT1 (2020): *Support amongst teachers.*

GT2 (2020): *Yeah, we do use GeoGebra and that is part of one of the applications that they use. Not so many applications are what they use … GeoGebra is the most famous success …*

GT2 (2022): *I use laptop connected to the projector.*

GP1 (2020): *The school is not an ICT school. What does this mean? It means not all the classrooms have smartboards and stuff. However, we do have a system in the school where teachers, who especially in the grade 8 and 9 classes, those who want to and are familiar and in using Zoom, ICT, and stuff. So, we then have that arrangement to say they can swop out classes on that day and time to be able to use the smartboard … I will not say that they are well versed in terms of designing lessons.*

GD2 (2020): *Limited use of PowerPoint for presenting lessons. The focus is mainly on grade 12. Old ways of teaching are still dominant.*

GD3 (2022): *Change management (mindset) as teachers have been given training (on technology use). The innovators or young teachers are early adopters.*

The above responses show that teachers lack digital skills for course delivery. However, there is knowledge about dynamic software tools such as Excel and GeoGebra and a strong desire to get training on basic digital skills (MS programs such as Excel, Word, and PowerPoint) as well as intermediate and/or advanced digital skills (dynamic software tools such as GeoGebra, Geometer's Sketchpad, and others).

5.3.3 Digital teaching experience

Digital teaching experience [Question A3]: *How are teacher-centred, learner-centred, and learning-centred teaching strategies working (or not working) in the early digital learning environment? [A3.1] What strengths and weaknesses do you experience in linking different branches of mathematics in a single lesson, or series of lessons? [A3.2] What obligations and expectations (school culture) will need to be met during digitally supported teaching? [A3.3] What is needed for greater teacher empowerment and building your collective identity as digitally enabled teachers? [A3.4] What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools? [A3.5] Please add any other teaching experience and expected outcome issues not mentioned in this list. [A3.6]* These questions are answered individually below.

How are teacher-centred, learner-centred, and learning-centred teaching strategies working (or not working) in the early digital learning environment? [A3.1]

Below are some of the responses from teachers and district officials.

GD1 (2020): *It's a lecture given to learners … You know that some teachers don't even know how to use an overhead projector.*

GT1 (2020): *Mixture of teacher and learner-centred.*

GT2 (2020): *And the teacher teaching. The learner must be able to work independently on the curriculum itself. So, we do, even though the teacher-centred method, I don't think it is a very effective method. I think it was back then but now most teachers have adapted to using lots of different ways of delivering the curriculum.*

GP1 (2020): *If they've done but I didn't see but I know normally take rounds you know but I still see the traditional way of doing things because they're using chalk …*

GT3 (2022): *Prefer learner-centred approach.*

GD2 (2020): *There is a balance of both teacher-centred and learner-centred ways of teaching. Learners are becoming free sharing and working on their own. The ATP (Annual Teaching Plan) restrict teachers to a particular topic per term. Also, CAPS is for the whole country, and it is difficult to deviate from it.*

GD3 (2022): *Blended learning ... a shift is happening (from 2015) with ICT schools ... with learners being more cooperative and less absenteeism being observed. There is less ICT adoption amongst teachers (older teachers) and learners are ahead of teachers.*

The above statements show that teacher-centred practices are still prevalent (GD1, GT2, and GP1) but there is also a mixture of teacher-centred and learner-centred approaches (GT1 and GD2).

What do you think are the strengths and weaknesses of linking different branches of mathematics in a single lesson, or series of lessons? [A3.2]

Below are some of the responses from teachers, principals, and district officials.

GD2 (2020): *Part of learning can involve taking learners to the nearest golf course or having a video clip of golf and space launches, for example. The latter can be good for answering the question: why learn mathematics? The current curriculum provides the links – biology, geography and makes use of real-world examples.*

GT1 (2020): *Link mathematics with real-world examples i.e., discount percentages being offered during black Fridays. Support amongst teachers.*

GT2 (2020): *At least for now it's better because it's actually linking up mainly and talking to all other learning areas you can link the maths with the economics, finance. You know you can link your maths with some life sciences biological, so we are able to do mathematics using the context in biology. Using your mathematics in the context of geographic so I think it's interlinked so. Or in the context of you know a learner experience making examples of fitting things that learners are actually exposed to. You see so I wouldn't let me say we're the type of school although we are we don't even play golf. So, we cannot be asking learners things that are happening golf ball when golf balls travel from this distance to that distance*

GT3 (2022): *I do link the Euclidian Geometry with Euclidian algorithm.*

GP1 (2020): *But that from a teacher's point of view I think that is something very lacking in our teachers so yeah linking different topics to a particular skill yeah.*

The statements above show that there was theoretical knowledge about linking different branches of mathematics in a single lesson (GD1, GT2, GP1, GD2), but this was lacking in practice as teachers still focus on one concept (P1, 2020) as stated below.

What school culture will need to be met during digitally supported teaching? [A3.3]

Below are some of the responses from teachers, principals, and district officials.

GD1 (2020): *No, it's not very positive. The teachers that I've seen teaching maths all refer back to the board.*

GT2 (2020): *It's a very big school and we've got lots I think this is the one the schools; the school has an intake of learners which is more than all the other schools in the area. So, with the learners that we are getting are coming from disadvantaged families.*

GT3 (2022): *The school culture is supportive. We have meetings with the ICT coordinator every term for discuss[ing] new technologies and challenges.*

GP1 (2020): *You must be the culture that you want in the school. Every culture has got its own ups and downs. But I think a culture that says, I'm available I am willing to help you, I know you have problems, I can support you in areas where you need support.*

GD2 (2020): *Expectation for schools develop rules and policies, including a code of conduct for ICT usage i.e., cell phone usage in school.*

The above statements show that there is knowledge about a positive school culture (see P1, 2020) and how it can be developed. However, there is an expectation that this must be championed by schools, which is possible if schools are supported by the district and provincial departments.

What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools? [A3.4]

No response.

Please add any other teaching experience and expected outcome issues not mentioned in this list. [A3.5]

No response.

5.3.3 Leadership in the implementation of digitally supported teaching of secondary mathematics in schools

Please refer to or mention how national, provincial, and local (district/school) administrators provide guidance to schools to implement digitally supported teaching [Question B]: *In what ways is the national and provincial government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B.1) In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B2) What are other leadership concerns the necessary during the implementation of digitally supported teaching of secondary mathematics in your school? (B3)*

In what ways is the national (B1) and provincial government (B2) providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools?

Below are some of the responses from academic experts and teachers.

GD1 (2020): *They're really trying very hard. I can honestly say you know they send us for training on different things … They've said but how do we use technology how to set papers, how do we use technology that learners can use their phones in the class. So, they really try very hard from head office side which means that it comes from national as well … You give them stuff and you never see them use it. I'll be begging for advanced Excel training …*

GT1 (2020): *The national and provincial departments do not offer training on ICT integration. Mainly mathematics content training. Tablets for Grade 11 and 12.*

GT2 (2020): *With me I would say in terms of providing the resources it's there. You know they will provide you with all the resources but training I think there's still lack of training you know. So I'll prefer that if you support the school by giving it all the resources that are there and also support it by giving training. Skills and development into how best we can use those resources so but again I think they are mostly focused again on what you call grade 10, 11 and 12 efforts. To a small extent they are not fully supportive I'm not sure I think they've been doing overall saying this year we're doing grade 12, 11, 10 so it's slowly getting into 8 and 9. Workshops on the part of digital and on the part of digital technology. I think that is one part that we really need … I mean it's just the area we are changing from traditional way, traditional teaching methods to digital teaching method. Then as you know most learners now in the 21st century most of them have moved now to e-learning you know. The way things are being taught with experiences that we have now for the COVID-19.*

GT3 (2022): *National and provincial we get documents.*

GP1 (2020): *They do have a directorate on ICT and technology and stuff like that but because they once came to the school to come and see what we are doing and so on. So, in terms of them supporting, remember unfortunately there's protocol, they can't just leave their offices and come directly to this but according to the discussions we had with a gentleman he was saying they wanted to come and see how it works in primary, so they want to roll it out throughout the country. So, for now I would say nationally the strategy is not yet there. Unless they're working on something for now, but the province has managed to give our teachers tools but not everything that they would require.*

GD2 (2020): *There are 15 districts that have a grade 8 and 9 (senior phase) mathematics one coordinator for national to district. Organises workshops. People must assist teachers to apply what they have learned in schools (class).*

The above statements show that both the national and provincial departments do provide support in terms of training and providing resources to schools. However, there are limitations such as a lack of training on how to integrate digital technologies for teaching mathematics (the focus is on content only), applying what was learned in class, and limited support. The in-class support to teachers, particularly for technology integration, is important as this new paradigm requires thorough preparation considering the content to be delivered.

In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B3)

Below are statements regarding the local district guidance.

GT3 (2022): *District we get materials.*

GP1 (2020): *Ah it is still doing a wonderful job … our gadgets are functional, if they're not functional we have to liaise with them and then we'll send them there. But in short, they are very good conduit between us and the province.*

GD3 (2022): *The district does provide workshops and have employed internes (two ICT champions) in each school and teach teachers on one-to-one basis. Other initiatives include ICT coordinators, interns responsible for schools (through the Mathew Goniwe School of Leadership) and subject advisors are trained to support school on ICT integrations. Challenges include unions who do not want training to happen during school holidays.*

These statements show that schools work very closely with district offices and liaise with them regarding day-to-day issues. This means that the training of district officials can influence the implementation of any shifts that are required in the education system, including the use of dynamic software tools, and associated digital pedagogies.

5.3.4 School digital infrastructure

Please mention or comment on the following issues related to school digital infrastructure [Question C]: *What kind of internet connectivity do you have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why? (C1) What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why? (C2) What type of devices, applications and content does your school have for digitally supported teaching of secondary mathematics? Why? (C3) Comment on any other relevant school digital infrastructure issue. (C4)*

What kind of internet connectivity do you have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why? (C1)

Below are some of the responses from academic experts and teachers.

GD1 (2020): *We don't have internet … It is for the office [for administration].*

GT1 (2020): *Internet connectivity available – admin, teachers, and laboratory for grades 11 and 12.*

GT2 (2020): *I'd provide some work sheets you know send them to the WhatsApp groups and ask the learners after school go to the area where it is because the way the Wi-Fi has been connected it is so that it does not reach that class. Then they must come closer to the staff room access their Wi-Fi so they can be able to download whatever sent to them.*

GT3 (2022): *Wi-Fi is available.*

GP1 (2020): *They don't even have access to Wi-Fi so now the only time they have access to Wi-Fi is when they are in school. So, we resorted to WhatsApp, and you know teachers were teaching via WhatsApp and stuff like that.*

GD2 (2020): *Dedicated for grade 12 and is password-protected. No access or restricted internet connection. Reported internet issues are away from the town. Reasons: (i) community issues (destruction/vandalism) and (ii) safety issues (for companies installing in the townships).*

GD3 (2022): *Connectivity is managed via the Department of e-Government (Gauteng Broadband Network), with dongles being supplied to schools and routers for e-tutors (for live tutoring). School's a free Wi-Fi zones, CSI for schools and content zero-rated. Challenges include loadshedding on 80 percent of the connected schools.*

The comments above show that a technical architecture is needed to address issues around internet connectivity, including physical security and coverage.

What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why? (C2)

Below are some of the responses from academic experts and teachers.

GP1 (2020): *I don't know what you call it, but it becomes a little bit slow so now yeah, we're trying to see what we can do. But I just had a gentleman who is interested in putting up a tower … The admin staff can also have their own because what we saw was when they come in during lunch, they need to start being slow. So, we found oh that means maybe it's overloaded.*

GT3 (2022): *Up and down.*

The statements above show that the quality of internet connectivity is poor and needs to be improved. Where internet connectivity is available, it is slow, particularly around lunchtime because it is overloaded (GD1, 2020). GP1 (2020) states that internet connectivity is intermittent at times (D2, 2020). GD2 noted a lack of technical support since the school is a non-ICT school and a non-fee-paying school (and thus has a limited budget).

What type of devices (C3), applications (C4), and content (C5) does your school have for digitally supported teaching of secondary mathematics? Why?

Below are some of the responses from academic experts and teachers.

GD1 (2020): *There are no data projectors no laptops. Look if you're in the class the only classes that will be having the smart screens will be the grade 12 classes. They don't share with grade 8 and 9s … You know a simple laptop with a data projector would be nice, for me. In the beginning, forget about the* *smartboards and the stuff. You know, just a data projector and a laptop that can connect to it. It will be such a huge beginning. No apps.*

GT2 (2020): *It's mostly laptops … For learners no laptops have not really been provided the teachers do have the laptops … We do use the lab. Our digital room where we take learners to that room so they can be watching all the digital lessons that they might be explained through you know. … We do have cell phones learners normally use their personal cell phones to connect.*

GT3 (2022): *No devices for Grades 8 and 9, only models. Laptops and tablets for Grade 12. GeoGebra is also available.*

GP1 (2020): *No grade 8s, don't have devices … Yeah 8 and 9 don't have devices. I think even at university I also did not do geometry at university. But you still have to cover other topics as well.*

GD2 (2020): *Senior officials should see grade 8 and 9 will go to Grade 12 (they will be used to these gadgets by then) … The disadvantage of plotting in a book you have to plot and re-plot graphs. Although it is also important, technology can take a step further to ensure dynamic manipulation of parameters to notice the effect.*

GD3 (2022): *Slogan is one teacher, one laptop, one learner, one tablet, one school, one connectivity. Laptop for teachers and tablets for learners … apps include MySDLR (my Supplementary Digital Learning Resources), multimedia content programming languages for IT.*

The above statements show that there are no applications available for grade 8 and 9 teachers, and a lack of remote platforms (GD1 and GT2, 2020). GT1 (2020) indicated that there was a WhatsApp group for grade 8 and 9 teaching, and that one teacher was using GeoGebra (on their own initiative). GP1 (2020) noted that apps like Excel and PowerPoint were not used but indicated that there was a desire to know how to use dynamic software tools like GeoGebra and Sketchpad. Regarding content, GP1 (2020) pointed out that there is a mismatch between university mathematics and school mathematics, noting that geometry is not taught at university.

Comment on any other relevant school digital infrastructure issue. (C4)

The emergent dimensions of the social challenges encountered are briefly outlined below.

5.3.6 Security

GT3 (2022): *Weapons are searched and recovered by security. Also fights from the township make their way to the school. Police are invited to search the school, including parents.*

5.3.7 Poverty

GD3 (2022): *Poverty (devices are sold), muggings/robbery and lack of adoption (laggards donate to their university children). Return on investment i.e., LED board cost around R100,000 and a laptop around R8,000 while utilisation is minimum.*

5.3.8 Technical support

GP1 (2020): *Technical support is a challenge.*

GP1 (2020): *School break-ins during holidays can be prevented if community can benefit, then they can protect the school i.e., Wi-Fi for nearby community for safety.*

5.3.9 Teacher professional development

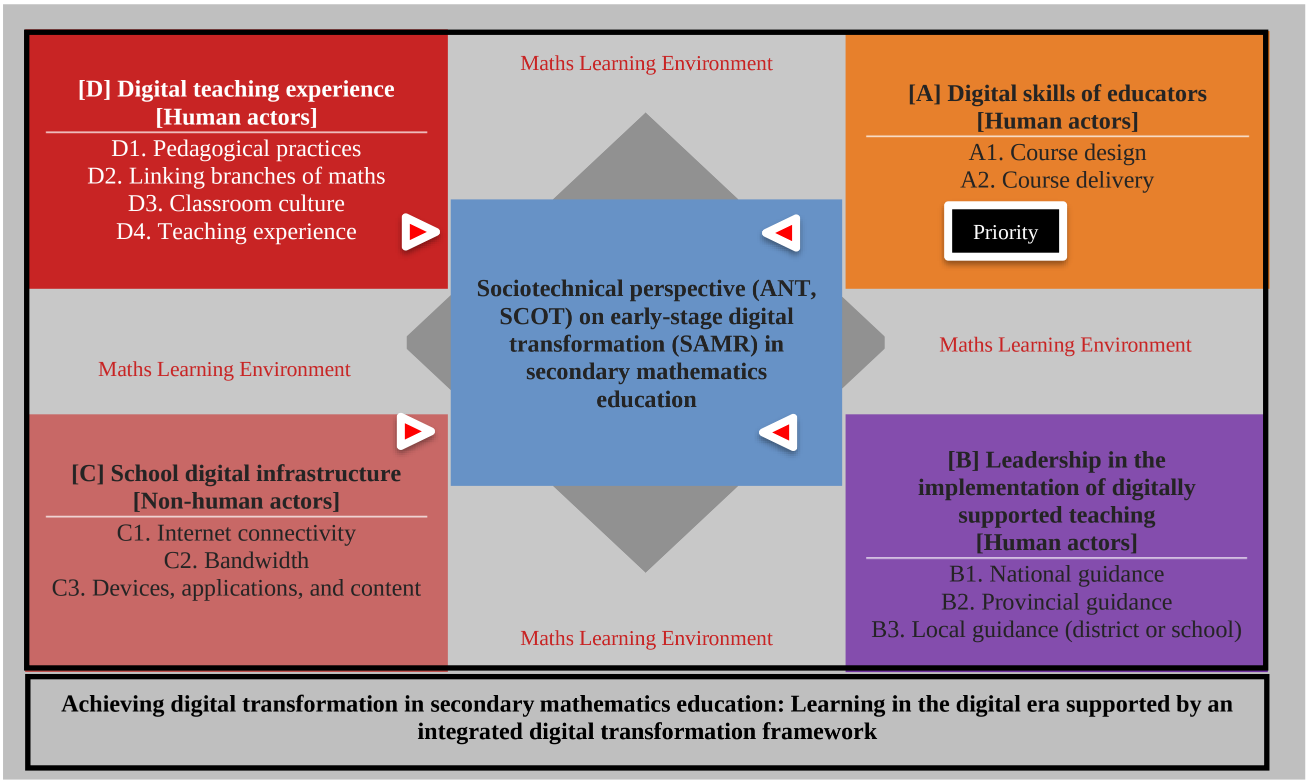
GP1 (2020): *I said come and see how I do things and incorporate that if you can in your lessons as well. And then gradually I moved out now she can find her way around. That's why I was so pleased when the teacher came to me and said I am going to take the grade, because we do have revision timetable in between exams.*

The above statements show that there are challenges associated with the rollout of digital infrastructure in school; these include security, poverty, technical support, and a disconnect between university and high school mathematics.

5.4 CHAPTER SUMMARY

This chapter provided evidence that educators lack digital skills (intermediate and advanced), and there is a lack of technical architecture to address issues of connectivity (i.e., support, security, coverage, intermittent connectivity, and devices, among others). Various initiatives such as Gauteng Online aim to address school connectivity. There is also a lack of a formal governance structure to hold key role-players accountable during the design, development, and implementation of digital education policies, as well as the continued use of teacher-centred pedagogical approaches. The disconnect between university and school maths (classroom practice) was also raised. In Figure 32 the red arrows show the limited contribution of the four dimensions to the shifting of digital transformation in secondary mathematics education beyond the early stage.

Figure 32
DT-SME framework for case study B – GDE schools



The next chapter examines government policy documents that espouse the use of digital technologies for teaching secondary mathematics and presents the perspectives of independent experts (academics who did not form part of the two case studies).

Chapter 6: The Use of Digital Technologies for Teaching Secondary Mathematics Espoused by the Government Policies and Perspectives from Independent Experts

6.1 INTRODUCTION

The previous chapter reported on the data that was collected from case study B (GDE) in order to answer the study's research question to determine the approaches for shifting digital transformation in secondary mathematics education beyond the early stage. The purpose of this chapter is to report on the data that was collected from seven key government policy documents and independent experts in order to respond to the study's research question which seeks to determine approaches that can be used to shift digital transformation in the teaching of secondary mathematics beyond the early stage. The government policy documents and the independent experts are presented in this separate chapter as they do not form part of the two case studies.

Structurally, the chapter consists of three thematic sections with relevant sub-sections. The first section provides an overview of the seven key government policy documents: (i) the White Paper on e-Education Policy 2004; (ii) the Guidelines on e-Safety 2018; (iii) the Professional Development Framework for Digital Learning 2018; (iv) the Mathematics Teaching and Learning Framework 2018; (v) the National Broadband Policy 2013; (vi) the Professional Learning Communities 2015; and (vii) the draft Curriculum and Assessment Policy Statement for Grades 7–9 – Coding and Robotics. The second section provides the perspectives of the independent experts on the four specific dimensions of the DT-SME framework (i.e., digital skills of educators, leadership in the implementation of digitally supported teaching of secondary mathematics, school digital infrastructure, and digital teaching experience). The chapter concludes with the chapter summary and the focus for the following chapter.

Figure 33 shows the flow chart for Chapter 6.

Figure 33
Chapter 2 flow chart

Chapter

6. The use of technologies for teaching secondary mathematics espoused by the government policies and perspectives of independent experts
6.1 Introduction
6.2 Results from the analysis of key government policy documents
6.3 What government policy documents say about digital transformation in education
6.4 What the independent experts say about digital transformation in education
6.5 Chapter summary

The sociotechnical perspective will be provided by the actor-network theory (ANT) on human-related attributes (digital skills of educators, leadership, and digital experience) and non-human-related resources (school digital infrastructure) while the social construction of technology (SCOT) theory will be used to analyse technology usage in schools. Table 11 lists the independent experts (IEs).

Table 11
Independent experts (human actors)

Date	Pseudonym	Role	Location

3 February 2022	IE1	Independent expert – ICT in education	Virtual
23 June 2022	IE2	Independent expert – ICT in education	Virtual
23 June 2022	IE3	Independent expert – Digital learning	Virtual
23 June 2023	IE4	Independent expert – Digital learning	Virtual
27 June 2022	IE5	Independent expert – Maths education	Virtual
18 January 2023	IE6	Independent expert – Maths education	Virtual
14 February 2023	IE7	Independent expert – Education	Virtual

Source: Author, 2023

6.2 RESULTS FROM THE ANALYSIS OF KEY GOVERNMENT POLICY DOCUMENTS

Document analysis is a systematic way of reviewing and evaluating documents that include adverts, agendas and minutes, media statements, and public records (Bowen, 2009). The process of analysis entails carefully reviewing obtained documents (DCs) to interpret and extrapolate meaning from their content. The objective of this study is to investigate approaches to shifting digital transformation in secondary mathematics beyond the early stage i.e., using technology in a transformational manner in the teaching and learning of mathematics in secondary schools in South Africa. In particular, the study investigates the role of the study's dimensions (Ds), namely digital skills of educators (D1), leadership in the implementation of digitally supported teaching (D2), school digital infrastructure (D3), and digital teaching experience (D4). Table 12 lists the government policy documents and analysed data.

Table 12
Government policy documents and analysed data

Government policy document	Analysed data
DC1: White Paper on e-Education (DBE, 2004)	D1: Digital skills of educators D2: Leadership in the implementation of digitally supported teaching D3: School digital infrastructure D4: Digital teaching experience
DC2: Guidelines on e-Safety in Schools (DBE, 2018b)	
DC3: Professional Development Framework for Digital Learning (DBE, 2018c)	
DC4: Mathematics Teaching and Learning Framework (DBE, 2018d)	
DC5: National Broadband Policy (2013)	
DC6: Professional Learning Communities (DBE, 2015)	
DC7: Draft Curriculum and Assessment Policy Statement (CAPS) Grades 7–9: Coding and Robotics (DBE, 2021a)	

(i) **White Paper on e-Education (DBE, 2004) – Government Gazette No. 26734 (Notice 1922 of 2004)** – focuses primarily on the GET (primary and secondary) and FET institutions

This was developed by the South African Government and was signed by the then Minister of Basic Education, Ms Naledi Pandor. The document comprises 46 pages covering aspects of teaching and learning in the General Education and Training (GET) phase, which includes primary and secondary school, as well as the Further Education and Training (FET) phase, which comprises grades 10 to 12. The document is written in formal language and refers to other policies that are relevant in the rollout of digital school infrastructure, such as the Telecommunications Act 103 of 1996, as amended in 2001. The use of technology for teaching and learning is discussed in three pages in chapter 3. The goal of the policy is that "[e]very South African learner in the general (primary and secondary) and further education and training bands will be ICT capable (that is, use ICTs confidently and creatively to help develop the skills and knowledge they need to achieve personal goals and to be full participants in the global community) by 2013." The document is old and still uses the term "ICT".

The document does not focus separately on the primary, secondary, and tertiary levels as these levels have different needs. According to Conrads et al. (2017), digital education policy initiatives focus on virtual learning environments and cloud computing in primary education; there is a strong tendency towards integrating laptops, netbooks, and tablets into teaching in secondary education; and MOOCs and e-learning are mainly used in tertiary education. For primary and secondary education, the document does not state how this goal will be achieved. The document was developed in response to the digital divide agenda that is focused mainly on access to digital infrastructure.

Key evidence from this document:

- **Digital skills of educators:** Only refers to technical skills.
- **Digital teaching experience:** The document mentions the intention enable the use of ICTs to extend and enrich education experience across the curriculum.
- **Leadership in the implementation of digital supported teaching:** The document mentions that educational leaders at all levels (national, provincial, district and institutional).
- **School digital infrastructure:** The document only refers to access to reliable infrastructure

(ii) **Guidelines on e-Safety in Schools: Educating towards responsible, accountable, and ethical use of ICT in education (DBE, 2018b)** – focused on the e-safety of teachers, learners, and management

The document was developed by the South African Government and was signed by the current (as at 2024) Minister of Basic Education, Ms Angie Motshekga. The document comprises 72 pages and mainly discusses issues related to ICT access in schools, and responsibilities and strategies for managing ICT access in schools. This document is written in formal language and replaced the Draft Schools Safety Policy of 2010. The document considers the South African Schools Act 84 of 1996 and the White Paper on e-Education 1994. The document was written recently and suggests mainly five strategies for managing ICT access in schools: (a) acceptable use policies (AUPs); (b) school software security; (c) antivirus software; (d) monitoring software; and (e) document security. The document states that its purpose is to "identify the different ICTs currently used by school communities in particular, teachers and learners and to recommend strategies around managing ICTs for the appropriate and optimum use in, and for, education. This can be done by identifying all role players involved and their role and responsibility toward electronic safety (e-safety)" (DBE, 2018b, p. 7). Its scope applies to all learners, teachers, school management, and school governing bodies (SGBs) in the South African education environment (primary and secondary education).

Key evidence from this document:

- **Digital skills of educators:** The document notes that teachers should be made aware of how to safely teach using the internet.

- **Digital teaching experience:** The document notes that teachers can direct learners to appropriate content and websites.
- **Leadership in the implementation of digital supported teaching:** The document mentions that provincial and district must be mindful of the context which school operate when during the implementation of digitally supported teaching in schools. Also, the district and school level leaders are responsible for ethical and accountable use of technology in schools.
- **School digital infrastructure:** The document mentions the use of antivirus software, monitoring software, and AUPs, among others.

(iii) **Professional Development Framework for Digital Learning (DBE, 2018c)** – focused on ensuring that educators are competent to "use ICTs to enhance teaching and learning" (DBE, 2018c, p. 9)

The document was developed by the South African Government under the current (as at 2024) Minister of Basic Education, Ms Angie Motshekga. The document comprises about 90 pages and mainly discusses the digital learning competencies of educators and the integration of digital tools and resources. The document cites the White Policy on e-Education of 2004 as having the elements for transforming teaching and learning via the use of digital technologies. The document was preceded by the Guidelines for Teacher Training and Professional Development in ICT of 2007. The Professional Development Framework for Digital Learning 2018 is viewed as a new approach to the professional development of teachers and stakeholders who are involved in the improvement of education outcomes using digital tools and content. The purpose of the framework is to "provide guidelines for professional development, specifically to ensure competent educators who use ICTs to enhance teaching and learning and leaders and support staff who are able to facilitate the development of educator digital learning competencies" (DBE, 2018c, p. 9). The primary target audience of this framework is therefore teacher trainers, school leaders and teachers, e-learning specialists, and curriculum subject specialists. The main aim of the framework is to define professional development for digital learning in an education system that seeks to improve access, quality, equity, redress, and efficiency. The document is intended for the primary and secondary education sectors. The document further notes that the achievement of its aims will give rise to the following outcomes in the education system:

(i) Education leaders (nationally, provincially, and at the district and institutional levels) will have a clear plan for professional development in terms of digital learning.

(ii) Teachers in schools will have a clear plan for their individual needs for professional development in terms of digital learning.

(iii) Learners will achieve curriculum goals with the support of appropriate teaching and learning approaches, and the use of digital tools and content resources.

Key evidence from this document:

- **Digital skills of educators:** The framework mentions three digital learning areas and 13 digital competencies.
- **Digital teaching experience:** The document mentions the pedagogical and effective use of digital tools, but only states that teachers can direct learners to appropriate content and websites.
- **Leadership in the implementation of digital supported teaching:** The document mentions that education leaders at all levels (nationally, provincially and district) play an important role during the rollout of school digital infrastructure.
- **School digital infrastructure:** Teachers should be aware of and should be able to use digital tools and resources in class.

(iv) **Mathematics Teaching and Learning Framework – Teaching Mathematics for Understanding (DBE, 2018d)** – focused on guiding teachers to teach mathematics to improve outcomes

The document was developed by the South African Government and was signed by the current (as at 2024) Minister of Basic Education, Ms Angie Motshekga. The document is recent and comprises 92 pages. The framework consists of four dimensions: conceptual understanding, procedural fluency, reasoning, and strategic competence; each of these is underpinned by a learning-centred approach. The implementation of the framework targets in-service and pre-service teachers, subject advisors, teacher educators, and all those involved in mathematics education. The purpose of the document is to guide and assist mathematics teachers in a way that improves learner outcomes.

Key evidence from this document:

- **Digital skills of educators:** The document notes the need to incorporate ICT in the classroom, including the use of software and applications such as GeoGebra and Desmos, citing their potential to promote learners' "conceptual understanding".
- **Digital teaching experience:** The language of learning and teaching (LoLT) is also mentioned as a key aspect in the teaching and learning of mathematics.
- **Leadership in the implementation of digital supported teaching:** The framework should be mediated with all DBE stakeholders across provinces and key institutions.
- **School digital infrastructure:** The document mentions the prioritisation of teacher professional development (TPD) for teachers to develop a deep knowledge of the mathematics content.

(v) **National Broadband Policy – South Africa (SA) Connect: Creating Opportunities, Ensuring Inclusion (DCDT, 2013)** – focused on providing a vision and long-term strategy for broadband connectivity in South Africa

The National Broadband Policy 2013 replaced the National Broadband Policy 2010 and was published by the then Department of Communications (DoC), now the Department of Communications and Digital Technologies (DCDT). SA Connect is a national broadband policy with a strategy and plan that gives expression to the vision in the National Development Plan for the country. The document comprises 62 pages, and its vision is that all South African citizens will have universal access to reliable, affordable, and secure broadband infrastructure and services by 2020. The purpose of the document is to provide a vision and long-term strategy that can be implemented immediately to catalyse broadband connectivity in South Africa. The document defines broadband as an ecosystem of high capacity, high speed, and high quality electronic networks, services, applications, and content that enhances the variety, uses, and value of information and communications for different types of users.

Key evidence from this document:

- **Digital skills of educators:** The document mentions coordination between the DoC and the DBE for the promotion of digital skills.
- **Digital teaching experience:** No evidence.
- **Leadership in the implementation of digital supported teaching:** The document mentions the establishment of institutional capacity in the DBE to enable the uptake and use of broadband in schools.
- **School digital infrastructure:** The internet target was 100% of schools for the year 2020.

(vi) **Professional Learning Communities – A Guideline for South African Teachers (DBE, 2015)** – focused on stimulating and supporting provincial education departments and other stakeholders to set up and maintain professional learning communities (PLCs), and ensure that they work effectively

The document was also developed by the South African Government under the current (as at 2024) Minister of Basic Education, Ms Angie Motshekga. The document has 18 pages and mainly discusses the digital learning competencies of educators and the integration of digital tools and resources. Additionally, the document "is for staff at the provincial and district offices of education and school-based educators" (DBE, 2015, p. 4) and was written in order to promote "the practice of teachers working together … There is also uncertainty about what PLCs are and they should be implemented" (DBE, 2015, p. 4). The document defines PLCs as "communities that provide the setting and necessary support for groups of classroom teachers, school managers and subject advisors to participate collectively in determining their own developmental trajectories, and to set up activities that will drive their development" (ISPDTED, 2011, p. 14).

The document mentions key role-players, namely, teachers, school management teams, districts, provinces, national government, teacher unions, the South African Council of Educators (SACE), and higher education institutions. The document also mentions some of the activities that can be undertaken by PLCs, such as analysis of learners' results, and links these with teaching quality and professional development needs, preparing lessons together, and observing each other and discussing how a certain part of educational research could be conducted, among others.

Key evidence from this document:

- **Digital skills of educators:** The document only refers to district support PLCs on the use of ICT.
- **Digital teaching experience:** The document mentions lesson preparation for team teaching.
- **Leadership in the implementation of digital supported teaching:** The document states that districts should support PLCs on the use of ICT.
- **School digital infrastructure:** No infrastructure is mentioned.

(vii) **Curriculum and Assessment Policy Statement (CAPS) Grades 7–9: Coding and Robotics**

The DBE is in the process of introducing subjects such as coding and robotics, which are related to advanced digital skills in the curriculum, from the lower grades. The DBE states that the objectives of introducing coding and robotics are to provide understanding and develop skills and competencies to prepare for the Fourth Industrial Revolution (4IR). Additionally, the specific aims cited by the DBE are, first, guiding and preparing learners to solve problems, to think critically, to work collaboratively and creatively, to function in a digital and information-driven world, to apply digital and ICT skills, and to transfer these skills to solve everyday problems and their possibilities. The second aim is to equip learners to contribute in a meaningful and successful way in a rapidly changing and transforming society. This shows that the DBE is mindful of coding and robotics as key 4IR-related advanced digital skills that the country requires now and in the future. However, mathematics remains the foundation of both coding and robotics. The document recommends that digital skills, end-user computing, coding, and robotics knowledge and skills be integrated into each subject from grade R to grade 12.

The DBE has since formulated a proposal to incorporate coding and robotics into CAPS for the intermediate phase (grades 7 to 9) in four topics:

(a) **Algorithms and coding** – hybrid coding platform; flow diagrams, logic gates, and truth tables; variables strings, integer, floats, Boolean and lists; mathematical, operational, logic, and relational operators; conditional and nested conditional statements; looping mechanisms; functions and parameter passing; and programming libraries

(b) **Robotics skills** – logical processing steps; mechanical systems including pulleys, gears, and linkages; microcontrollers and components for input and output; hybrid and line-based programming; and CAD

(c) **Internet and e-communication** – cyber threats, security, and authentication; viruses and malware; AI, virtual reality, machine learning, and the Internet of Things; social media; and Big Data and data processing techniques

(d) **Application skills** – end-user skills that are used on different digital platforms. In the senior phase learners will engage with applications that build on data analysis and website development skills. The application skills strand teaches the following skills and content: HTML and CSS and spreadsheet applications.

The DBE notes that these topics have been organised to ensure that the concepts developed in the intermediate phase are reinforced in the senior phase. Table 13 shows the pilots for grades R to 3 and grade 7 coding and robotics pilot schools.

Table 13

Grade R to 3 and grade 7 coding and robotics pilot per province

NO	PROVINCE	NO OF GRADE R to 3 SCHOOLS	NO OF GRADE 7 SCHOOLS
1	EASTERN CAPE	25	111
2	FREE SATE	15	111
3	GAUTENG	33	111
4	KWAZULU-NATAL	33	111
5	LIMPOPO	22	111
6	MPUMALANGA	17	111
7	NORTHERN CAPE	10	111
8	NORTH WEST	15	111
9	WESTERN CAPE	30	111
TOTAL		**200**	**1000**

Source: DBE (2021b)

The DBE has already started to pilot the introduction of coding and robotics in the school curriculum. The pilots are underway for grades R to 3 in all nine provinces in South Africa and are recorded in the draft curriculum document aligned to CAPS for Coding and Robotics for grades R to 3, grades 4 to 6, and grades 7 to 9.

Analytical comments

The analytical comments below are framed around four questions.

What are they saying about the 4IR? Response: In 2021 the DBE published proposed amendments to CAPS to make provision for coding and robotics in grades R to 9 in response to the developments related to the 4IR.

What are they doing about it? Response: After publishing the amendments to CAPS for the inclusion of coding and robotics, the DBE is also planning to conduct a countrywide pilot programme (see Table 23) in about 1,200 schools (200 grades R to 3 schools and 1,000 grade 7 schools).

What is the gap between what they say and practise? Response: There is currently no sight of the final CAPS documents as well as the evaluation report from the pilots on the DBE website. The implementation roadmap gave full implementation timelines of around 2023 for grade 7, 2024 for grades 4 to 6, and 2025 for grade 9. The researcher will also solicit further information from the pilot schools, if possible.

What inferences can be drawn based on the current status quo? Response: The requirements listed for coding and robotics are enormous and it remains to be seen how the DBE will meet these requirements before addressing the similar challenges faced in the introduction of digital teaching and learning of mathematics in secondary schools. What is crucial is the intermediate and advanced digital skills of educators that encourage creating, searching, and using appropriate digital tools for the in-class teaching of secondary mathematics concepts. Coding and robotics are the key advanced digital skills associated with the 4IR, and mathematics is the foundation. Once again, if this is the familiar leapfrogging approach that aims to skip the foundational skills to catch up with developed economies, this may result in people understanding coding and robotics mainly for the consumption of pre-existing products and services.

An example is the introduction of mobile telephony, where leapfrogging was promoted so that developing nations could catch up with developed nations through the introduction of the latest technology generation (i.e., 5G). This has resulted in massive consumption of devices and applications, but with few countries producing devices, applications, and related products and services. This further poses a major threat to the economies of developing countries since product maintenance, support, and spare parts come from outside the countries.

Key evidence from this document:

- **Digital skills of educators:** This document is about developing the advanced digital skills of coding and robotics.
- **Digital teaching experience:** No evidence.
- **Leadership in the implementation of digital supported teaching:** This is a national policy document.
- **School digital infrastructure:** The document mentions the requirements, which include free open-source software for block and line-based coding and free open-source software HTML editor, electronic components, sensor modules and tools, among others.

Evidence shows an awareness of basic digital skills (DC1, DC2, DC3, DC4, DC5, and DC6) except DC7 where an attempt is made to develop advanced skills; this project is still in a pilot phase. The impact on the promotion of intermediate and advanced digital skills will only be evident after implementation. Additionally, the evidence also point to various aspects associated with the rollout of infrastructure in schools, such as the need for reliable infrastructure (DC1), safety online (DC2), awareness of digital apps (DC3), need for training, and 100% internet connectivity in schools. In practice, there is a gap in most of these aspects.

6.3 WHAT INDEPENDENT EXPERTS SAY ABOUT DIGITAL TRANSFORMATION IN EDUCATION

6.3.1 Independent experts’ views on digital transformation in education

This sub-section presents the responses from independent experts in the in-depth interviews.

[Question A0]: The following question was asked during the in-depth interviews: *How do you refer to digital transformation in the education sector (e.g., the use of digital technologies for teaching, learning, administration, other)?*

Below are some of the responses from independent experts (IEs).

IE1 (2022): *ICT in education.*

IE2 (2022): *Use of digital technologies and digital pedagogies in teaching and learning.*

IE3 (2022): *ICT in education.*

IE5 (2023): *Teaching with technology … assumes technology is digital; use of digital tools.*

IE6 (2023): *ICT integration made it possible for a variety of means, including productive software, multimedia devices with the diffusion of personal computers which opened new horizons of the development and implementation of innovative teaching strategies.*

6.3.2 Digital skills of educators

Digital skills for course design [Question A1]

The following question was asked during the in-depth interviews: *Which digital skills of educators should be developed for successful course design in schools, specifically for mathematics education? Please add any other influencing skills not mentioned above.*

Below are some of the responses from IEs.

IE1 (2022): *Lack of digital skills for course design (things are created for them) ... for using devices, particularly in the quintile 1 to 3 schools.*

IE2 (2022): *But also, the skill of instructional design needs to be developed for educators as it guides or helps in the design and development of all types of resources like your lesson plans, your teaching and learning materials, your presentations … There is an overall lack of digital skills. At times it seems because teachers are afraid to integrate ICTs in their learning environments. This is especially with the older individuals – it's like they are afraid that if they press something on a laptop for example that it may explode. Some feel because why change the way I do things or the way I teach if it's working.*

IE4 (2022): *So, to answer your question I don't think they have them, definitely not.*

IE5 (2023): *The younger teachers are able to prepare lessons and older teachers are reluctant to use technology. Technology is not used in all lessons.*

IE6 (2023): *To develop course design in mathematics the teacher must develop the following skills: (1) Technology integration – the ability to use technology to enhance learning with learners to engage in the maths concept; (2) Teacher must understand and use the TPACK (Technological Pedagogical Content Knowledge) model for successful technology integration with learning and teaching of the maths concepts; (3) Digital resource creation – the ability to create digital videos, resources, presentations and simulations to help learners in their learning; (4) Online collaboration – the ability to work with colleagues and learners online through shared documents and online communication platforms; and Edtech tools – Teachers must familiarise themselves with edtech tools, different digital platforms, educational software and collaboration tools.*

IE7 (2023): *Most teachers are able to prepare lessons using technology. Wide adoption is prevalent amongst new teachers.*

Digital skills for course delivery [Question A2]

The following question was asked during the in-depth interviews: *Which digital skills of educators should be developed for successful course delivery in schools, specifically for secondary mathematics education? Why? Comment on the current state of digital skills for course delivery, specifically for secondary mathematics education. Please add any other influencing skills not mentioned above.*

Below are some of the responses from IEs.

IE1 (2022): *Lack of digital skills for course delivery ... The use of PowerPoint and Excel was a surprise to most teachers. Excel only used for data capturing (admin).*

IE2 (2022): *... it is poor. Educators are afraid. Some educators are attending teacher training courses to better their skills and understanding of how to use technologies ... Educators need to be able to read and explore to see what apps there that is out there can make their teaching and learning more efficient. Take doing quizzes in class rather than writing on the board then learners answer then they manually mark then the bell rings and they might not be finish, also the teacher erases it just to rewrite it for the next class ... Rather make use of an app – so the teacher designs and develops the quiz on maybe or Google forms then shares the link with their learners who then complete the quiz, the app then marks it, and immediate real time feedback is provided to both the learner and the teacher.*

IE5 (2023): *The younger teachers are able to deliver lessons using technology and older teachers are reluctant to use technology. Chalkboard is widely used because it works for teachers.*

IE6 (2023): *Skills that should be developed for educators should be the use of PowerPoint where YouTube videos and educational games can be linked into a presentation. Using Excel to draw graphs for interpretation and show how graphs change dynamically when certain variables are changed. Using GeoGebra to draw accurate shapes with values. In MS Word as well as MS PowerPoint how to use equation editor effectively for typing of paper, memorandum, and the use in a presentation.*

IE7 (2023): *Most teachers are also able to deliver lessons using technology.*

The evidence points to the lack of digital skills for course design and delivery. This may be due to the overall prevalence of basic digital skills that can only assist in operating digital tools, particularly in relation to content creation or programming.

6.3.3 Digital teaching experience

Digital teaching experience [Question A3]

The following questions were asked during the in-depth interviews: *How are teacher-centred, learner-centred, and learning-centred teaching strategies working (or not working) in the early digital learning environment? [A3.1] What strengths and weaknesses do you experience in linking different branches of mathematics in a single lesson, or series of lessons? [A3.2] What obligations and expectations (school culture) will need to be met during digitally supported teaching? [A3.3] What is needed for greater teacher empowerment and building your collective identity as digitally enabled teachers? [A3.4] What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools? [A3.5] Please add any other teaching experience and expected outcome issues not mentioned in this list. [A3.6]*

These questions are answered individually below.

How are teacher-centred, learner-centred, and learning-centred teaching strategies working (or not working) in the early digital learning environment? [A3.1]

Below are some of the responses from IEs.

IE1 (2022): *Teacher-centred approaches still prevalent … copying text and pasting slides for presentation … digital adapted to face2face. School culture not supportive in public schools (quintiles 1–3). Quintiles 4–5 schools do make their own adjustments. Hence, they are like private schools.*

IE2 (2022): *It varies between teacher-centred and learner-centred.*

IE3 (2022): *I believe in constructivism. So having teaching and learning environments more learner-centred. And with the use of digital technologies, learning can also become customised. So, educators can use various digital technologies to cater for their learners' learning styles, their pace too basically their overall learning needs.*

We need to move away from the traditional teaching methods where it was teacher-centred, where learners are treated as empty vessels that need to be filled. But rather to teaching and learning environments where learners are actively involved in their learning, they are busy with hands-on activities and activity learning and educators act as facilitators to guide their learners as they are active.

In terms of weaknesses, I think it can be information overload. So, educators need to be strategic on how they demonstrate the linking of different concepts across different topics.

On the plus side, it is important that learners understand the links and integration between topics as concepts across topics can't be seen in silos. And when it comes to a subject like maths or science or accounting, it's important to see the links and relationships as a lot of work is a build-up on previous work and knowledge.

IE4 (2022): *Absolutely, or maybe very tragically so [teacher-centred]. That is what we are trying to address with this all techno-blended approach and within the techno-blended approach there is also very importantly the learner-centred pedagogy strategy … So, I pointed to a techno-blended model. So, we used the term techno-blended just to differentiate it from branded learning which you probably know more about of these.*

IE5 (2023): *Teacher-centred approaches are prevalent. Teacher-centred or learner-centred are neither good nor bad. Linking of different branches of maths in a single lesson is difficult for most teachers due to: (1) scripted lessons received to the education department, and (2) time constraints to finish the syllabus. School culture is supportive in terms of advocacy and not supportive for provisioning of resources … mission to get resources.*

IE6 (2023): *Teacher-centred approach because teachers use mostly only substitution e.g. project an activity from the textbook or just play a video without any interaction. The most common reason for this strategy is learners do not respond to teacher questions. Teachers feel they must continue with the lesson as he/she will be losing out and will fall behind with ATP.*

IE7 (2023): *Blended learning is promoted hence, learner-centred is happening.*

The evidence points to the prevalence of teacher-centred approaches. Several social issues were also reported as follows.

What strengths and weaknesses do you experience in linking different branches of mathematics in a single lesson, or series of lessons? [A3.2]

IE6 (2023*)* *Learners can experience how different skills from different branches of mathematics can be used to solve problems. They can start to think "outside the box" to solve problems. They will also be encouraged to see the hierarchical nature of Mathematics in that skills build on other skills. This is important in developing a better understanding and application within Mathematics too.*

What obligations and expectations (school culture) will need to be met during digitally supported teaching? [A3.3]

What is needed for greater teacher empowerment and building your collective identity as digitally enabled teachers? [A3.3]

IE6 (2023) *Using technology responsibly from both learner and educator. Learners should also be responsible enough not to get distracted when using a tablet for example for self-learning and not Facebook/Instagram. The school will have to adapt their cell phone policy to allow learners to use these devices for educational purposes. Learners will take chances in the beginning but once they see how they can actively learn by using the ICT they will start enjoying it and become more involved and responsible.*

What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools? [A3.4]

IE6 (2023) *When using ICT educators should still ask questions and keep learners actively engaged and make use of a learner centered approach. When teaching with ICT the learners should not only be engaged but also actively involved, for this to be effective we need the learners to have a device (tablet, cell phone)* *or computer in front of them. A blended approach is also necessary such as integrating the digital aspects with written aspects too. This will allow opportunity to cater for different learning styles within the classroom too.*

Please add any other teaching experience and expected outcome issues not mentioned in this list. [A3.5]

No response.

6.3.4 Leadership in the implementation of digitally supported teaching of secondary mathematics in schools

Please refer to or mention how national, provincial, and local (district/school) administrators provide guidance to schools to implement digitally supported teaching [Question B]:

The following questions were asked during the in-depth interviews: *In what ways is the national and provincial government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B.1) In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B2) What are other leadership concerns that are necessary during the implementation of digitally supported teaching of secondary mathematics in your school? (B3)*

In what ways is the national (B1) and provincial (B2) government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools?

Below are some of the responses from IEs.

IE1 (2022): *ICT is a national priority and is political driven (not ground up). There are provincial programmes such as Gauteng paperless schools where the provincial education MECs are at the forefront. Also, there is a disconnect between the pronouncements by MECs and school principals as they have different priorities.*

IE2 (2022): *I am not sure of these. However, I can say that there are policy documents that are put together and shared on public domains. So, like your white papers, your teacher competencies for digital education or your professional development framework.*

IE6 (2023): *Material is made available on a Google drive/Google classroom for educators. SA's districts are developing material on MS PowerPoint that will be shared with educators in province. PLCs for maths curriculum online (MCO) and teacher development sessions are planned to support teachers. Two eLearning advisors and one eLearning projects facilitator support the implementation of ICT across all phases and subjects.*

In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools? (B3)

Below are some of the responses from IEs.

IE3 (2022): *Locally in schools I don't think so. I don't think the principals are really forcing it so much because I feel like if they were, they would have found other methods to work with the lack of infrastructure.*

IE5 (2023): *Coordination is need between the different levels i.e., national, provincial, district, and school. A school level driver of ICT is needed. Currently, ICT is to be from outside and when it broken, the school wait for someone from outside to replace it. There is no sense of ownership by the school that something is broken and how the school can fix it. Advocacy is not realistic i.e., empty promises.*

IE6 (2023): *The WCED has a provincial strategy on e-learning which is driven by districts and schools. This includes provision of infrastructure and devices at selected schools. There are also very good in-service training opportunities for teachers at our provincial training institute, CTLI … Subject advisors advocate the use of ICT in classes. Baseline assessment is done online. Material is made available on e-portals that teachers can use. South Africa's department of basic districts are developing material on MS PowerPoint that will be shared with educators in province.*

IE7 (2023): *ICT committees.*

What are other leadership concerns the necessary during the implementation of digitally- supported teaching of secondary mathematics in your school? (B4)

IE2 (2022) *I think a lack of funding, infrastructure and lack of access needs to be considered too.*

IE6 (2023) *That digitally supported teaching will substitute the teacher (Teacher is in class, but prefer to play a video and then give learners exercise). Furthermore, if the leadership of the school fails to recognize the value of digitally supported teaching of the subject; teachers may well not receive adequate support at school level in order to enforce and implement this approach successfully. There needs to be a top down approach in terms of the vision of digital transformation within the school from the principal to SMT members, to teachers, parents and learners and this should be the driving force of the school community as a whole and not simply left in the hands of one individual which is so often the case.*

The evidence indicates the existence of a gap in policy design, development, and implementation in both the local and the provincial spheres, including a lack of evidence related to the formal governance structure that involves various actors (DBE, DCDT, Vodacom, MTN, USAASA, ICASA, universities, etc.).

6.3.5 School digital infrastructure

Please mention or comment on the following issues related to school digital infrastructure [Question C]

The following questions were asked during the in-depth interviews: *What kind of internet connectivity do you have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why? (C1) What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why? (C2) What type of devices, applications and content does your school have for digitally supported teaching of secondary mathematics? Why? (C3) Comment on any other relevant school digital infrastructure issue. (C4)*

What kind of internet connectivity do you have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why? (C1)

Below are some of the responses from IEs.

IE1 (2022): *Connectivity in most schools is a nightmare. However, there are some innovative initiatives such as remote servers where contend is loaded somewhere and transported back to the school. Quality differs. Devices are lacking (one or two laptops in a school or one old machine). GeoGebra the prevalent app.*

IE2 (2022): *[Internet connectivity] This will depend on the area that the school is situated and that the teachers are from. Also, one will need to consider budgets and funding of the schools and the background of the teacher and learners ... the only problem is that now the lack of infrastructure … [Devices] But what I would say is in your poorest schools there is a lack of devices … middle tier where it is like they got devices but its outdated, its slow, the antivirus has expired, they are sitting there with computers with viruses, trojans and all of that. It's quite scary…*

IE3 (2022): *The only biggest issue that I have is now the issue, does it have internet connectivity, is it you know when a software expires are you able to renew that? It is, what happens when the computer is giving you guys a problem, is there somebody there to assist to troubleshoot those kinds of things. But I think in most of the schools maybe there is some sort of a computer lab or a computer in the school.*

IE5 (2023): *There is an instance in one school where a chalkboard was replaced with a smartboard and then there was no electricity, the teacher had nothing to write on ... this is a result of poor planning. In another school, poor Wi-Fi signal was also witnessed where a teacher had to move around during the lesson to get a stronger signal, which delays the class. Loadshedding has exacerbated the challenge of using technology in class; it contributes to less productivity … alternatives are needed.*

IE6 (2023): *[Connectivity] Most schools still have ADSL connectivity, which sometimes is a problem when interactive videos get played. Because all learners and educators have access to internet at school internet connectivity becomes so slow and videos, don't play or they may not be able to use platforms such as MS teams etc.*

IE7 (2023): *[Connectivity] Broadband network is available to 46 of the 77 schools. Model C schools have their own connectivity arrangement.*

What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why? (C1)

Below are some of the responses from academic experts and teachers.

IE1 (2022): *Quality depends on where you are .*

IE2 (2022): *This will depend on the area that the school is situated and that the teachers are from. Also, one will need to consider budgets and funding of the schools and the background of the teacher and learners.*

IE6 (2023): *Sufficient. Can do what is necessary to support online learning.*

What type of devices (C2), applications (C3) , and content (C4) does your school have for digitally supported teaching of secondary mathematics? Why?

Below are some of the responses from academic experts and teachers.

IE1 (2022): *The popular one is GeoGebra.(C3)*

IE7 (2023): *We have a slogan: One learner, one device; one class, one smartboard. Teachers have laptops; learners have tablets. eBooks are available for both teachers and learners. Math boards are also available. (C3)*

IE6 (2023): *Computers are outdated, and internet connectivity is a problem. Not all educators have access to data projectors in their classrooms. Installation of infrastructure, e.g., air conditioner in lab, electricity, woodwork, burglar bars are expensive and not all schools can afford the additional expenses. Insurance cover (not infrastructure) on devices is expensive and in some instances the devices are not covered. (C2)*

IE6 (2023): *Laptop and projector in class to present lesson. Sufficient audio equipment so that a class of 50 can hear clearly. A set of tablets per math educator so self-learning can take place over virtual platforms. Interactive whiteboard – to make math come alive. (C2)*

IE7 (2023): *My SDLR (Supplementary Digital Learning Resources) is not specifically for mathematics and is available both online and offline from Grade R to 12. Digital lessons for mathematics (video), with features such as mediated lessons, link can be shared, have an assessment option and animation, amongst others. The content is also interactive and includes past question papers.(C3 & C4)*

IE6 (2023): *GeoGebra, Siyavula, math and science lessons. Desmos.*

The evidence points to the absence of technical architecture to address connectivity issues holistically i.e., strategy for devices, local support, and security (online and physical), among others.

Comment on any other relevant school digital infrastructure issue. (C5)

IE2 (2022) *In South Africa, we have beautiful policy, but we lack in the implementation, in the follow through of it.*

IE6 (2023) *Computers are outdated, and internet connectivity is a problem. Not all educators have access to data projectors in their classrooms. Installation of infrastructure e.g., air conditioner in lab, electricity, woodwork, burglar bars are expensive and not all schools can afford the additional expenses. Insurance cover (not infrastructure) on devices is expensive and in some instances the devices are not covered.*

The emergent dimensions of the social challenges encountered are briefly outlined below.

6.3.6 Collaboration

IE1 (2022): *Schools operate as islands. Hence, theft and vandalism are common as there is no buy-in from the surrounding communities.*

Security

IE2 (2022): *So, the one issue I would say is also the whole thing of the resources not being configured, or not being prepared correctly or properly, that is the one. The other one, I mean I heard the story one of my lecturers …, when we were doing master's because he was part of one of these initiatives, I think they were bringing in tablets or computers or something but the first day they set up the lab, they put in the computers, and they locked the burglars. The next day they went, everything was stolen; everything was gone.*

IE5 (2023): *Security in schools. The use of cell phones in some schools is banned. The use of iPad while examinations are handwritten. The use of technology makes people get used to typing but exams are handwritten, which becomes a challenge.*

6.3.7 Corruption

IE3 (2022): *Do you think corruption is the social issue? Because why else when you are going to set up a computer lab and the infrastructure needs to be placed, you know the first thing that you do is that you go and observe the school and like is there a room to keep things, is there a plug to keep these things? Why would you buy things and not even look at the basic things?*

6.3.8 Discipline

IE6 (2023): *[Educators] Discipline – teachers find it difficult to teach where learners are disruptive. Absenteeism – learners who does not attend school due to various reasons – work must be repeated and influence the results.*

[Learners] Gangsterism – learners are involved in gangsterism and/or are affected by gangsterism in urban areas, substance abuse, and bullying.

[Other comment] Theft and vandalism, Cable theft and other damages – the repairs of it are time consume, unemployment – influence the finances of the school, single parent homes, and teenage pregnancies.

6.3.9 Overcrowding and migration

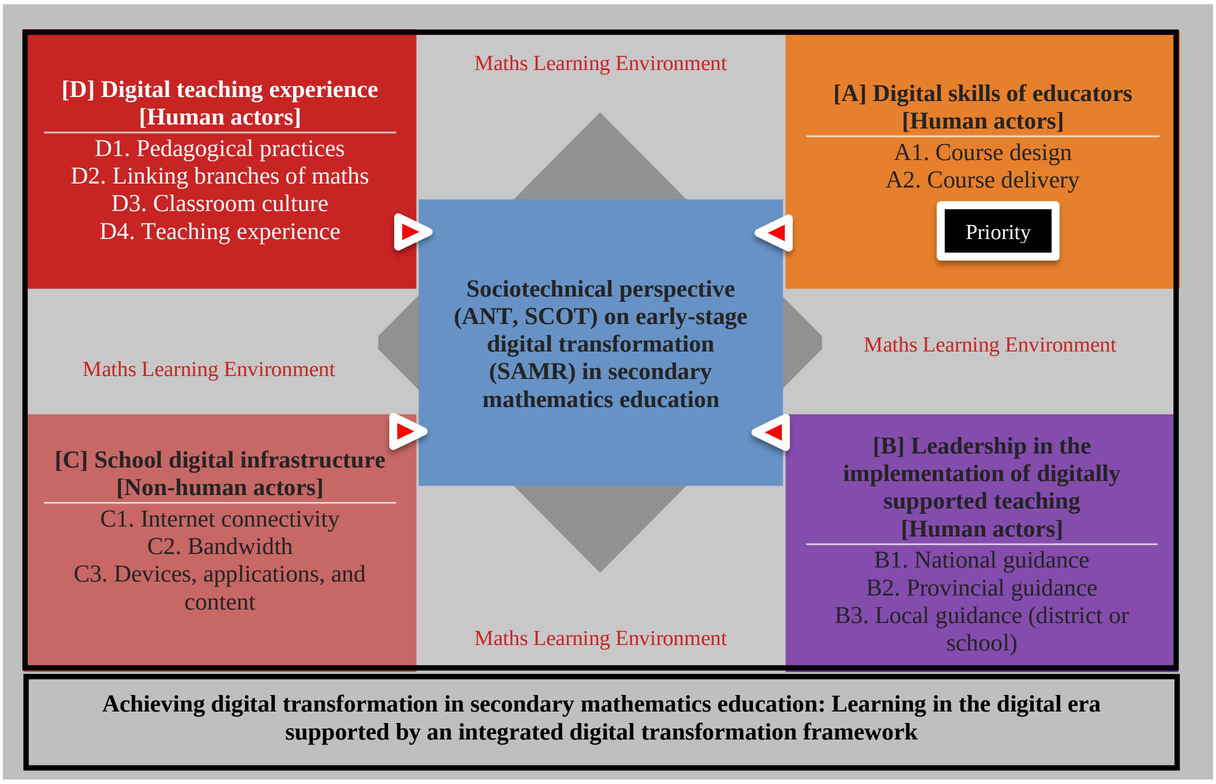
IE7 (2023): *Overcrowding because of migration from other provinces and countries makes it difficult to keep up with the numbers to supply infrastructure and devices. Additionally, inadequacy of teachers' skills development due to time as training must take place outside teaching period. Furthermore, teacher unions challenges refusing training outside school hours. Moreover, management of existing ICT resources due to theft by learners and vandalism. Other issues include lack of innovation by teachers, lack of adoption, particularly by older teachers and lack of motivation amongst some teachers, amongst others.*

The evidence confirms several social issues facing schools.

6.4 CHAPTER SUMMARY

This chapter described the perspectives of key government policies and independent experts. These also show, overall, that there is lack of digital skills of educators, lack of digital leadership, lack of technical architecture to address issues of connectivity, and that teacher-centred approaches are still prevalent. In addition, the inclusion of the 4IR-related advanced digital skills such as coding and robotics in the curriculum was briefly discussed. Also, technology integration was found not to be assessed during the teaching and learning of secondary mathematics in schools. Moreover, the independent experts noted social issues such as theft, vandalism, and corruption, among others. In Figure 34 the red arrows show the limited contribution of the four dimensions to the shifting of digital transformation in secondary mathematics education beyond the early stage.

Figure 34
DT-SME framework for DBE and IEs



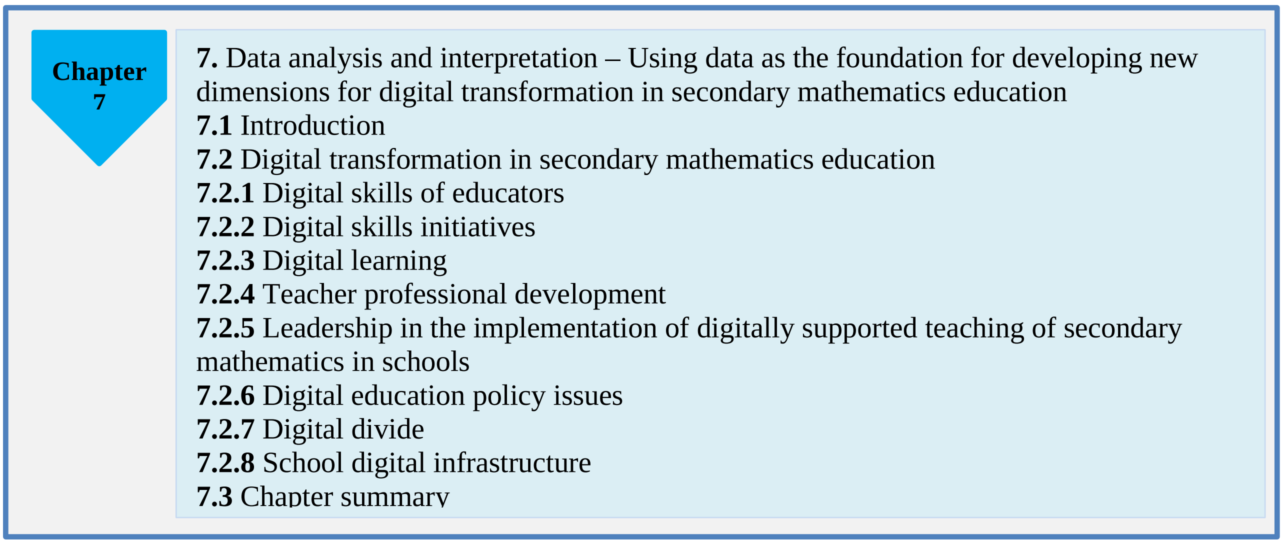
Chapter 7 presents an analysis and synthesis using the data analysis software ATLAS.ti to develop new dimensions for digital transformation in secondary mathematics education.

Chapter 7: Data Analysis and Interpretation – Using Data as the Foundation for Developing New Dimensions for Digital Transformation in Secondary Mathematics Education

7.1 INTRODUCTION

The previous chapter reported on the data that was collected from seven key government policy documents and seven independent experts in order to respond to the study's research question, which seeks to determine approaches that can be used to shift digital transformation in the teaching of secondary mathematics beyond the early stage. The purpose of this chapter is to present an analysis and interpretation of the data collected in this study to answer the research question. As indicated earlier, the analysis mainly uses inductive reasoning by drawing a general conclusion from the data (Saunders et al., 2023), and counter-inductive reasoning to explore other ways of explaining a phenomenon or "taking the way things are within our experience as a guide to how they will not be outside our experience" (Oxford University Press, 2023). Additionally, such analysis is key in uncovering those aspects prohibiting the transformational ways of using dynamic software applications during the teaching of mathematics in secondary schools. This chapter further provides the evidence to confirm this claim and uncovers other additional dimensions from the initial framework. This chapter mainly focuses on revisiting the initial proposed analytical framework comprising four dimensions, namely, digital skills of educators, leadership in the implementation of digitally supported teaching of secondary mathematics, school digital infrastructure, and digital teaching experience. Also included are other contributing emergent dimensions that are key for shifting digital transformation in secondary mathematics beyond the early stage. The actor-network theory (ANT) and social construction of technology (SCOT) perspectives serve as analysis tools for actors (human and non-human) and technology use respectively. The chapter consists of two thematic sections with relevant sub-sections. The first section provides the DT-SME framework and its eight dimensions are described in subsequent sub-sections. The second section provides a chapter summary and the focus for the following chapter. Some of the key codes that were generated in ATLAS.ti can also be viewed in Appendix F. Figure 35 shows the flow chart for chapter 7.

Figure 35
Chapter 7 flow chart



Next, digital transformation in secondary mathematics education (the apex dimension) and the eight dimensions of the research are analysed using both inductive and counter-inductive reasoning, as indicated above.

7.2 DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION

Saldanha (2006) provides guidance on the process to follow towards theory-building, including the initial analytical theoretical framework, by moving from coding the datasets, then developing categories to dimensions that demonstrates the relationships between the dimensions and concepts. Van de Bulk et al. (2019) similarly provide thematic analysis for organising data which consists of the analytical construction of (i) codes, (ii) themes, and (iii) patterns (van de Bulk et al., 2019). Additionally, the authors, citing Braun and Clarke (2006), provided six steps of thematic analysis that were closely followed in this research study, namely:

Phase 1: Familiarizing yourself with your data: This phase entails breaking down the data and searching for patterns of meaning by taking notes and associating interviewee statements with other data i.e., production of transcripts from the interviews.

Phase 2: Generating initial codes: These are labels assigned to data segments relevant to the research questions. Due to the high volume of materials obtained during the research, the researcher decided to use the qualitative data analysis (QDA) software ATLAS.ti to code the data and to assist with organising the data for analysis. A total of 48 documents were collected and were grouped as follows: government policy documents (7), interview transcripts (11), memos from case study A (3), and correspondence in case study A (21). The research study generated 771 quotations, 259 codes, and 31 networks. Appendix F lists the complete list of codes that were generated by breaking down the data gathered into individual ideas and concepts using ATLAS.ti. Although ATLAS.ti 9 was useful for data manipulation, a significant amount of researcher interpretation was present.

Phase 3: Searching for themes: This is where the coded data is organised under specific themes, starting with the four themes from the initial analytical theoretical framework of the study, namely digital skills of educators, leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience.

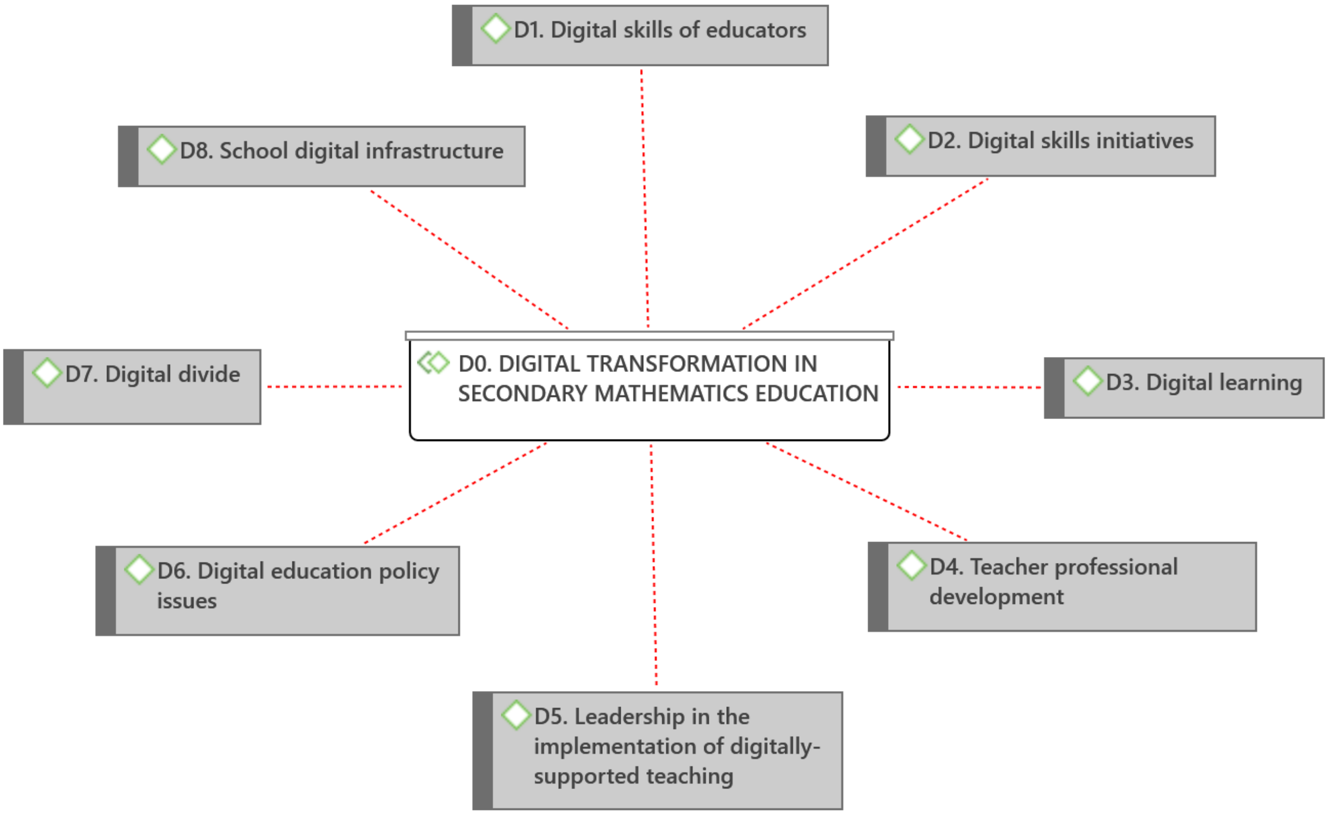
Phase 4: Reviewing themes: This entails organising themes meaningfully and discarding what is not relevant.

Phase 5: Defining and naming themes: The names of themes are reviewed and specified in this phase i.e., what does the theme indicate to us that is relevant to the research question? How does it fit into the overall story that the researcher wants to tell about the data?

Phase 6: Producing the report: This is about documenting all the phases from phase 1 to 6. “Throughout the process of analysis the researcher simultaneously deals with the whole data set, the data extract focused on at any one point in time and the analytical report which is produced. This requires the researcher to move constantly back and forward. The final report should contain such data extracts as interview quotes which best represent a particular theme that emerged from the analysis” (Van de Bulk et al., 2019, p.395-396).

The apex dimension of digital transformation in secondary mathematics education comprises eight dimensions (building on the four dimensions of the initial analytical theoretical framework) that are theorised to be key for shifting digital transformation in secondary mathematics beyond the early stage. These dimensions include (D1) digital skills of educators; (D2) digital skills initiatives; (D3) digital learning; (D4) teacher professional development framework; (D5) leadership in the implementation of digitally supported teaching; (D6) digital education policy issues; (D7) digital divide; and (D8) school digital infrastructure. Figure 36 shows the eight dimensions for shifting digital transformation in secondary mathematics education.

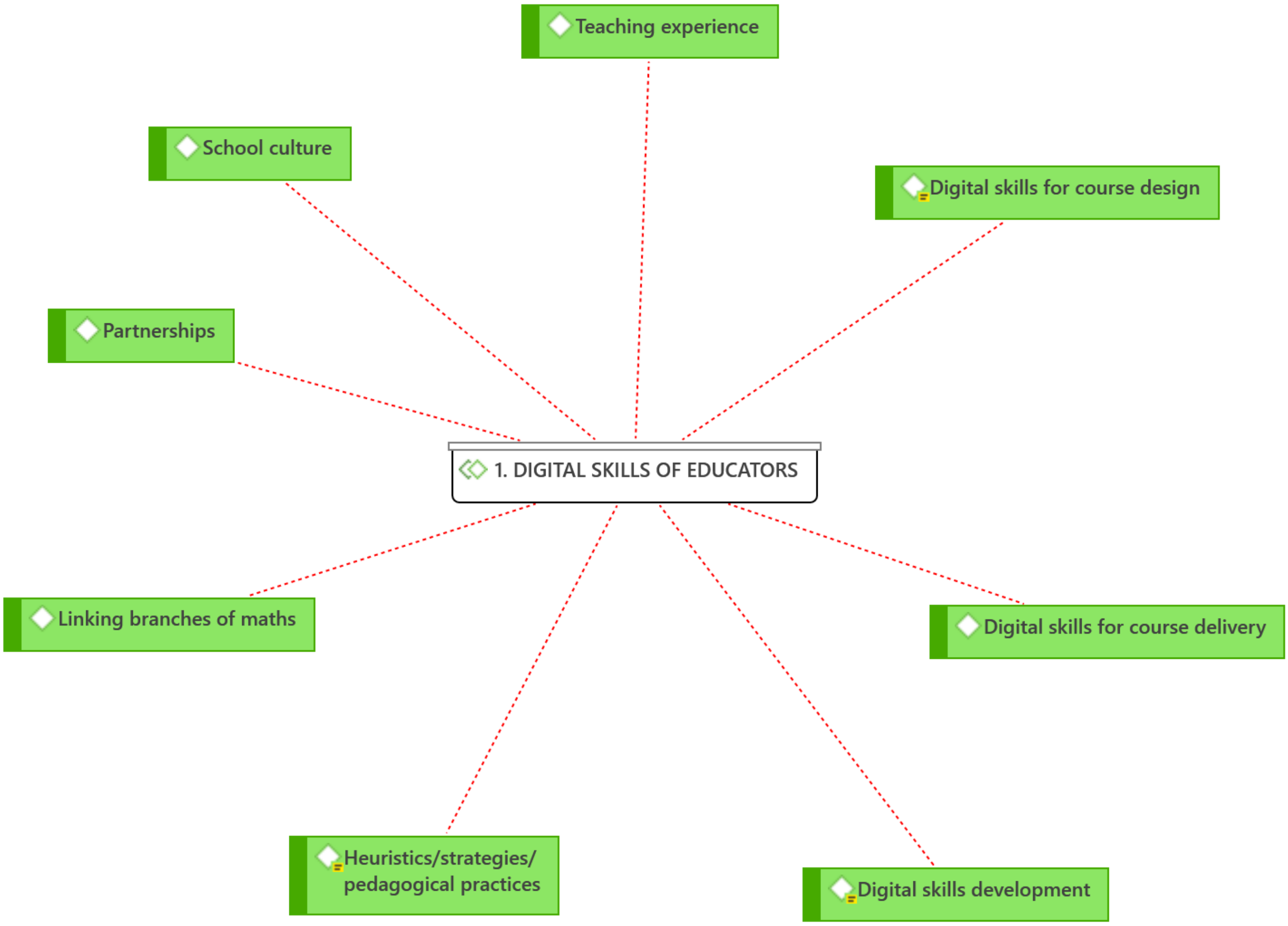
Figure 36
Digital transformation in secondary mathematics education



7.2.1 DIGITAL SKILLS OF EDUCATORS

This dimension is about various aspects of the digital skills of educators (see Figure 37) that include digital skills for course design, digital skills for course delivery, digital skills development, pedagogical practices, linking branches of maths, school culture, teaching experience, in-service training, and partnerships. The digital skills of educators are the main focus of this study and other dimensions (i.e., leadership in the implementation of digitally supported teaching, school digital infrastructure, and digital teaching experience) are considered as they relate to digital skills. Figure 37 shows the digital skills of educators.

Figure 37
Digital skills of educators



The dimension "digital skills of educators" includes digital skills for course design, digital skills for course delivery, digital skills development, pedagogical practices, linking branches of maths, school culture, teaching experience, in-service training, and partnerships.

D.1.1 Digital skills for course design – inductive reasoning

The responses show, overall, that there is a lack of digital skills for course design, although there is an awareness of these skills. In particular, there is a lack of digital skills for designing the teaching of mathematics using digital technologies such as GeoGebra, Desmos, Sketchpad, Microsoft programs (Word, Excel, PowerPoint, etc), overhead projectors, and calculators, and for understanding the affordances, including the appreciation of the value of using digital technologies across the sector. Teachers received lesson plans that were already prepared; hence there was no need for designing lessons, particularly using technology.

E2 (2021): *Teachers don't design lessons, they take their cue from the workplan which they like to call the curriculum and textbooks, so they would mostly select three or four problems to do and usually those are already available for download, or they copy it from textbooks, hardcopies.*

WT1 (2022): *No, I wouldn't say they don't use. Like we have got a media centre and most of them, we have a system where you need to prepare your lesson plans two weeks in advance and that must be submitted to our deputy principal that handles the curriculum.*

WT2 (2022): *I would say that it's a yes and a no. The yes would be according to using Word and Excel and all of that program to form a lesson, then yes, to form a lesson, to type up a physical lesson then that is fine. But the no would be using GeoGebra or Sketchpad because all teachers are not familiar on how to use the programs.*

GD1 (2020): *Not in grade 8 and 9. Grade 8 to 9 they want lesson plans from other people … They don't want to do their own lesson plans, so they rely on whatever comes from head office.*

GT1 (2020): *Design classwork and homework at home so as not to waste time.*

GT3 (2022): *Create graphs and shapes using GeoGebra.*

Counter-inductive reasoning: There are several challenges associated with digital skills for course design. These challenges include lack of digital skills for course design, partial use of digital tools, underdeveloped digital skills for course design, preparation of lessons at home, and a need for training on digital tools. Additionally, digital skills for course design are related to the creation of resources for teaching mathematics such as lesson plans, dynamic software applets, spreadsheets, PowerPoint slides, and Word, amongst others. Furthermore, advanced online search, the creation and presentation of teaching material, including the use of dynamic software tools, require intermediate and advanced digital skills (i.e., programming).

The possible reason why there is a lack of intermediate and advanced digital skills related to course design, particularly in the education sector, is the fact that most educators are older and did not have training opportunities during their pre-service training. The other reason might be a lack of clear categorisation of digital skills (basic, intermediate, and advanced) that is linked to application. This is also closely linked to the misalignment of the pre-service training of educators and classroom practice i.e., if teachers are not trained during their teacher training, this will result in a lack of preparedness to integrate digital technologies in class. Furthermore, the word "enhancement" is used loosely to mean technology use or integration, not necessarily the levels of technology integration advocated in this study, such as Puentedura's (2006) SAMR model.

D.1.2 Digital skills for course delivery – inductive reasoning

Some of the responses related to digital skills for course delivery show that these skills are limited.

E1 (2021): *For successful course delivery I think that teachers need to be very comfortable with multiple software brands if I could call it that.*

WT1 (2022): *What I am saying is that delivering the lessons with computer devices and electronic devices, technology devices, that is a challenge at my school.*

The following comment from GD1 illustrates how the school is still learning:

> *Look, I tried the other day to show some of the teachers know how to draw graphs … So, I tried showing them how to do it using Excel. There is an encouragement for teachers to use Excel. Advantages of using Excel include performing diagnostic analysis to zoom into every question and find out how learners performed in this question. And why they are performing so that the data is not just data but becomes information. Schools are still busy with mathematics content. Look at the moment you're still fighting with teachers regarding content delivery. The traditional way of doing things is still prevalent because teachers use chalk. The DBE provides teachers with already designed material.*

Counter-inductive reasoning: There are several challenges associated with digital skills for course delivery. These challenges include limited exposure to digital tools, limited use of digital tools, limited ability to use digital tools, and inadequate devices for course delivery. Digital skills for course delivery entail the presentation of lessons using dynamic software applications such as GeoGebra, Geometer's Sketchpad, and Desmos, including MS programs – Excel, PowerPoint, and Word, among others. Thus, teachers need training on how to use digital technologies for presenting lessons using dynamic software tools which require intermediate and advanced digital skills (i.e., programming). The misalignment of teachers' university training and classroom practice is also applicable to digital skills for course delivery as these skills must be embedded in pre-service programmes for teachers to be confident about implementing them in the classroom, coupled with the availability of related infrastructure.

Emergent sub-dimensions

D1.3 Pedagogical practices – inductive reasoning

The responses show the continued use of teacher-centred pedagogical approaches. This was attributed to teachers' need to be in control of the classroom, large class sizes, and teachers wanting to get something accomplished or get the work done, among others.

WT3 (2022): *Teacher-centred approach still prevalent. The PP: ADS short course has shown me how to improve my teaching approach … to first probe learners about what they already know.*

WT4 (2022): *Teacher-centred approach common.*

E1 (2021): *Definitely, teacher-centred … They don't have the experience of using digital technologies and dynamic software in the classroom.*

E2 (2021): *I think still teacher-centred. It depends on who judges. Even with the use of technology most of what I see is still exposition, just style it's not engaging learners.*

Counter-inductive reasoning: The challenges include the need to adopt a range of pedagogical approaches to improve the potential of digital tools and resources, the lack of digital pedagogy, the lack of learner-centred teaching due to large class sizes, the lack of knowledge of learning-centred approaches, the need for a pedagogy shift to learning-centred approaches, the need for training to improve digital pedagogy, the need to deepen digital pedagogy, the prevalence of teacher-centred approaches, and failure to use of learning-centred approaches. A frequent explanation for the prevalence of teacher-centred approaches was large class sizes. Teacher-centred approaches result in passive learners, even if the teacher is using dynamic software applications linked to transformational ways of secondary mathematics teaching and learning, meaning that the learning gains are constrained. This study suggests that digital pedagogy is optimised when learning-centred approaches are adopted, intermediate and advanced digital skills are available, and the SAMR transformation stage is applied. Currently, teachers are expected to be able to use transformational ways of digital teaching for secondary mathematics while they possess basic digital skills, which is nearly impossible.

Furthermore, even in instances where pre-configured dynamic software tools are provided (which is the case in the other university initiatives) and readily available for use, if there is no pedagogy shift to learning-centred approaches, the net effect will be minimal due to the passivity of learners (in the case of teacher-centred approaches) or misdirected learners, (in the case of learner-centred approaches). However, clear guidance and instruction during learner-centred approaches in the form of a flipped classroom can provide some advantages, particularly to independent learners with the necessary digital tools and resources.

D1.4 Linking branches of maths – inductive reasoning

There is knowledge about linking different branches of mathematics in a single lesson, but the current practices showed that this was not being done. In practice, algebra and geometry are taught separately or in separate terms of the year. Participants were asked about the perspectives on linking various mathematics topics in a single lesson and their responses are provided below:

E2 (2021): *Well, I think it's always important because understanding comes from making connections and understanding mathematics fully comes from making connections. It is no use anymore today to teach the circle in circle geometry and to teach it in an analytical geometry or give a formula for the relation that's a circle and the two never meet. You know it's unfortunate it still happens, but it mustn't.*

WT2 (2022): *So, yes, I would say we do integration between different topics. Sometimes we try to do it with different subjects, but it doesn't always work. I would say the strengths is that when the learner understands the basic or the core of the topic, it would be easier for the learner to understand the next one.*

Counter-inductive reasoning: There is a general lack of linking of different branches of mathematics in a single lesson or series of lessons, although there is knowledge about it and its advantages i.e., this makes it easier to understand the other topics, including problems, if one topic is not understood. The current curriculum is rigid, sequential, and does not allow for the linking of different branches of mathematics in a single lesson (the lesson topic sequence has been predetermined and must be followed). Additionally, assessment practices call for a certain topic to be covered at a particular time of the year, making it difficult to link different topics that fall into different time periods.

Although it is understandable that various concepts should be introduced step by step, it is important to bring in the element of integrating various branches of mathematics topics in real-life examples i.e., in finance, engineering, agriculture, and geography, amongst others, where concepts such as gradient, slope, and area are used.

D1.5 School culture – inductive reasoning

It appears that school culture hinders the implementation of digitally supported teaching of mathematics in secondary schools.

E1 (2021): *My main comment is that teachers must be given time. How, I don't know. Teachers must have time to use and learn these digital aids particularly the dynamic software on their own and as a mathematics community of practice.*

Counter-inductive reasoning: The experience of the PP: ADS short course showed that spending longer periods of about an hour or more on a concept (until the concept is understood) and collaborative seating arrangements to facilitate collegial conversation on the topic are useful. Additionally, the education leadership should create an environment that embraces experimentation with technology, including exposing teachers and learners to various events such as competitions, expos, and conferences that promote collaborative projects and innovative ideas about the modern classroom. Furthermore, the reality is that the modern classroom should be dynamic, collaborative, exploratory, and allow experimentation. The seating arrangement should be in pairs, and periods should be longer to allow for the exposition of particular concepts (i.e., congruency) and to allow for the movement of individuals for collegial assistance, among others.

D1.6 Teaching experience – inductive reasoning

Time constraints affect the creation of a pleasant teaching environment due to the need to cover the syllabus.

E1 (2021): *My main comment is that teachers must be given time. How, I don't know. Teachers must have time to use and learn these digital aids particularly the dynamic software on their own and as a mathematics community of practice.*

Counter-inductive reasoning: There is not enough time to learn and use dynamic software applications in a secondary mathematics classroom. Participants from the primary research site expressed difficulties with their own learning, noting that it was difficult or impossible to provide for one-on-one engagement to address the use of dynamic software tools, and to facilitate in-classroom activities. Additionally, teachers specifically reflected on the following issues: (i) during the pandemic, schools had only partial attendance or half-empty classrooms; (ii) teachers needed more time to practise using the software on their own and in the classroom; (iii) it was difficult for teachers to use Sketchpad in the classroom since only the teachers had the software, not the learners, but teachers could switch to using GeoGebra in the classroom; (iv) there were only a few laptops to be shared among teachers, and similarly among learners, and there were instances where no laptops were available to learners; and (v) 45-minute teaching periods were too short to convey the optimal mathematics learning experience and the particular benefits of using dynamic software applications.

Furthermore, technical problems, including an inability to use various functions of digital platforms such as the "take control" feature in the MS Teams virtual platform, tend to deter teachers from using such remote platforms. Hence, teachers need time to learn to use digital technologies for teaching mathematics in secondary schools; involvement in the mathematics community of practice and discussions in class are some of the ways that can improve teaching experiences. Thus, aspects such as teaching, demonstration, collaboration, independent practice, and reaction or feedback are important for the successful digital teaching of secondary mathematics, and these were employed during the proceedings of the PP: ADS short course. However, these aspects are missing in current practices.

D1.7 In-service training – inductive reasoning

There is a misalignment between university mathematics teacher education and school mathematics.

GP1 (2020): *I said come and see how I do things and incorporate that if you can in your lessons as well. And then gradually I moved out now she can find her way around. That's why I was so pleased when the teacher came to me and said I am going to take the grade, because we do have revision timetable in between exams.*

The statement above is about the teacher who was scared to teach a geometry class and an experienced educator invited her to come and observe the educator. GP1 (2020) indicated that universities must prepare teachers in geometry and strengthen their teacher training programmes to align them to what teachers are supposed to teach in the classroom. GP1 added that teachers must do mathematics programmes (re-skilling for existing teachers) to gain more experience and become better teachers, and that a positive teacher empowerment environment is vital for confidence-building, particularly for the new teachers.

Counter-inductive reasoning: There is a need to ensure the alignment of mathematics teachers' pre-service and in-service training with classroom needs i.e., technology integration should be part of pre-service training and those who are already practising who require training on the use of digital tools must be provided with in-service training. It appears that most current in-service training initiatives are focused on mathematics content teaching. Ideally, both pre-service and in-service training should be aligned with the needs of teachers for effective in-class integration of digital tools during secondary mathematics lessons. This is currently not the case, and may be a result of the fact that the university staff leading secondary mathematics education have not been exposed to modern ways of teaching and learning using digital tools.

Enhancement (early-stage) ways of technology use for the teaching and learning of secondary mathematics have provided a superficial modern classroom with no widespread positive education gains in most cases. This is driven by the desire to have technology in schools rather than first determining the transformational affordances that will address the positive education outcomes i.e., conceptual understanding for improved outcomes. While in-service training is important for practising teachers to ensure that teachers keep abreast with curriculum changes, it is important to address pre-service training in universities to ensure that it is aligned to the classroom needs. Additionally, regarding content misalignment, geometry is not taught in some universities' pre-service training, yet teachers need to teach geometry in class. This means that the only geometry that teachers are exposed to is from their high school learning and their in-service training, which is odd. In the case of technology integration, separate initiatives are undertaken by various universities' in-service short courses through partnerships. This reminds me of the parable of the wine skin: put new wine in a new wineskin and they will both be preserved (Matthew 9: 16–17). The point here is that universities are maintaining the status quo i.e., they continue to provide misaligned pre-service courses on both content and technology integration.

D1.8 Partnerships – inductive reasoning

Partnerships are critical during the implementation of digitally supported teaching of secondary mathematics in schools.

SR2 (2022): *The long-term plans for the Open Saldanha programme as a whole are that it will likely sit within the innovation campus programme, with projects within the IDZ just for the governance arrangements to be suitable to access third party funding, donor funding and to get others on board. I think these figures, I think this thing will take a life on its own and we have limited resources and capacity to give it up between operating the IDZ and Open Saldanha programme if you consider the scale that it needs to go to. I mean nine schools of students of over a thousand each, you know teaching body you know 30, 40,* *50 teachers per school. Like you know it's a big, massive programme and it needs to have a home of its own and I think that home will be within the innovation campus entity that we are going to be establishing which will likely probably be an NGO entity to make sense.*

LEDA3 (2022): *I think like just from the work that we have been doing the past few years, since I would say we started this teacher training, for me it's just the realisation that I would say it is the realisation that it's going to take a lot of collaboration. Like we can't do it alone. So, it's a matter being able to provide the internet to the schools, it's a matter of finding people who see the vision and are willing to collaborate with us.*

Counter-inductive reasoning: Partnerships are key for the implementation of digitally supported teaching of mathematics in secondary schools. Additionally, partnerships entail the collaboration of government departments for STEM and the involvement of the private sector. The involvement of partners is key in the policy development process, in the promotion of digital skills of educators, the provision of resources (funding, devices, etc.) and training (academia). Moreover, the modern economy requires advanced digital skills, and the private sector has started to be proactive in partnering with institutions of higher learning for the empowerment of mathematics teachers and learners.

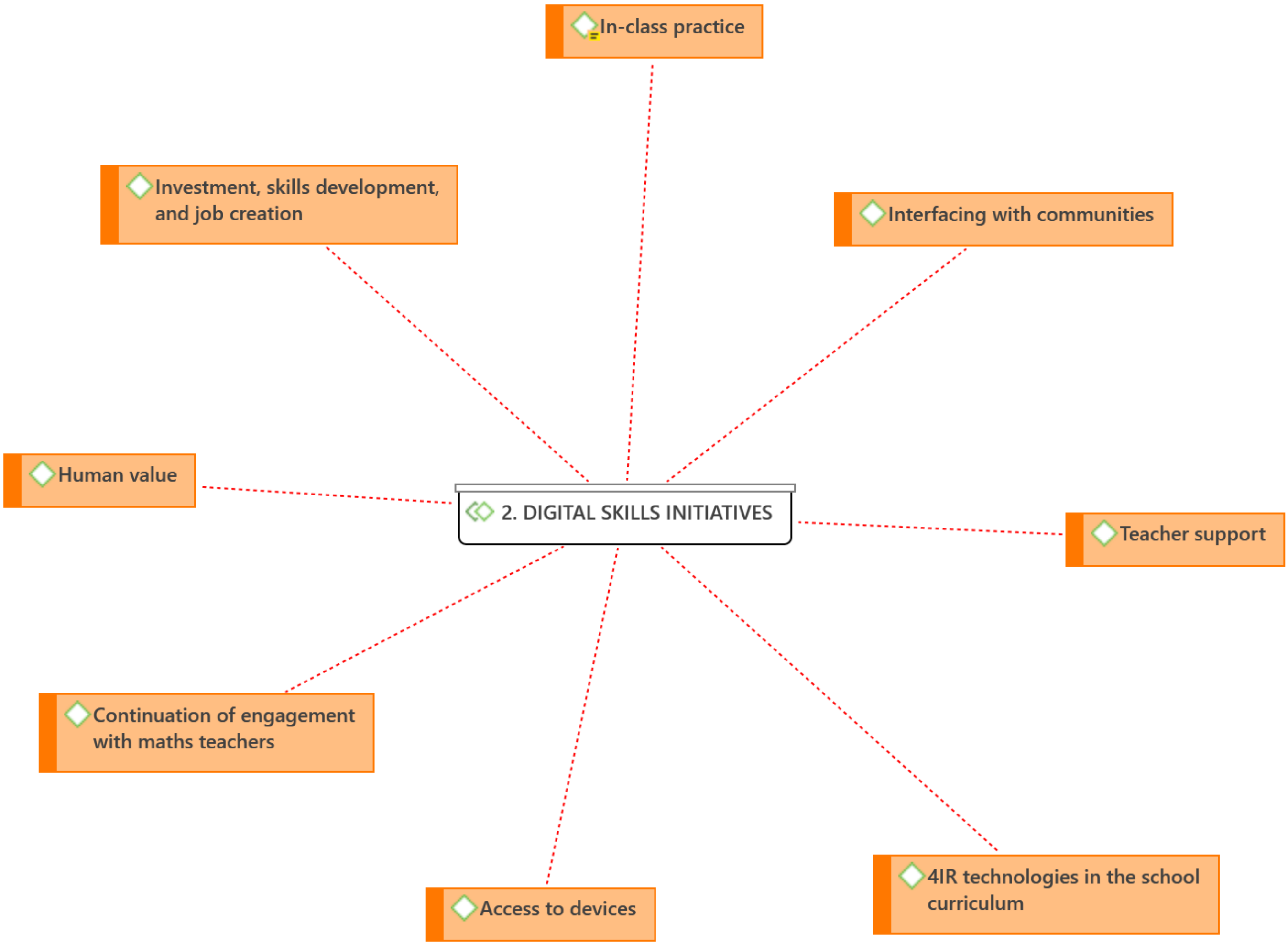
The involvement of partners via a formal governance structure is key during the design, development, implementation, and monitoring of digital education policies. This is to ensure that commitments that are made during the policy design and development phases are carried out during the implementation and monitoring phases. Additionally, this will avoid the setting of different targets by different policy documents, indicating that targets were not universally agreed for the country, but thumb-sucked or bench-marked by departmental staff without involving the relevant stakeholders i.e., broadband rollout in schools should involve the Department of Communications and Digital Technologies (DCDT), the Independent Communications Authority of South Africa (ICASA), universities and the private sector, among others.

7.2.2 DIGITAL SKILLS INITIATIVES

This emergent dimension associated with the teacher professional development programmes to improve digital skills of educators and has sub-dimensions that include: interfacing with communities; investment, skills, and job creation; human value; 4IR technologies in the school curriculum; teacher support; continuation of engagement with maths teachers; in-class practice; and access to devices (see Figure 38). These wide-ranging objectives show an organisation that cares about the communities that surround it, and which therefore decides to collaborate to forge a common future. In particular, the focus on teacher professional development (TPD) and the provisioning of associated resources is one of the major concerns of teachers i.e., teachers want training to be accompanied by the required digital tools, including assistance of teachers to implement what they have learned in the classroom.

This dimension highlights issues that must be taken into consideration when rolling out digital skills initiatives in schools. This is to ensure community buy-in and the sustainability of such initiatives, among others. More important is the follow-up support provided to teachers after any training intervention to ensure the in-class application of the newly acquired skills and the mobilisation of the required resources.

Figure 38
Digital skills initiatives



Emergent sub-dimensions

D2.1 Interfacing with communities – inductive reasoning

Companies should forge relationships with local schools in order to penetrate communities.

LEDA1 (2021): *.... how do we penetrate communities? They are very fractured those communities so various organs of social production and reproduction again not unlike other parts of South Africa have been completely undermined ... In the meanwhile, what we are going to say is how do we make this intervention work most effectively? How do we penetrate communities? I think school are good apparatus to do that.*

Counter-inductive reasoning: Interfacing with communities is an emergent category and is one of the objectives of the LEDA involved in case study A, which aimed to penetrate the communities and to promote social cohesion through schools. Schools are seen as the most viable option as they present an opportunity not only to link with the communities, but also to prepare a pool of potential skilled individuals. Furthermore, the reason why schools are important as a way of interfacing with the communities is that they have a pool of young people who have the potential to build a reimagined future society that is integrated and productive. Education is undoubtedly linked to the prosperity of the nation and focusing on demographic differences is not helpful. Rather, the empowerment of every citizen regardless of racial profile will ensure that everyone has an equal chance to succeed in life. Booker T. Washington (1878) said that the quality of work and good work ethics is appreciated, regardless of race. Social cohesion will be a reality once every member of society is able to do dignified work and can take care of their families, with opportunities for their children to be who they want to be regardless of demographics.

D2.2 Investment, skills, and job creation – inductive reasoning

Socio-economic problems need to be addressed during company investment in an area or region.

LEDA2 (2022): *Okay, so why we started it [Open Saldanha Project] … is because for two reasons. Number one is the purpose of SEZs no matter what country you are in and what has been the purpose of the SEZ is to bring in investment and particularly we started with the foreign direct investment and to get the benefits of jobs … you want jobs, but you want it most successful when you have those local spill overs happening in knowledge, in technology exchange, in skills and in economic spill overs … So, skills development of school leavers, everybody outside of schools put it that way. But we knew that even to get deeper and understand and understanding our context in Saldanha is that we needed a programme that with school students, so learners, and that is why if you take that all into consideration, that is why we started with the Open Saldanha Programme because we knew that we need to make an intervention into schools to reap the benefits 20 years from now.*

LEDA3 (2022): *So, to my understanding the Open Saldanha Project was started by just looking at the mandate of the Saldanha Bay IDZ which is really to create this economic growth in Saldanha Bay and the West Coast and ultimately in South Africa.*

Counter-inductive reasoning: Investment in a region should be accompanied by training and development to ensure that people in the area can be employed. For the long-term sustainability of projects, economic spinoffs should be felt in the surrounding communities. It is therefore critical that people have skills so that they do not feel like outsiders in their own communities because companies need to bring in foreigners.

D2.3 Human value – inductive reasoning

Human dignity is also important to ensure that we have holistic development of individuals who not only well-off but are confident and see their place in society, and not as second-class citizens.

LEDA1 (2021): *Maths and science are important but so is singing important and so is art important, so many other things are important because all of those things enable, they tangibles this determination for children and only embracing the humanity, the human value. And so I think that before you talk about maths and science or arts or anything else, we need to start by saying we have to engage a process that enables people to understand their individual value and the value of other people by this or that to renegade the fundamental proposition around human value …*

Counter-inductive reasoning: Human value is also an emergent category and is one of the objectives of the LEDA in case study A. Data showed that the LEDA sought not only to focus on the economic development of the disenfranchised individuals in the Saldanha Bay area but also to restore their dignity. Hence, a holistic approach is embedded in the Open Saldanha Bay Project which includes arts-oriented programmes precisely to develop the concept of human value (i.e., so that children in this area develop confidence and know they can be who they want to be). Additionally, the human value concept is like ubuntu (I am because we are) – a concept that has been lost due to the political enrichment that has been adopted by various societal institutions (municipalities, departments, companies, etc.) through patronage networks. Furthermore, a common South African identity is needed where, for example, an engineer is recruited based on qualifications, regardless of which region in South Africa the person is from. Similarly, public budget resources should be distributed equally, regardless of whether the area is urban or rural, or the township status of schools, clinics, hospitals, and connectivity, amongst others. The return of education budgets to National Treasury because of poor planning in some provinces should be treated as a crime (and there should be a penalty) as provincial officials are paid to oversee such resources.

D2.4 Fourth industrial revolution (4IR) technologies in the school curriculum – inductive reasoning

LEDA3 (2022): *And then the long-term goal I would say would be to just integrate 4IR technologies into the curriculum in schools. Being able to see like that schools in Saldanha Bay are, like doing like they are being taught 3D printing, robotics, coding, like all of those 4IR skills are actually being integrated,* *have been integrated into the school system in Saldanha Bay and being able to find partners who are, who see the vision and importance of this and are able to fund this. I think the energy and the maritime industry like looking at the picture it's going to be just a myriad of complicated jobs basically that are going to be so integrated with technology.*

Counter-inductive reasoning: Another emergent category is Fourth Industrial Revolution (4IR) technologies in the school curriculum. Data showed that there is a need to integrate 4IR skills such as 3D printing, robotics, and coding into the school curriculum, including the creation of awareness about careers that the digital era presents and the role of subjects such as mathematics. The hope is that this will generate interest in the 4IR skills-related careers (3D printing, robotics, etc). The foundation skills for 4IR technologies are primarily mathematics and should be the focus while 4IR skills can be highlighted as career options. Focusing on the 4IR skills is similar to the leapfrogging approach that was punted during technology evolution in mobile telephony, and it should be avoided as it resulted in South Africa being among the top consumers of technology, rather than a major producer. Application developers, programmers, and 3D printer developers will be the scientists and engineers who have advanced mathematical and scientific skills. Anyone can be taught how to fly a drone, but few can design, develop, and produce drones. This issue is directly related to the support of technology infrastructure in schools i.e., if local support is not available, then sustainability becomes questionable. It is important that issues such online and offline storage, and local and remote support should be carefully evaluated based on sustainability. This to avoid denial of service in cases such as using cloud services which are accessible when payment is made, but access is denied if no payment is made.

D2.5 Teacher support – inductive reasoning

The rollout of digital infrastructure in school should be accompanied by teacher support in classrooms so that newly acquired digital skills for technology integration in the teaching of mathematics in schools can be implemented.

LEDA3 (2022): *I would say the short-term goals, the work that we are doing right now with the teachers, so now we have had this programme with the teachers, and they are going to be graduating towards I would say possibly this month, then how do we continue from that? Like how we move forward because we need to be able to put this into the classrooms and how can we support the teachers. How do we give them the support for them to actually be able to integrate this into the classrooms? And sort of like what other opportunities can we introduce the teachers to? It does not have to just be the maths programme. Like for example last year we sort of like excited the teachers as well in Saldanha Bay by introducing them to drawing technology, and like what other programmes can we actually bring into the schools and I would say that the, one of the main short-term goals as well is to be able to support the teachers and actually giving them that confidence and actually making them to understand that they are playing such a huge role and that is one of the things that we want to do is to provide these leadership skills to the teachers which I think are very important.*

Counter-inductive reasoning: Teacher support is required during the implementation of digitally supported teaching of secondary mathematics in schools. Data showed that there is a need to continue working with schools (after teacher training), and that maths programmes must start with teachers who need to practise building knowledge and capacity (in-class practice). Additionally, in-class practice is related to teachers needing to practise their use of dynamic software applications or digital tools for teaching secondary mathematics in the classroom, with the support of resources and academic experts. Furthermore, teachers should be ahead of learners so that they are confident about teaching a particular topic. Moreover, once the pre-service training of teachers addresses the misalignment of teacher preparation and classroom practice, teachers will be ahead of learners, including the integration of digital technologies for teaching and learning mathematics in secondary schools. Thus, TPD programmes should cover general MS programs and specific mathematics dynamic software applications (Excel, GeoGebra, Geometer's Sketchpad, and Desmos, amongst others), in addition to the content knowledge that teachers should be competent on, including support after training.

D2.6 Continuation of engagement with maths teachers – inductive reasoning

Participant observations (2020) showed that one of the risk factors is leaving maths teachers on their own, after only very basic training. Additionally, teachers asked whether the end of the course would mean the end of the engagement and expressed interest in continued collaboration. Furthermore, the teachers suggested that the building of a mathematics community of practice would be one way of addressing this logical requirement for continuing engagement.

Counter-inductive reasoning: On the continuation of engagement with maths teachers category (emergent), the data showed that there is a risk in leaving maths teachers on their own after only very basic training and that a maths community of practice is necessary to continue engagement with teachers beyond the training. Hence, a community of practice needs to be established in the Saldanha Bay circuit to ensure that the trained teachers share their experiences; various experts can be invited to present aspects of transformational ways of teaching using technology, including searching, and using online resources for teaching secondary mathematics. Additionally, the community of practice can also facilitate the sharing of preconfigured GeoGebra applets, lesson plans, and worksheets for technology integration. For example, key transformational affordances of dynamic software applications, namely feedback, dragging, measuring, and tracing require intermediate and advanced digital skills and can be mastered through practice, with teaching objectives at the forefront. This requires selecting appropriate dynamic software applications to accomplish specific teaching objectives i.e., proving that the sum of the angles of a triangle is equal to 180 degrees can start with pencil and paper using a drawing set (drawing three triangles), measuring, tabulating the results, and then proceeding to select an appropriate GeoGebra applet (tabulating the results).

D2.7 Access to devices – inductive reasoning

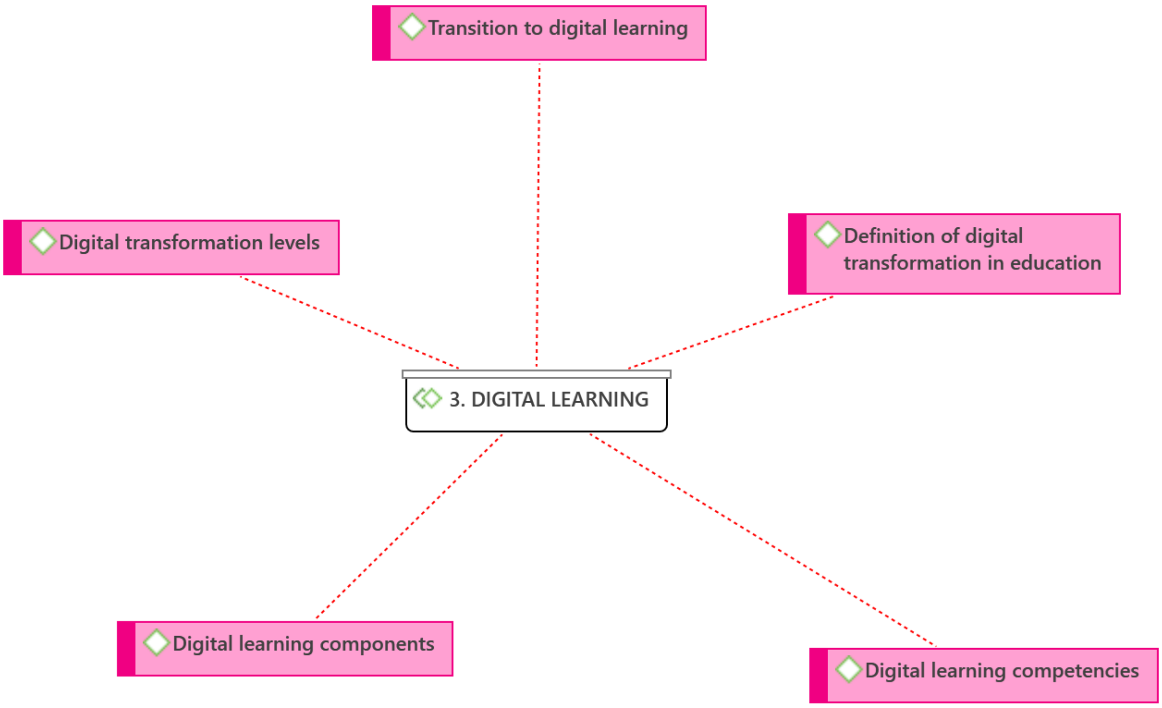
Another risk factor is access to devices. Both teachers and learners need access to laptop devices to address what is commonly referred to as the "digital divide". The maths teachers need their own devices, over and above the pool devices available at school, while learners could share devices initially. Maths teachers need to be able to practise, progressively transferring the teaching practice from the "chalk and talk" process to the use of dynamic software for each component of the curriculum, even if not for every lesson.

Counter-inductive reasoning: Digital devices need to be provided by the department and private sector partners for both teachers and learners to ensure successful digital learning. Currently, this is lacking, with teachers provided with laptops in some schools and learners provided with tablets (mainly grade 12 learners), which are not suitable for effective digital learning using digital tools. A laptop is most appropriate for both teachers and learners in secondary schools for digital mathematics teaching as it promotes active learning and content creation (advanced digital skills). The use of laptops will also facilitate the smooth transition of learners from high school to university as university students mainly use laptops to access available campus-wide Wi-Fi.

7.2.3 DIGITAL LEARNING

This dimension is about digital learning (or teaching) issues that include the competencies that are required, including managing the change from current practices to digital learning. At the heart of managing change is the capacitation of all the involved individuals to ensure that everyone embraces and supports the transition to digitally supported ways of teaching and learning secondary mathematics in schools. Figure 39 shows the digital learning dimension.

Figure 39
Digital learning



D3.1 Digital learning components – inductive reasoning

Participant observations (2020) showed that digital learning components (digitally supported teaching) include blended teaching and virtual or remote teaching in case study A. However, there is limited use of both blended and virtual or remote teaching in the current classroom.

Counter-inductive reasoning: The limitations of using both blended and virtual teaching and learning was highlighted during the COVID-19 pandemic, where physical contact restrictions were enforced and both teachers and learners were forced to use virtual or remote platforms, including social media. For example, the short course in case study A had to be completed virtually, which uncovered a range of challenges that teachers were currently facing, such as lack of laptop devices, limited internet connectivity, and lack of digital skills to use virtual platforms, among others. These should be factored in during the development of a technical architecture that will ensure that lessons continue despite these highlighted challenges.

D3.2 Digital learning competencies – inductive reasoning

Digital competencies include the ability to use digital tools and resources, facilitating teachers' professional growth and knowledge about the value of digital tools and resources, the appropriate use of digital tools and resources to attain curriculum objectives, and demonstrating leadership vision for digital learning (DBE, 2018b

Counter-inductive reasoning: There is a widespread lack of digital learning competencies in the secondary mathematics education sector, particularly competencies for using digital tools and resources. Although the digital learning concepts are highlighted in the DBE documents, such as the Professional Development Framework for Digital Learning, it seems that these concepts have not found their way into the secondary mathematics classroom i.e., the use of appropriate digital tools and resources to attain curriculum objectives.

D3.3 Digital transformation levels – inductive reasoning

There are mainly four digital transformation levels from Puentedura's (2006) SAMR model, namely, substitution, augmentation, modification, and redefinition; the substitution level is prevalent in the secondary mathematics education sector. The first stages constitute enhancement or early-stage development, and the latter two constitute transformation.

Counter-inductive reasoning: There must be a clear distinction between the levels of technology integration in secondary mathematics. Current studies compare the traditional use of chalk and talk with technology use in teaching and learning mathematics in secondary schools. Although some of these studies have shown that the use of applications such as GeoGebra have led to higher gains than traditional means, this has not translated into a substantial improvement in matric mathematics results. This might also be attributed to the sporadic use of these applications i.e., not in all schools throughout South Africa.

D3.4 Transition to digital learning – inductive reasoning

The transition to digital learning requires that schools develop a rubric and a change management strategy (DBE, 2018b). Although the rubric for schools and change management steps are outlined in the DBE's Professional Development Framework for Digital Learning (DBE, 2018b), the transition is not apparent in the current practices. Furthermore, teachers often raised the issue that TPD should be accompanied by related digital tools and resources.

Counter-inductive reasoning: It seems that frameworks are researched (benchmarked) and developed using a top-down approach where there is no consideration of where teachers are, particularly with regard to their digital skills, requisite digital tools, and resources, including available or required school digital infrastructure. Hence, it is important to work closely with teachers to ascertain their needs (training, resources, etc), including their fears, to design a flexible teacher development programme to cater for those specific needs.

D3.5 Digital transformation in education – inductive reasoning

Here is a sample of definitions of digital transformation in education:

E1 (2021): *Digital learning or digital enabled learning.*

E2 (2021): *e-learning or online teaching, those are the terms we use.*

GT1 (2020): *ICT.*

GT2 (2020): *Yeah, we call it E-learning.*

GD2 (2020): *ICT and e-learning.*

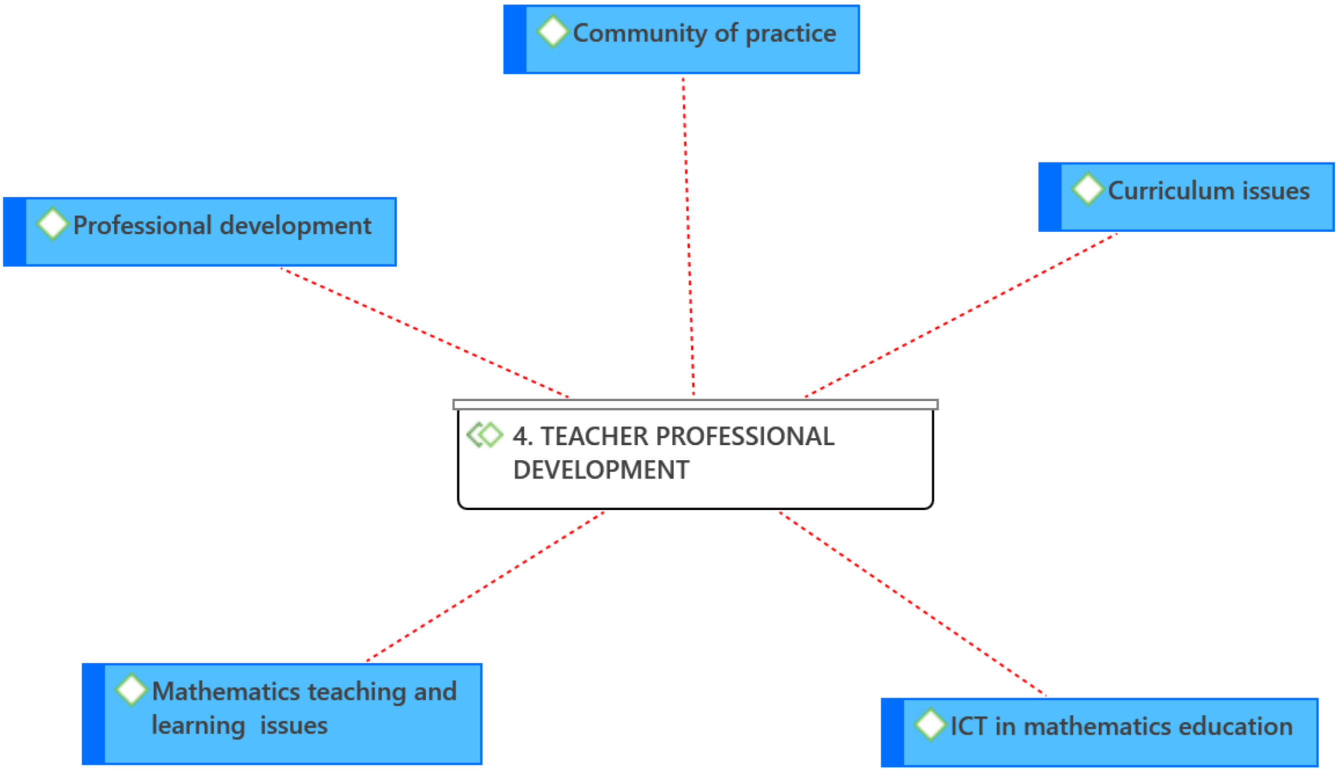
Counter-inductive reasoning: There is a need to standardise the terms for defining digital transformation in education, particularly in the teaching and learning of secondary mathematics. Modern terms such as digital teaching or learning of secondary mathematics should be used, for example.

7.2.4 TEACHER PROFESSIONAL DEVELOPMENT

The data presented under this dimension mainly focuses on various aspects of TPD that include mathematics teaching and learning, curriculum, community of practice, ICT in mathematics education, and professional development (see Figure 40). This dimension covers the need for TPD programmes to address not only mathematics content issues, but also curriculum issues (length of class periods), training on intermediate and advanced digital skills, and the availability of required resources.

Figure 40

Teacher professional development



D4.1 Mathematics teaching and learning issues – inductive reasoning

The DBE's (2018c) Mathematics Teaching and Learning Framework covers issues related to a learning-centred classroom that are more about promoting deep conceptual understanding, as opposed to rote learning, which is associated with learning material being stored in learners' short-term memories. Additionally, deep conceptual understanding ensures that learners can comprehend the fundamental principles and are able to apply the knowledge acquired to solve high-order word problems presented i.e., interpret word problems to develop equations and subsequently find a solution(s). Furthermore, a teacher's content knowledge is directly linked to promotion opportunities, which robs the learners in that grade in which the teacher was involved.

Counter-inductive reasoning: Understanding mathematics concepts requires a range of strategies, both pencil-and-paper-based, as well as dynamic software applications. While dynamic software applications help with the visualisation of changes prompted by varying certain parameters (e.g., the slope of a straight-line graph), the use of pencil and paper is critical in planning or drafting a rough sketch based on the properties of straight-line graphs, for example. Hence, enough time is needed to explore each mathematical concept to ensure that it is widely understood theoretically and that its application to real-life situations is also understood, including future linkages to the learners' next grades. Therefore, the curriculum should allow for longer maths periods to expose learners to a variety of situations (using pencil and paper as well as dynamic software) to foster deep conceptual understanding.

For example, the period could be increased to one to two hours (a double period) to ensure that various issues related to a concept are tackled. It must be noted that short periods come from international formats which hold that learners have short attention spans and cannot focus for long periods. This may no longer be applicable given the excitement that technology visualisation has brought into the classroom. Additionally, it might be a good idea to teach mathematics-related subjects on a particular day i.e., mathematics and science on Monday, languages and literature on Tuesdays, and geography on Wednesday, for example. This will eliminate the possible detrimental effects of a variety of subjects in one day, where periods are very short, as is currently the case.

Innovative incentive schemes should be devised to keep a good teacher in the same grades while improving his or her professional wellbeing, for example, a bursary scheme to research issues around mathematics in the same grade, including modern ways of teaching and learning using dynamic software tools, attendance of conferences both locally and abroad, and salary scale adjustments, among others.

D4.2 Curriculum – inductive reasoning

The South African curriculum is called the Curriculum and Assessment Policy Statement (CAPS) and is a single, comprehensive, and concise policy document, which replaced the Subject and Learning Area Statements, Learning Programme Guidelines and Subject Assessment Guidelines for all the subjects in 2011 (Pearson, 2021). Further, CAPS forms part of the National Curriculum Statement (NCS) Grades R–12, which represents a policy statement for learning and teaching in South African schools and comprises the following: (i) Curriculum and Assessment Policy Statements (CAPS) for all approved subjects; (ii) National policy about the programme and promotion requirements of the National Curriculum Statement Grades R–12; and (iii) National Protocol for Assessment Grades R–12. Furthermore, the NCS provides the mathematics content that needs to be covered by the various grades from grade R to grade 12.

Counter-inductive reasoning: The sequencing of the secondary mathematics topics for teaching and learning is one of the important elements of the school curriculum. Hence, it is important to review the curriculum so that it is in line with the current realities in the classroom. For instance, the curriculum aspirations of technology integration in secondary mathematics should be accompanied by related guidance on how this should unfold, with associated teacher support and assessment modalities of technology integration. If the technology integration is not assessed, then teachers, including district officials, will not take it seriously. This means that the assessment of digital learning of secondary mathematics must be carefully considered to form part of continuous assessment to build a culture of technology use.

D4.3 Community of practice – inductive reasoning

Participant observations (2020) show that a budget needs to be allocated to create a mathematics community of practice. A mathematics community of practice is associated with the publishing of lesson plans, content design and input, and project management for all schools, as was the case in the Saldanha Bay circuit. Additionally, workshops, videos of lesson study events, proposal budgets, individual sessions with subject advisors, lessons from other countries (such as Japan) and benefits realisation are shared.

Counter-inductive reasoning: The community of practice proposed for mathematics teachers is geared towards providing a forum for community members (teachers) to help each other with everyday work needs (ELRC, 2017). Examples include using dynamic software applications for teaching mathematics in secondary schools. A community of practice is a good way of ensuring continuity through collaboration and the sharing of resources among teachers and the experts involved. However, setting up a community of practice requires time and resources (budget) for both offline and online interactions. A collegial environment is a safe space that can ensure that teachers in remote areas keep abreast with current developments in the field of technology integration into secondary mathematics teaching and learning.

D4.4 ICT in mathematics education – inductive reasoning

Participant observations (2020) showed that enough time must be allocated to use technology during the teaching and learning of secondary mathematics in schools i.e., the current class period length of about 45 minutes be reviewed 1 hour. This category is related to the use of digital technologies for the teaching and learning of secondary mathematics, such as devices (computers, laptops, tablets, and cell phones, etc.), dynamic software applications (digital tools or apps) and resources, and safety, amongst others.

Counter-inductive reasoning: The use of digital teaching and learning in secondary mathematics requires enough practice time for both teachers and learners, including time to set up the class, particularly if the class has multiple users, rebooting, latest software updates, and connectivity issues, among others. Thus, a technical architecture unique to each school should be developed to serve as a guide for anticipated challenges and mitigation i.e., during loadshedding, a school can invest in a generator or a few solar panels to ensure continued connectivity and operation.

D4.5 Professional development – inductive reasoning

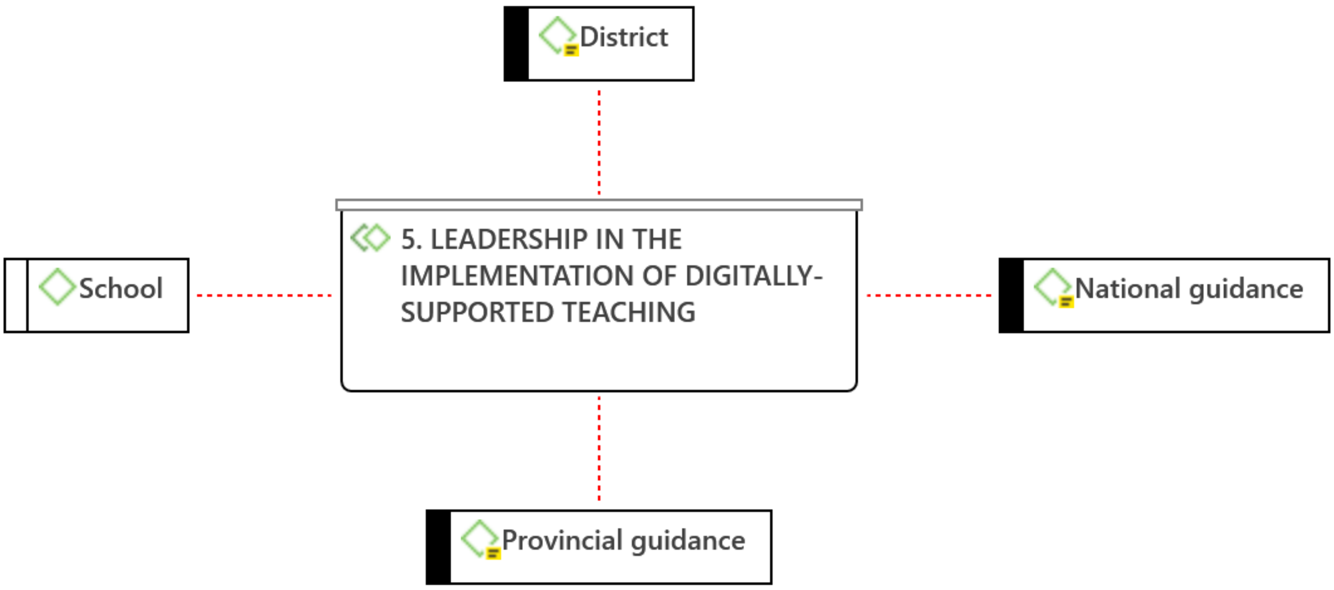
The DBE's (2015) professional learning communities document indicated that teacher development centres are available in districts, although funding and resources are needed for the training of teachers. Access to digital tools and resources must be ensured, as well as training on intermediate and advanced digital skills. TPD should be accompanied by the provisioning of associated infrastructure and resources. Additionally, teacher development centres should be made available in the districts to ensure that schools are constantly engaged with the latest approaches and frameworks for using technology to teach secondary mathematics.

Counter-inductive reasoning: The professional development of teachers should not only deal with content issues but also with issues related to the availability of infrastructure and resources. Additionally, TPD, particularly in-service training, should use a bottom-up approach as far as possible to uncover teachers' needs first and then design an appropriate curriculum. This is exactly what happened during the PP: ADS short course where the initial assumption was that teachers had intermediate and advanced digital skills to use dynamic software applications (pre-configured applets) only to discover that this was not the case. Hence, a multi-pronged approach of addressing the lack of intermediate and advanced digital skills, even basic digital skills (opening, using, and saving Excel spreadsheets, for example) had to be taught alongside using dynamic software tools such as Excel to generate patterns to subsequently plot graphs. TPD funding through partnerships should be embraced, particularly for the development of the intermediate and advanced digital skills needed for creating digital education content and resources. Also, private sector players should be engaged as they are ahead in terms of developing solutions for online assessment.

7.2.5 LEADERSHIP IN THE IMPLEMENTATION OF DIGITALLY SUPPORTED TEACHING OF SECONDARY MATHEMATICS IN SCHOOLS

The data presented under this dimension mainly focuses on various aspects of digital leadership that include national guidance, provincial guidance, and local guidance – at the district and school levels (see Figure 41). Leadership at all levels should have the same understanding of what needs to be done to support the digitally supported teaching of secondary mathematics in schools. For example, the submission of research outputs to the DBE should be followed by a workshop of all those involved in supporting secondary mathematics education from the national office, provincial departments, and local levels (district or school-based mathematics HoDs). Figure 41 summarises how leadership in the implementation of digitally supported teaching should occur.

Figure 41
Leadership in the implementation of digitally supported teaching



D5.1 National guidance – inductive reasoning

National guidance is available in the form of policies and strategies.

E1 (2021): *Yes, so national I think that the Professional Development Framework for Digital Learning is a very powerful document, very powerful document.*

WT1 (2022): *What I would have done or had love for them to do is that first start with the infrastructure. You cannot build a new school without the infrastructure of getting it to, say technologically advanced school, you still build a school as if it was still in the 1980s without the smartboards, without the projectors included in the building. If there are 40 classrooms, include 40 projectors, 40 computers, 40 whatever you want to do, then you give the framework and from there you give the training and from there we can implement, and you can monitor and then we can reflect on where we are now and then we can strengthen it.*

GT1 (2020): *The national and provincial departments do not offer training on ICT integration. Mainly mathematics content training. Tablets for grade 11 and 12.*

Counter-inductive reasoning: The national department of education should ensure that the training of educators on using digital tools for teaching mathematics in secondary schools is accompanied by the necessary resources and related support . The major issue related to national guidance is the lack of training for technology integration in secondary mathematics teaching and learning in schools. Additionally, the lagging behind of the education sector in general in digital transformation, particularly in the area of digital teaching of secondary mathematics, shows the problem in both government and academic institutions, where the digital transformation phenomena are known by those involved, but they lack the requisite competencies to apply these phenomena. Partnerships and collaborations are key to bridging the gap by working more closely with ground-breaking researchers in the field of digital transformation in education, particularlyin secondary mathematics.

D5.2 Provincial guidance – inductive reasoning

Provincial guidance is also available, to some extent.

WT1 (2022): *Provincially there is something, and you can apply, and you can use some of your …*

GT1 (2020): *The national and provincial departments do not offer training on ICT integration. Mainly mathematics content training. Tablets for Grade 11 and 12.*

GT2 (2020): *With me I would say in terms of providing the resources it's there.*

Counter-inductive reasoning: There is a gap between policy design, development and implementation and most often policies are available but are not implemented. The policy development process requires a multi-stakeholder governance structure, proposed in this study, to ensure common understanding among key role-players in relation to the mobilisation of resources for successful policy implementation and joint monitoring.

D5.3 District guidance – inductive reasoning

The district offices work closely with schools.

WT1 (2022): *With the districts, you know, we have, we get support in terms of there is training, there is programmes and there are courses that our teachers can go to. I think we must stop talking, we must implement what we are saying and that for me it's a huge concern, like I said, I would love when the day come when a teacher gets to a school, he gets all his tools.*

GT3 (2022): *District we get materials.*

GD3 (2022): *The district does provide workshops and have employed interns (two ICT champions) in each school and teach teachers on one-to-one basis. Other initiatives include ICT coordinators, interns responsible for schools (through the Mathew Goniwe School of Leadership) and subject advisors are trained to support school on ICT integrations. Challenges include unions who do not want training to happen during school holidays.*

Counter-inductive reasoning: District officials need to participate and must be exposed to using dynamic software applications for the teaching and learning of secondary mathematics in schools. Additionally, for national policies to filter down to schools, the district and schools should work together to assess the training needs of teachers and to design appropriate interventions. The training should also involve district officials, principals, then teachers, and lastly learners. Schools cannot move forward, even if some teachers are innovative, particularly young teachers who might be familiar with modern ways of teaching, without the support of district officials and school principals.

D5.4 School guidance – inductive reasoning

Champions in schools are essential.

E2 (2021): *My experience is, either you have a champion in the school … and that must a headmaster or a head of mathematics that says my school is going to take this up and then really drives it and find support or you need a teacher that already can do it.*

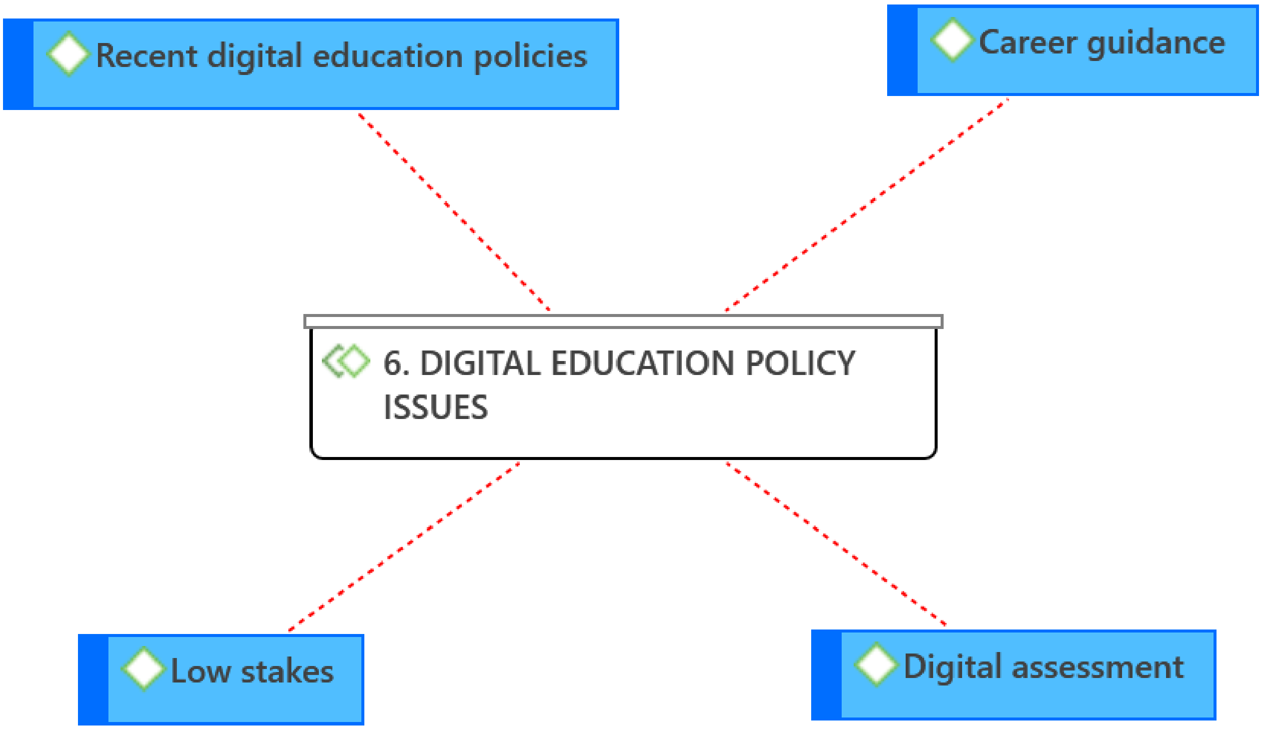
Counter-inductive reasoning: School champions are needed to promote and support the implementation of digitally supported teaching of secondary mathematics at school level for the training of teachers and learners. School-based leadership that includes the principal and heads of departments (HoDs) responsible for mathematics should embrace secondary mathematics digital teaching initiatives for school-wide adoption. Additionally, the champion could be a principal or deputy principal of the school, who should be deliberately exposed to modern ways of secondary mathematics teaching using technology.

Furthermore, workshops should be organised on those curricula-related research findings that are deemed to be ground-breaking to address the complexities that involve the use of digital tools for teaching and learning mathematics in secondary schools. Such complexities include a digital pedagogical framework and the prerequisite of successful application in the classroom, as well as the resources, including the technical architecture to support such a framework.

7.2.6 DIGITAL EDUCATION POLICY ISSUES

This dimension mainly focuses on various aspects of digital education issues that include recent digital education policies, career guidance, digital assessment, and low stakes (see Figure 42). It highlights policy-related matters such as digital assessment, including examination of digital teaching and learning to drive the adoption and usage of digital tools during secondary mathematics in schools.

Figure 42
Digital education policy issues



D6.1 Career guidance – inductive reasoning

Participant observations (2020) showed that there is lack of career guidance to promote science, technology, engineering, and mathematics (STEM) pathways, particularly in the rural and peri-urban environments.

Counter-inductive reasoning: Career guidance should commence in earlier grades to ensure that learners are aware of the career limitations presented by their subject choices, particularly in the case of mathematics-related science and engineering careers.

D6.2 Digital assessment – inductive reasoning

The old ways of testing and examination (pen and paper) are prevalent. Digital assessment provides instant feedback and can be good for continuous assessment.

E2 (2021) *There were no examinations for teaching and learning with technology as current assessment practices used pen and paper.*

Counter-inductive reasoning: Mainly private sector players have developed the digital assessment platforms, which might be expensive for the public sector given the large numbers and the disparities related to digital infrastructure, as stated earlier.

D6.3 Low stakes – inductive reasoning

E2 (2021) *Digital teaching and learning of secondary mathematics are not assessed, hence the stakes are low. Teachers tend to focus on what is stipulated to be examinable in schools, as is the case with matriculation examination preparations.*

Counter-inductive reasoning: The initial weight for such assessments might be set lower to encourage adoption and progress that is monitored. The assessment of transformational ways of teaching using digital tools in secondary mathematics will increase the stakes for adoption and use in the classroom.

D6.4 Recent education policies – inductive reasoning

Conrads et al. (2017) state that recent digital education policies, stakeholders involved in policy design, implementation and monitoring aimed at improving infrastructure, and teaching capacity focus on the different levels of primary, secondary, and tertiary education.

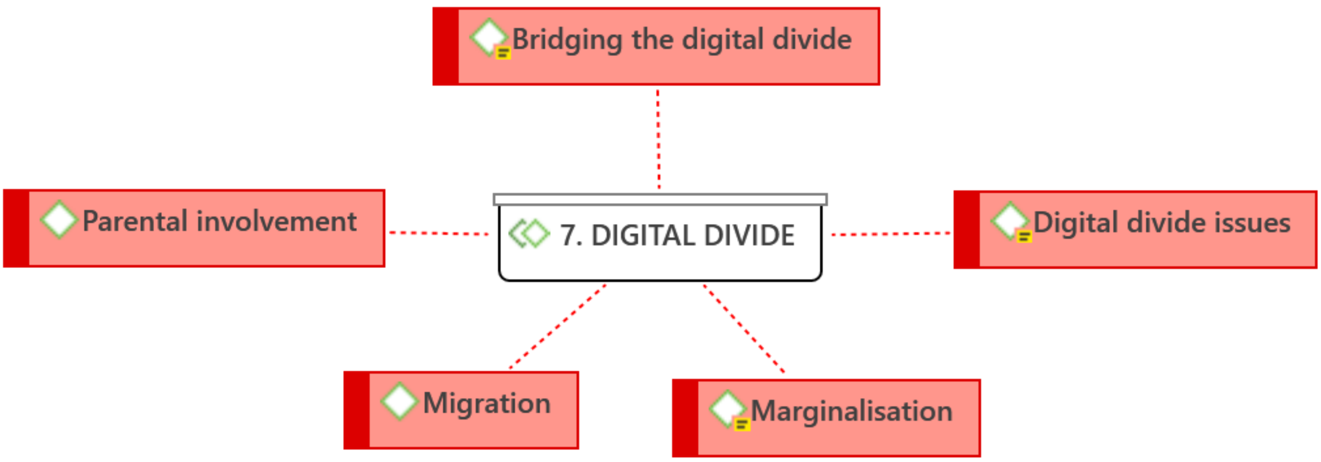
Counter-inductive reasoning: There is a need to integrate evaluation and monitoring into the policy design, to promote innovative teaching and learning, and to provide multiple pathways for supporting teachers. Recent digital education policies are holistic and involve all key stakeholders throughout the policy development process, and attend to different levels of education due to the different needs. For example, primary education learners' technology needs may be addressed by the rollout of tablets as these learners mainly consume content, whereas secondary learners need laptops, as these are more suitable for content creation.

Teachers need training to implement the policies, frameworks and strategies in schools. For example, the DBE's (2018b) Professional Development Framework for Digital Learning is known by some teachers, but the framework is not applied in the classroom because of various limitations; the main limitation is a lack of training on how to use dynamic software applications. Additionally, the researcher noted that there is a distance between policy designers, developers, and those who must use the policy for guidance (the result of a top-down approach). Therefore, the involvement of multiple stakeholders via a formal governance structure for accountability can decrease this gap. Also, a workshop that involves all levels of leadership (national, provincial, and local) and teachers could be key in ensuring the alignment of expectations.

7.2.7 DIGITAL DIVIDE

The data presented under this dimension focuses on various components of the digital divide, such as bridging the digital divide, marginalisation, parental involvement, and migration (see Figure 43). This dimension is about the socioeconomic conditions that need to be factored in during the design, development, and implementation of digital education policies. This allows policymakers to pay more attention to the disparities that exist between various communities i.e. rural, peri-urban, urban, etc.

Figure 43
Digital divide



D7.1 Bridging the digital divide – inductive reasoning

Participant observations (2020) show that there is a need for digital mathematics content and its accessibility to all schools irrespective of their geographic location.

Counter-inductive reasoning: The challenges that are faced by rural and peri-urban schools are multi-faceted due to a range of socioeconomic issues such as poverty, unemployment, and low education levels, among others. Additionally, government departments, state-owned enterprises (SOEs), and private sector players prioritise urban centres that are economically viable when providing services.

D7.2 Digital divide issues – inductive reasoning

Participant observations (2020) showed that there is a difference in technology availability between urban and rural schools in the education sector, particularly in relation to dynamic software applications for secondary mathematics teaching and learning.

Counter-inductive reasoning: The digital divide has also shifted to the quality of internet connectivity with rural people experiencing poor or limited connectivity compared to their urban counterparts, particularly on mobile telephony, which is translated to schools i.e., intermittent connectivity in rural and peri urban schools. There is a need for secondary mathematics digital content development initiatives and a regulatory framework for connectivity in schools.

D7.3 Marginalisation – inductive reasoning

Marginalisation means the exclusion of some communities from economic participation. Participant observations (2020) showed that teachers in general, and in this case mathematics teachers, they are generally marginalised from the economic and social activities that can validate their investment in teaching.

Counter-inductive reasoning: Professional learning communities that are advocated by the national department of education allow teachers to attend local and international events, particularly teachers from rural and peri-urban areas.

D7.4 Migration – inductive reasoning

The migration of people from other parts of the country and the continent to the Western Cape is posing a challenge for schools in some areas; these schools cannot keep up with the numbers or plan for the allocation of resources.

IE7 (2023): *Overcrowding because of migration from other provinces and countries makes it difficult to keep up with the numbers to supply infrastructure and devices. Additionally, inadequacy of teachers' skills development due to time as training must take place outside teaching period. Furthermore, teacher unions challenges refusing training outside school hours. Moreover, management of existing ICT resources due to theft by learners and vandalism. Other issues include lack of innovation by teachers, lack of adoption, particularly by older teachers and lack of motivation amongst some teachers, amongst others.*

Counter-inductive reasoning: The migration of people shows the failures of the government, whether it is inside the country or illegal immigration as this put a strain schools i.e., places that have influx of people will have to add classrooms and other resources. For example, if people migrate, it means they lack something where they are or seek opportunities elsewhere. Additionally, a caring government should ensure that the norms and standards are adhered to so as to ensure that schools are at the same level, whether rural or urban. They should be accountability in government to ensure that failing provincial heads are fired and more competent people are hired. If money from provincial education departments can be returned to National Treasury when those departments' schools have no toilets, surely such failures should be offences.

D7.5 Parental involvement – inductive reasoning

There is a general lack of parental involvement in poor communities.

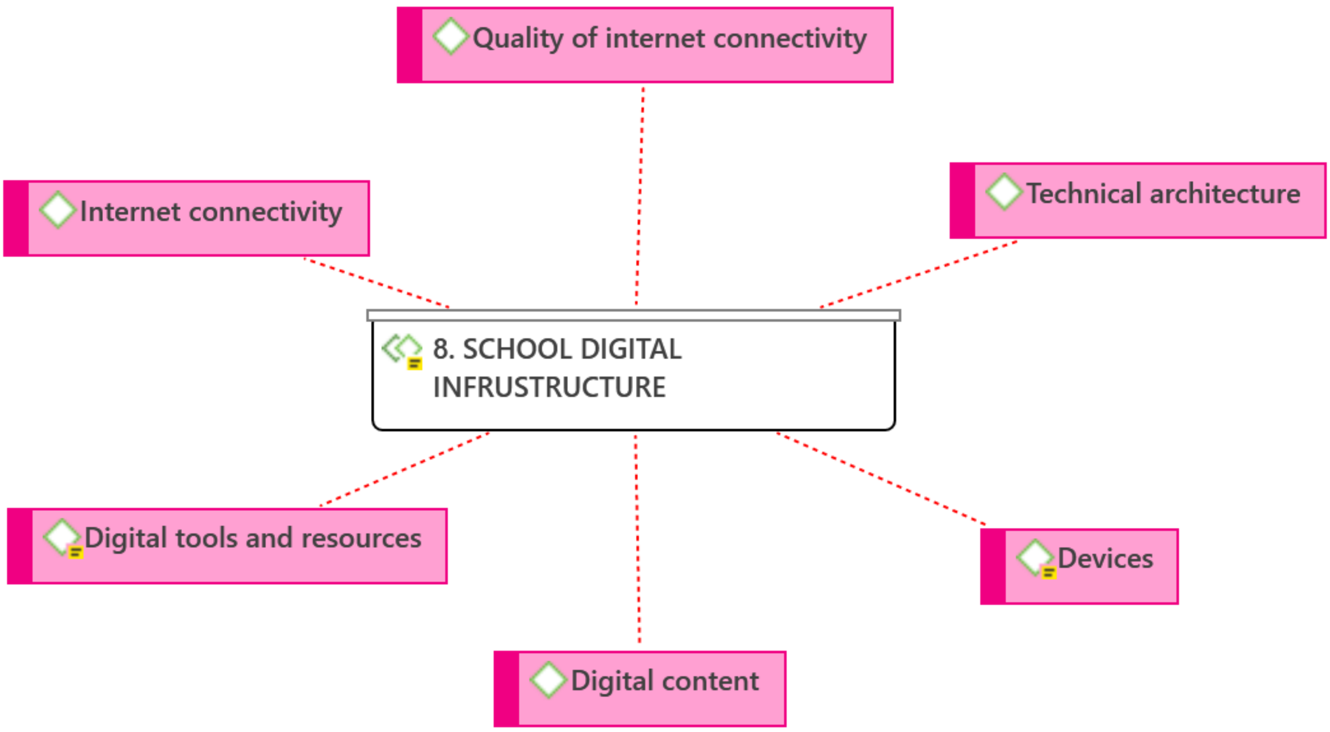
WT1 (2022): *Look, in our case I will say the social economical context from which our learners are coming here, it places a barrier on using these devices. At the moment we have an influx of many learners … in most cases or some, let me not say most cases, what we have found is that in some cases these learners are sent from other provinces to come and live by with an uncle, or a nephew or cousin whatever the case may be or even they live on their own with a friend. Though the parent involvement is becoming minimised or get to a point where there is no parent involvement and now how do you control the use of technology within the house where there is no parental structure, or you know what there is nobody that is controlling how learners is using these devices.*

Counter-inductive reasoning: Some learners stay with relatives or friends, which makes it difficult for the school to contact parents to ensure accountability.

7.2.8 SCHOOL DIGITAL INFRASTRUCTURE

The data presented under this dimension focuses on various components of school digital infrastructure that includes internet connectivity, quality of internet connectivity, devices, digital content, and digital tools and resources (see Figure 44).

Figure 44
School digital infrastructure



D8.1 Internet connectivity – inductive reasoning

Internet connectivity is generally available in most schools.

WT1 (2022): *We do have Wi-Fi at our school. For the teachers at home most of them is still using their own mobile data from what we have done research on, some do have Wi-Fi at home but it's out of their own pockets, it's nothing from school or like in this case, in this course they gave us a bundle and said you can use this at home whenever you do research or when you listen to the trainers or whatever the case may be. But that is not happening at the school.*

GD1 (2020): *We don't have internet ... It is for the office [for administration].*

GT1 (2020): *Internet connectivity available – admin, teachers, and laboratory for grades 11 and 12.*

Counter-inductive reasoning: Broadband internet connectivity is recommended for virtual classes despite the general lack of IT support. It also emerged that teachers self-provide for internet connectivity at home. Lastly, most schools have internet connectivity, but the quality is poor.

D8.2 Quality of internet connectivity – inductive reasoning

There is unsuitable internet connectivity for teachers at school or at home; the quality of internet connectivity is poor and needs to be improved.

E2 (2021): *Quality wise as I say, I think it's slow, it's in our country it's insufficient bandwidth it's not just the problem for the schools so I think that is something that must be tackled at national level. But again, I don't think it's to complain about it, it can be done.*

WT1 (2022): *It's very slow and inconsistent.*

GT3 (2022): *Up and down.*

Counter-inductive reasoning: One of the elements of school digital infrastructure that can support transformational learning experiences is ubiquitous connectivity i.e., constant access to high-speed internet in and out of school (US Department of Education, 2020). The US Department of Education (2020) adds that "preparing students to be successful for the future requires a robust and flexible learning infrastructure capable of supporting new types of engagement and providing ubiquitous access to the technology tools that allow students to create, design and explore." Furthermore, broadband-like internet connectivity is key for the digitally supported teaching of secondary mathematics in schools.

D8.3 Devices – inductive reasoning

Teachers mostly have laptops and learners have tablets.

GT2 (2020): *It's mostly laptops ... For learners no laptops have not really been provided the teachers do have the laptops ... We do use the lab. Our digital room where we take learners to that room so they can be watching all the digital lessons that they might be explained through you know. ... We do have cell phones learners normally use their personal cell phones to connect.*

GT3 (2022): *No devices for grades 8 and 9, only models. Laptops and tablets for grade 12. GeoGebra is also available.*

Counter-inductive reasoning: Devices such as laptops for teachers (and learners in high school), a projector or smartboard, and a power source need to be made available. Teachers also need to set up times to use devices as not all classes have devices. Securing funding for infrastructure is also important.

D8.4 Content – inductive reasoning

A national education portal must be developed and the development of mathematics digital content must be prioritised as there is currently a lack of adequate digital content. Digital mathematics content is a form of pre-configured dynamic software application for secondary mathematics that can be easily accessed by both teachers and learners. However, intermediate and advanced digital skills are still needed to download, adapt, and use such applications.

Counter-inductive reasoning: The drive to have digital mathematics content should be accompanied by measures to ensure equity to access it. This include the development of the requisite digital skills and associated support.

D8.5 Digital tools and resources – inductive reasoning

There is knowledge about digital tools and resources (apps) but these are useless if there are no devices in the first place.

GD1 (2020): *There are no data projectors no laptops. Look if you're in the class the only classes that will be having the smart screens will be the grade 12 classes. They don't share with grade 8 and 9s … You know a simple laptop with a data projector would be nice, for me. In the beginning, forget about the smartboards and the stuff. You know, just a data projector and a laptop that can connect to it. It will be such a huge beginning. Nothing.*

Counter-inductive reasoning: Knowledge about the integration of digital tools and resources such as GeoGebra must be developed. Additionally, the availability of laptop devices with apps like GeoGebra for high school teachers and learners has a potential improve the teaching and learning of mathematics in secondary schools. The key transformational ways of teaching and learning secondary mathematics in schools are through the visual affordances i.e. feedback, dragging, measuring, and tracing, as stated earlier.

D8.6 Technical architecture – inductive reasoning

Participant observations (2020) showed that a technical architecture must be developed to address the connectivity challenges faced by most schools, such as intermittent or poor connectivity and lack of technical support, among others.

Counter-inductive reasoning: A technical architecture will factor in all the digital infrastructure-related aspects that are needed for the successful implementation of digitally supported teaching of secondary mathematics in schools.

7.3 CHAPTER SUMMARY

This chapter, in addition to the previous chapters of data collection (Chapters 4, 5, and 6), focused on the analysis of data using ATLAS.ti, exploring approaches to shifting digital transformation in secondary mathematics beyond the early stage. The perceived aspects were examined through document analysis, participant observations, and interviews. The data was analysed and summarised. Chapter 8 offers the thesis statement and makes practice-oriented recommendations.

Chapter 8: Conclusion and Recommendations – Thesis Statement, Summary of Findings, and Practice-Oriented Recommendations

8.1 CHAPTER OVERVIEW

The previous chapter analysed and interpreted the data. This final chapter sets out the thesis statement, which is a clear statement of the thesis that the researcher has formulated, based on evidence and analysis. Structurally, the chapter consists of ten thematic sections with relevant sub-sections. The first section provides the thesis statement. The second section provides the motivation for the study, followed by a summary of the main findings and the presentation of the revised DT-SME 2022 framework. The fifth section provides the contribution of the study. The next sections turn to the limitations of the research study and also provide conclusions based on how the study answered the research questions posed in Chapter 1. The chapter then makes practice-oriented recommendations and highlights areas of future research. Lastly, the final word is presented. Figure 45 shows the flow chart for the chapter.

Figure 45
Chapter 8 flow chart

Chapter 8

8. Thesis statement and practice-oriented recommendations
8.1 Chapter overview
8.2 Thesis statement
8.3 Motivation for the study
8.4. Summary of the main findings
8.5 Design of the DT-SME 2022 framework
8.6 Contribution of the study
8.7 Limitations of the study
8.8 Conclusions
8.9 Recommendations
8.10 Areas of future research
8.11 Final word

8.2 THESIS STATEMENT

The use of digital technologies, in particular the use of dynamic software applications in a transformational manner (Puentedura, 2006), including the exploitation of its affordances such as feedback, dragging, measuring, and tracing (Hojsted, 2020) for teaching mathematics in secondary schools, is linked to the promotion of deep conceptual understanding for the improvement of mathematics education outcomes. Based on the data analysis in Chapter 7, the study proposes a theoretical and practice-oriented framework, called the DT-SME 2022 framework.

The study suggests that shifting digital transformation in secondary mathematics education beyond the early stage can be facilitated by applying the DT-SME 2022 framework, which advocates (i) the kinds of intermediate and advanced digital skills of educators that are crucial for the successful implementation of digitally supported teaching of secondary school level mathematics; (ii) attention to digital leadership, including the establishment of a formal governance structure for the participation of all stakeholders during the design, implementation, and monitoring of a digital education policy; (iii) an effective technical architecture to address connectivity issues; and (iv) a constructive and enjoyable digital teaching experience that encourages learning-centred pedagogical approaches.

8.3 MOTIVATION FOR THE STUDY

This study arose from the researcher's interest in improving matric mathematics outcomes in South African secondary schools. The researcher is a former high school mathematics teacher who taught grades 11 and 12 for two and a half years in the Coffee Bay area of Mqanduli, Eastern Cape, from 1996 to 1998. In 1999, the researcher transitioned from being a mathematics teacher to obtaining a postgraduate diploma in engineering (PDE) from Stellenbosch University, specialising in satellite communications. The researcher is particularly interested in improving the mathematics pipeline so that the country has enough people who can pursue engineering and science degrees that encourage advanced digital skills such as robotics, 3D printing, AI, and cybersecurity, among others.

8.4 SUMMARY OF THE MAIN FINDINGS

The study sought answers to the main research question and the research sub-questions. The main research question is:

How can digital transformation in secondary mathematics education shift beyond the early stage?

Digital transformation in secondary mathematics education can be shifted beyond the early stage by the application of the DT-SME 2022 framework.

The research sub-questions are:

(a) How does professional development for educators advance digital skills for effective curriculum design and delivery for mathematics teaching and learning (human actors)?

The analysis in Chapter 7 indicates that there is a lack of the intermediate and advanced digital skills necessary for both course design and delivery, and that teacher professional development (TPD) initiatives should address this.

(b) How does the exercise of leadership (at the provincial and district levels) promote or impede (intentionally or unintentionally) the implementation of digitally supported teaching in schools (human actors)?

Leadership at all levels should be exposed to digitally supported teaching using dynamic software tools and should develop related frameworks, policies, or guidelines for practice. Additionally, the frameworks, policies, and guidelines should be accompanied by the requisite resources and the training of all involved i.e., district officials responsible for mathematics, heads of mathematics departments (HoDs), and mathematics teachers. Furthermore, a formal governance structure that involves all stakeholders should be established for the design, development, implementation, and monitoring of a digital education policy to ensure a common vision and realistic targets.

(c) What can be done to ensure that there is adequate internet connectivity, sufficient bandwidth, availability of devices, applications, and content (non-human actors)?

A technical architecture should be developed during the implementation of digitally supported secondary mathematics education in schools to ensure connectivity, security, and support, among others. Also, teacher and learner connectivity should be considered i.e., laptop devices and data (at school and home), among others.

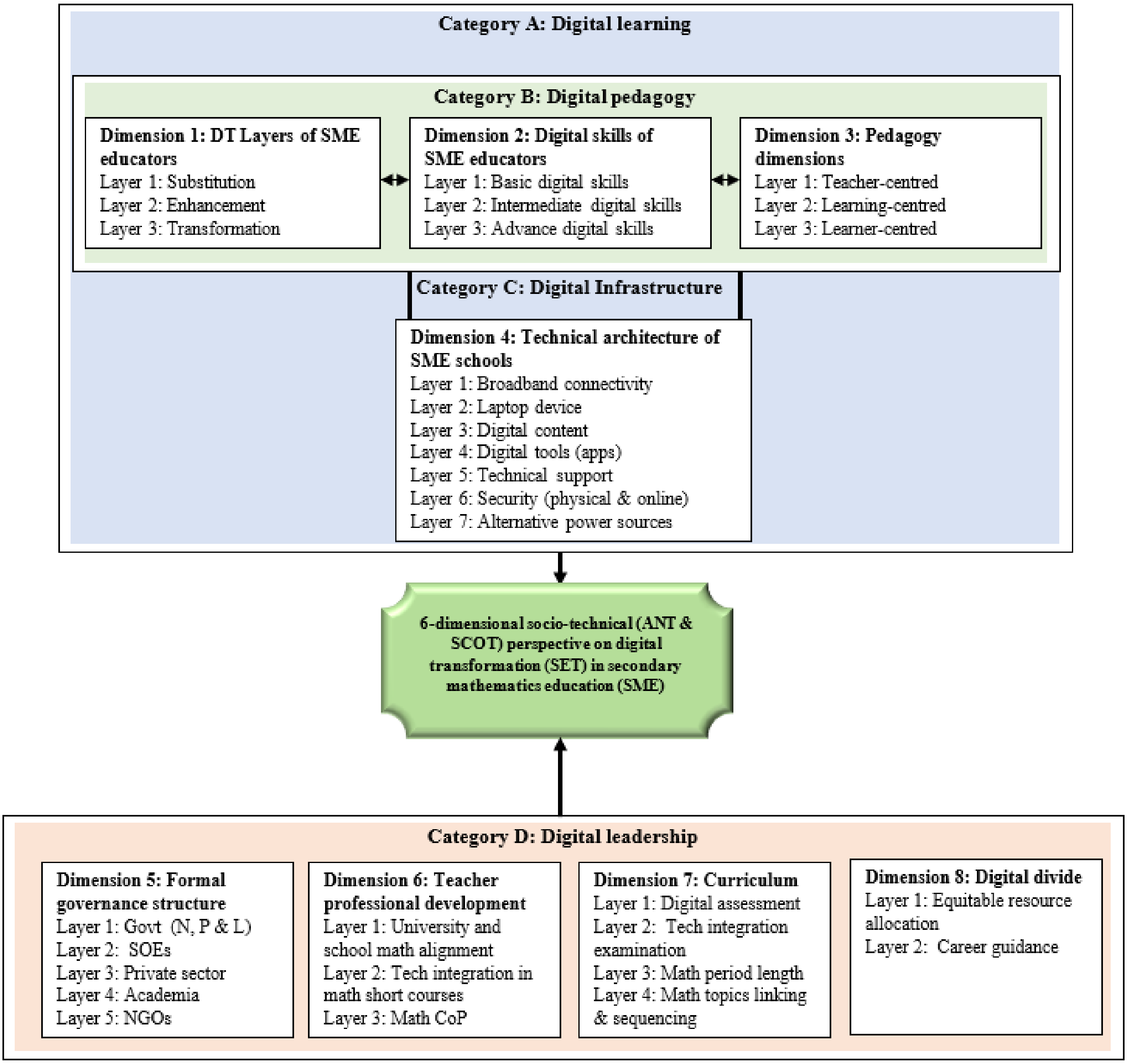
(d) How can digitally supported teaching improve the teaching experience and outcomes in secondary mathematics education (human actors)?

The analysis also indicates the need for educators to create a constructive and enjoyable digital teaching experience that encourages learning-centred pedagogical approaches.

8.5 DESIGN OF THE DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION 2022 (DT-SME 2022) FRAMEWORK

The main objective of this section is to design a revised DT-SME 2022 framework relevant for shifting digital transformation in secondary mathematics beyond the early stage, based on the interpretation of data that was presented in Chapters 4, 5, and 6. An exercise was undertaken to reorganise and prioritise the critical dimensions, including layers generated in Chapter 7, which resulted in a revised DT-SME 2022 framework with eight dimensions and 30 layers. Some of the key layers are briefly discussed under each dimension. Figure 46 shows the revised eight-dimensional DT-SME 2022 framework.

Figure 46
Revised eight-dimensional DT-SME 2022 framework



Source: Author

This adaptation ensures that the sociotechnical DT-SME 202 framework captures critical emergent ideas and dimensions that can be clearly understood, and it is focused on shifting digital transformation in secondary mathematics education beyond the early stage. Additionally, this research study shows a level of complexity associated with the implementation of digitally supported teaching of secondary mathematics education i.e., there is a nonlinear cause and effect relationship among the dimensions and the layers. This level of complexity involved in technology integration in secondary mathematics teaching and learning means that teachers, learners, schools, and the education system require orientation about dimensions, including the associated layers.

Furthermore, the dimensions of the revised DT-SME 2020 framework are broadly organised under four sociotechnical infused categories: category A – digital learning [human and non-human actors], which is conceptualised in this study to be constituted by category B – digital pedagogy [human actors] and category C – digital infrastructure [non-human actors], and category D – digital leadership [human actors]. Table 14 provides an overview of the eight dimensions.

Table 14
Overview of the dimensions used for the design of the final framework

Category A: Digital learning [human and non-human actors]		**Category D: Digital leadership [human actors]**
Category B: Digital pedagogy [human actors]	**Category C: Digital infrastructure [non-human actors]**	
Dimension 1: Digital transformation levels of SME educators	**Dimension 4:** Technical architecture of SME schools	**Dimension 5:** Formal governance structure during SME digital policy design, implementation, and monitoring
Dimension 2: Digital skills of SME educators		**Dimension 6:** Teacher professional development of SME educators
Dimension 3: Pedagogical dimensions of SME educators		**Dimension 7:** Curriculum
		Dimension 8: Digital divide

Furthermore, the updated framework has infused a sociotechnical perspective from the actor-network theory (ANT) and the social construction of technology (SCOT) theory, and transformation levels are described by the substitution-enhancement-transformation (SET) model adapted from Puentedura's (2006) SAMR model.

The DT-SME 2022 framework's eight imensions and the 20 associated layers that cover the key aspects of the research are detailed in this section.

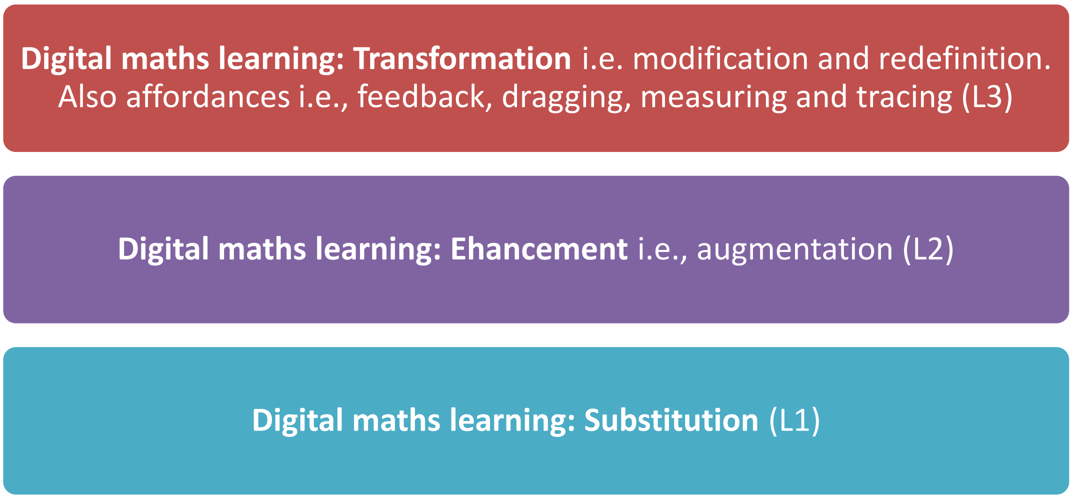
8.5.1 DIMENSION 1: DIGITAL TRANSFORMATION LEVELS OF SME EDUCATORS

Layer 1	Digital mathematics learning – Substitution
Layer 2	Digital mathematics learning – Enhancement
Layer 3	Digital mathematics learning – Transformation

The digital transformation levels of secondary mathematics education educators (or technology integration levels) have been adapted from Puentedura's (2006) SAMR model to the substitution-enhancement-transformation (SET) model where augmentation is equivalent to enhancement stage, and substitution and transformation are similar corresponding stages. Figure 47 provides an overview of the digital transformation levels of secondary mathematics education educators.

Figure 47

Overview of digital transformation levels of SME educators



Source: Adapted from Hojsted, 2020; Puentedura, 2006

These are briefly described below.

Digital maths learning – Substitution (layer 1): This is the simplest stage, where technology is used as a direct substitute for traditional practices. This stage is like Puentedura's (2006) SAMR substitution stage where technology acts as a direct substitute with no functional improvement, such as the current practices (use of e-textbooks on tablets and pdfs). Substitution strategies can save time and space by reducing laborious manual tasks in that, instead of printing resources that clutter the classroom, one can use technology to manage resources with just a few clicks (Best, 2015). The author further notes that substitution also provides a much more accessible introduction to technological soft skills and is the perfect opportunity for students to get comfortable with new technology before one starts to enhance or transform their learning i.e., substitution includes typing instead of handwriting, online quizzes and programs instead of pencil and paper, uploading of pdfs, using digital interactive white boards, as opposed to traditional white boards or blackboards, and saving results in a document. Moreover, the author indicates that the learning process or outcome is not affected by substitute techniques; before using technology, people must ask themselves what they will gain from it, and if it adds nothing but inconvenience, they should stick to pen and paper.

Digital maths learning – Enhancement (layer 2): Beyond convenience, technology might give students a clearer understanding of a complex topic or make it engaging in a way that traditional methods cannot. This stage is like Puentedura's (2006) SAMR augmentation stage, where technology acts as a direct substitute with some functional improvement, such as the use of static software (drawing on a smartboard and pdfs with links). Furthermore, technology may allow for the introduction of more independent and student-centric learning, where using technology becomes a source of information, and students can start to actively learn without requiring constant teacher-led instruction. In this study, enhancement is associated with the use of static software i.e., static Excel spreadsheets, pdfs with links, etc.

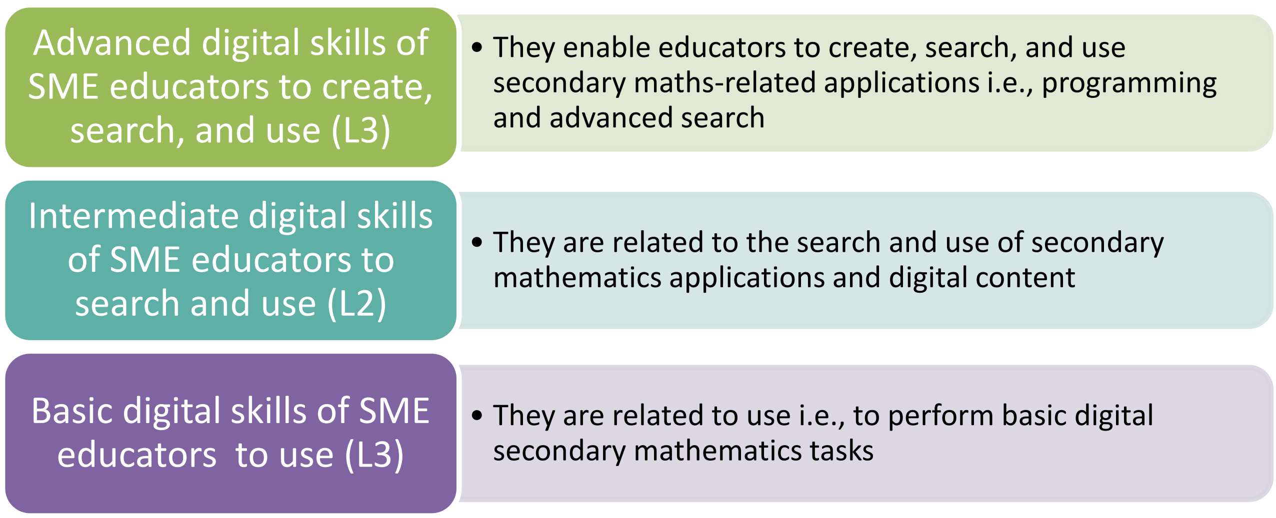
Digital maths learning – Transformation (layer 3): Technology is used to design interactive and dynamic tasks that go beyond the limitations of a traditional classroom and make entirely new learning opportunities possible. This stage is like Puentedura's (2006) SAMR transformation stage, where technology allows for significant task redesign (modification stage) and the creation of new tasks previously inconceivable without technology (redefinition stage), including the exploitation of the affordances of dynamic software applications i.e., feedback, dragging, measuring, and tracing from Hojsted (2020).

8.5.2 DIMENSION 2: DIGITAL SKILLS LEVEL OF SME EDUCATORS

Layer 1	Basic digital skills of SME educators to use (apps)
Layer 2	Intermediate digital skills of SME educators to search and use (apps)
Layer 3	Advanced digital skills of SME educators to create, search, and use (apps)

The layers have been adapted from the ITU's (2020) three broad categories: basic digital skills, intermediate digital skills, and advanced digital skills. The original dimensions have been changed i.e., digital skills of educators for course design have been changed to digital skills of SME educators to use (apps); and digital skills of educators for course delivery have been changed to digital skills of SME educators to create, search, and use (apps). Figure 48 shows the categories of digital skills of educators.

Figure 48
Overview and description of the study's categories of digital skills of SME educators



Source: Adapted from ITU (2020)

8.5.3 DIMENSION 3: PEDAGOGOGICAL DIMENSIONS OF SME EDUCATORS

Layer 1	Teacher-centred
Layer 2	Learning-centred
Layer 3	Learner-centred

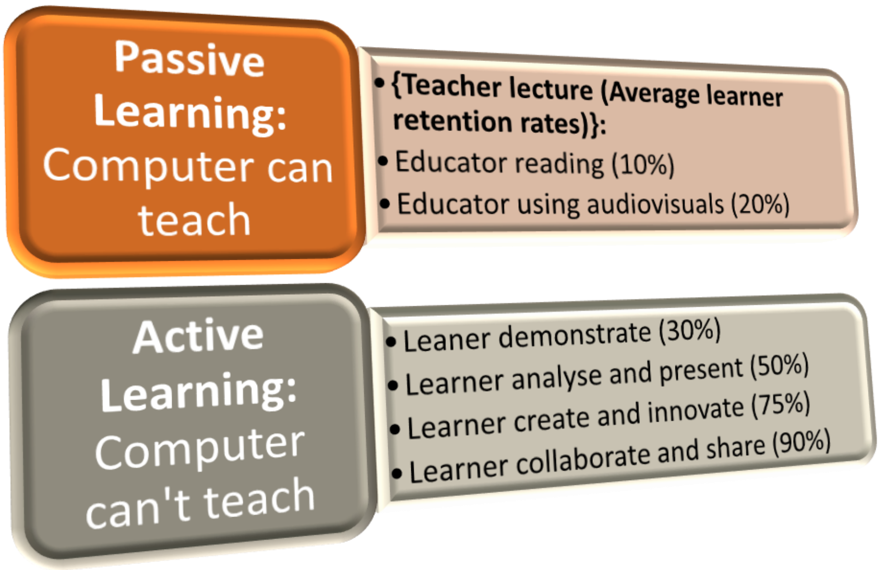
Pedagogy can be teacher-centred (behaviourist), learning-centred (behaviourist and social constructivist), and learner-centred (social constructivist), as indicated by Westbrook at al. (2013).

Teacher-centred (layer 1): "In a teacher-centred learning environment, the teacher functions in the familiar role of classroom lecturer, presenting information to the students, who are expected to passively receive the knowledge being presented. This may be considered the more traditional or conventional approach to education" (Lathan, 2023).

Learning-centred (layer 2): A learning-centred classroom focuses on learning – where the teacher designs learning experiences to help learners learn mathematics, using whatever teaching and learning strategies are thought to be most suitable for the specific lesson that will be taught (DBE, 2018b).

Learner-centred (layer 3): Learner-centred approaches are associated with active learning due to learner involvement which results in better learner retention rates and is not easily undertaken by a computer only as it requires guidance (E. Sampa, personal communication, 15 October 2020). Figure 49 depicts both passive and active learning retention rates.

Figure 49
Teacher-centred (passive) versus learner-centred (active) learning



Source: Adapted from Sampa, 2020

8.5.3.1 DIGITAL PEDAGOGY OF SME EDUCATORS

Digital pedagogy, in this study, is conceptualised as the intersection of (i) digital transformation levels of SME educators (digital mathematics learning – substitution, enhancement, and transformation); (ii) digital skills levels of SME educators (basic, intermediate, and advanced); and (iii) pedagogical dimensions of SME educators (teacher-centred, learning-centred, and learner-centred). Additionally, digital pedagogy is assumed to be optimal when teachers possess intermediate and advanced digital skills, learning-centred pedagogy is applied, and the transformational level includes the exploitation of dynamic software affordances i.e., feedback, dragging, measuring, and tracing (Hojsted, 2020). This study views digital pedagogy as a radical pedagogical shift that is required to reap the benefits of the digitally supported teaching of secondary mathematics in schools. Moreover, digital pedagogy is one of the missing links in shifting digital transformation in secondary mathematics beyond the early stage. However, the local context, class size, the physical environment, and the availability of resources, among others, should also be considered. Table 15 maps the digital pedagogy of SME educators being advocated by this study.

Table 15
Mapping of digital pedagogy of SME educators

Transformation levels [Digital skills levels]	**Digital maths learning – Transformation (modification and redefinition; affordances of dynamic software apps [Excel, GeoGebra, GSP, etc.] i.e., feedback, dragging, measuring, and tracing)** [*Advanced digital skills* i.e., programming or content creation]	**Modification and redefinition; affordances of dynamic software apps [Excel, GeoGebra, GSP, etc.] by teacher; Passive learning** i.e., **Demonstration; lecturing**	**Modification and redefinition; affordances of dynamic software apps [Excel, GeoGebra, GSP, etc.] by teacher & learner; Active learning** i.e., **collaboration; coordination; cooperation**	**Modification and redefinition; affordances of dynamic software apps [Excel, GeoGebra, GSP, etc.] by learner**; Active learning i.e., **Flipped classroom**
	Digital maths learning – Enhancement (augmentation) [*Intermediate digital skills* i.e., critically evaluate technology or content search]	Static software by teacher [i.e., pdfs with links, static Excel graphs] – **Demonstration; lecturing**	Static software by teacher & learner [i.e., pdfs with links, static Excel graphs] – **Active learning i.e., collaboration; coordination; cooperation**	Static software by learner [i.e., pdfs with links, static Excel graphs] – **Flipped classroom**
	Digital maths learning – Substitution [*Basic digital skills* i.e., performing basic task or content use]	Pdfs/e-textbooks and whiteboard by teacher – **Demonstration; lecturing**	Pdfs/e-textbooks and whiteboard by teacher and learner – **Active learning i.e., collaboration; coordination; cooperation**	Pdfs/e-textbooks and whiteboard by learner – Active i.e., **Flipped classroom**
NB: Dynamic software apps (GeoGebra, GSP, etc) can be in a laptop (with a projector), IWB or tablet (tablets are not recommended for high schools as they do not facilitate content creation)		**Teacher-centred** [Behaviourist]	**Learning-centred** [Behaviourist and social constructivist]	**Learner-centred** [Social constructivist]
		Pedagogy dimensions [Learning theories]		

Source: Author

Digital pedagogy is closely associated with the successful use of digital technologies for teaching secondary mathematics in schools. According to Blewett (2020), the failure of instructors to integrate digital technologies is due to our training in pedagogy, specifically digital pedagogy. The author proposed activated classroom teaching model (ACT) that uses 5 digital-age pedagogies (Curation, Conversation, Correction, Creation, Chaos) to encourage engagement. A consideration of Blewett's framework, however, is beyond the scope of this study.

Although the researcher agrees with Blewett (2020) that we cannot blame technology, the researcher's view is that teachers must receive training on intermediate and advanced digital skills to enable them to create or search and use digital tools, including training on learning-centred pedagogical approaches and transformational ways of using digital tools.

Furthermore, the literature supports the view that digital skills and pedagogy must be treated distinctly. According to Pouezevara et al. (2014, p. 120):

> ICT in education projects must favour neither the hardware nor the pedagogical aspects of the technology. Instead, they must layer the pedagogical use of technology on top of deliberate technology infrastructure. The technical and pedagogical aspects of the program should be treated as two distinct efforts with separate, but complementary goals. Paying attention to social, political, economic, and technological dimensions during the process can make a difference in sustainability and, ultimately, the success of the initiative.

On the other hand, critical digital pedagogy (associated with activism) is defined by Stommel (2014) as "an approach to teaching and learning based on fostering agency and empowering learners (implicitly and explicitly criticising oppressive power structures)." The author summarises that critical digital pedagogy:

- centres its practice on community and collaboration;
- must remain open to diverse, international voices, and thus requires invention to reimagine how communication and collaboration happen across cultural and political boundaries;
- will not, cannot, be defined by a single voice but must gather together a cacophony of voices;
- must have use and application outside traditional institutions of educations.

The author further mentions that "critical pedagogy demands that open and networked educational environments must not merely repositories of content. They must be platforms of engaging students and teachers as full agents of their own learning."

***There is no such thing as a neutral educational process. ~ Paulo Freire,* Pedagogy of the Oppressed**

Activism in the education sector should not stop at wage negotiations but should extend to professional development and investigating the latest digital pedagogical approaches, among others. However, in the current environment, teachers wait for departmental support for almost everything, instead of being radical in calling for their professional capacitation and canvassing the requisite resources, not only from government but also through their teacher unions and exercising their buying power, for example i.e., bulk buying products and services from companies through their union for members. A further discussion of critical pedagogy is beyond the scope of this study.

8.5.4 DIMENSION 4: TECHNICAL ARCHITECTURE OF SME SCHOOLS

Layer 1	Broadband connectivity
Layer 2	Laptop device
Layer 3	Digital content
Layer 4	Digital tools (apps)
Layer 5	Technical support
Layer 6	Security (physical and online)
Layer 7	Alternative power sources

A technical architecture for addressing internet connectivity issues in schools has been proposed, which includes some of the teacher connectivity (also learner connectivity) issues to ensure successful digital teaching and learning of secondary mathematics in schools. LeanIX (2022) defines technical architecture as "a form of IT architecture that is used to design computer systems. It involves the development of a technical blueprint regarding the arrangement, interaction, and interdependence of all elements so that system-relevant requirements are met." The seven layers can be described as follows (Adelabu at al., 2022; GP1, 2020; Mokotjo & Mokhele, 2021; US Department of Education, 2020):

Broadband connectivity (layer 1): High-speed internet connectivity in schools, including high-speed Wi-Fi throughout schools, and home internet access is essential.

Laptop device (layer 2): High quality low-cost devices are required.

Digital content (layer 3): High quality digital content is required.

Digital tools or apps (layer 4): The use of the dynamic software application GeoGebra in the teaching and learning of secondary mathematics promotes higher learning gains.

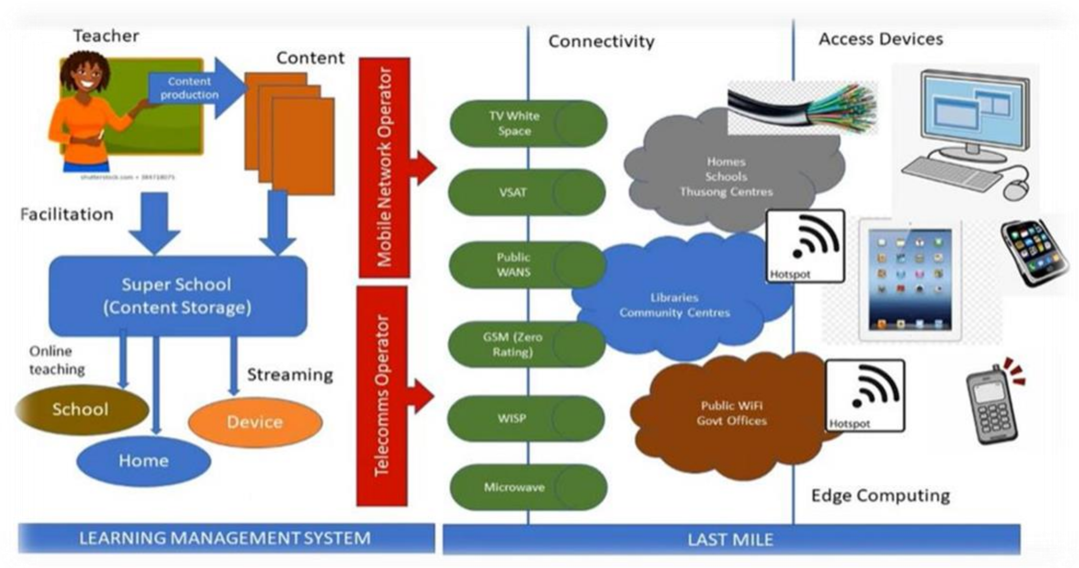
Technical support (layer 5): Technical support is a challenge for most schools in South Africa.

Security – physical and online (layer 6): Data privacy and security, digital citizenship, and responsible use are essential. High schools in South Africa are prone to robbery and vandalism of school digital infrastructure due to security lapses.

Alternative power sources (layer 7): Schools need alternative power sources to mitigate the effects of loadshedding or power outages in general, including planning activities that do not need power to be carried during periods of no power.

All the elements of the technical architecture should ensure connectivity for teachers and learners in schools and at home, including the availability of local support to ensure short turnaround times in case of connectivity issues. Data should be purchased for educators. Figure 50 depicts some of the aspects of a technical architecture.

Figure 50
A typical technical architecture for SME school and home Wi-Fi connectivity



Source: Adapted from Altron, 2021

8.5.5 DIMENSION 5: FORMAL GOVERNANCE STRUCTURE DURING SME DIGITAL POLICY DESIGN, DEVELOPMENT, AND MONITORING

Layer 1	Government (national, provincial, and local)
Layer 2	State-owned enterprises (SOEs)

Layer 3	Private sector
Layer 4	Academia
Layer 5	Non-governmental organisations (NGOs)

Conrads et al. (2017) found that one of the key drivers in digital education policy design, implementation, and monitoring for a country is the establishment of a specific formal governance structure. The authors state the following regarding the establishment of specific governance structures:

> Beyond mere coordination and monitoring functions, governance structures hold the project team accountable for putting an initiative into action, for implementing action plans and for delivering results. Often implemented in the form of a steering committee, specific governance structures help coordinate and monitor the initiative into action, for implementing action plans and for delivering results. (Conrads et al., 2017, pp. 39–40)

A formal governance structure proposes a way of organising key stakeholders for their involvement in the design, development, and implementation of a digital education policy to ensure the alignment of various government and private sector initiatives. Furthermore, a formal multi-stakeholder governance structure is key for ensuring that the targets set by the various stakeholders involved are similar and realistic. For example, broadband-like internet connectivity for schools should be agreed to by all the stakeholders involved in the digital infrastructure rollout in schools.

Government i.e., national, provincial, and local (layer 1): While the national Department of Education should coordinate the establishment of the formal governance structure, all the three tiers should form part of the structure. Schools should form part of the formal structure, as well as teacher union representatives in line with the three tiers of government.

SOEs (layer 2): SOEs such as Telkom, Eskom, Transnet, the Universal Services Agency of South Africa, and Sentech, among others, should also form part of the governance structure and provide inputs on the infrastructure requirements for schools.

Private sector (layer 3): These are companies such as MTN, Vodacom, and Cell-C.

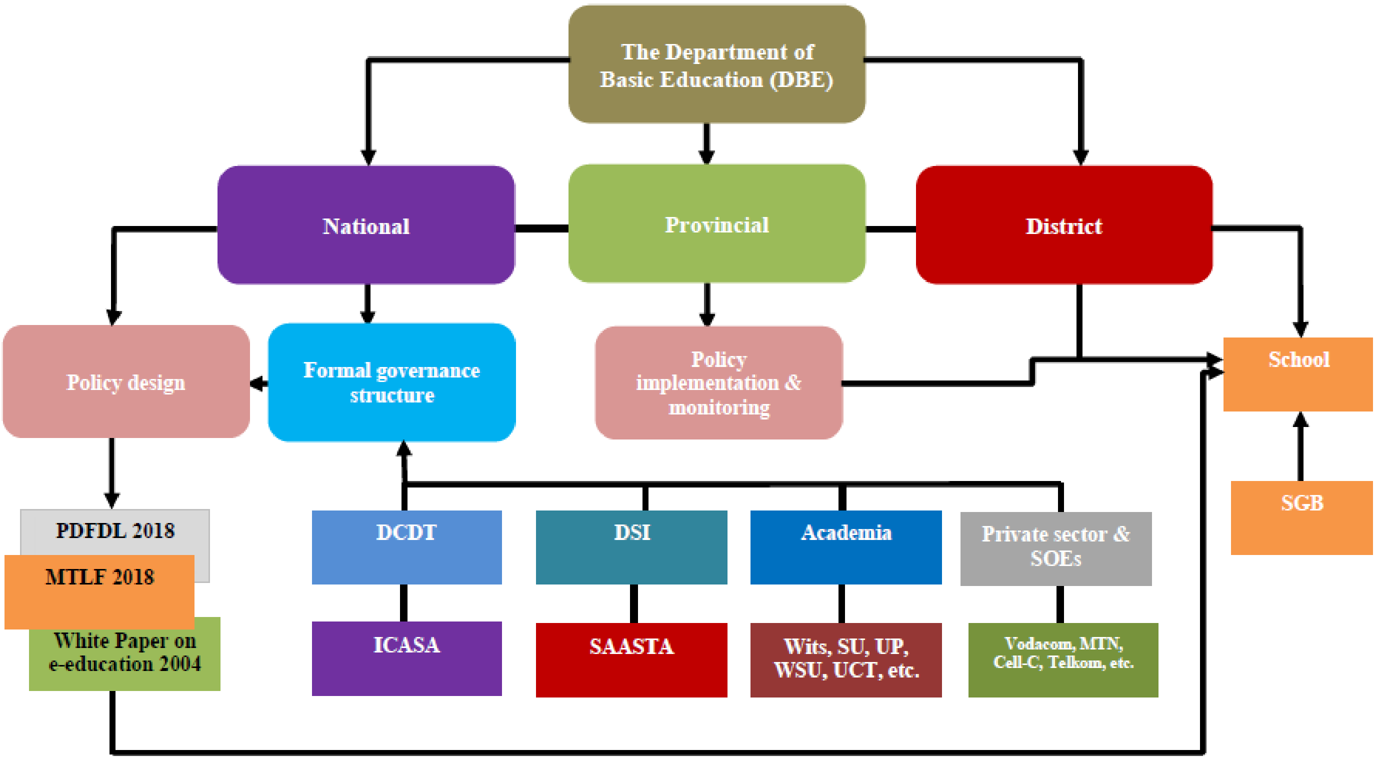
Academia (layer 4): South African universities such as the University of the Witwatersrand, Stellenbosch University, the University of Pretoria, and Nelson Mandela University, among others, should be part of the governance structure for research, making suggestions on the latest studies, and for tracking progress on implementation.

NGOs (layer 5): This sector is important to hold all the players accountable.

Figure 51 shows some of the components of a formal governance structure.

Figure 51

Formal governance structure for digital teaching of secondary mathematics in schools



Source: Author

8.5.6 DIMENSION 6: TEACHER PROFESSIONAL DEVELOPMENT OF SME EDUCATORS

Layer 1	University and school maths alignment
Layer 2	Tech integration in maths short courses
Layer 3	Maths community of practice

The TPD of pre-service secondary mathematics education teachers should be aligned to in-class mathematics needs.

University and school maths alignment (layer 1): GD2 (2020) pointed out that there is a mismatch between university mathematics and school mathematics, noting that geometry is not taught at university. In order to address this, education leaders should engage with universities. Additionally, universities and industry should develop short courses to promote technology integration in secondary mathematics teaching and learning, including closing the gaps in mathematics content.

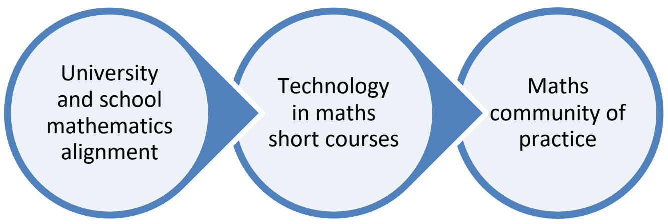
Technology integration in mathematics short courses (layer 2): Interventions in the form of short courses should primarily bridge the gap between university and classroom needs, such as the latest digital pedagogies related to technology integration in secondary education, including content, which is currently the main focus of most TPD initiatives.

Maths community of practice (layer 3): The establishment of a community of practice or mathematics professional learning communities for practising educators is essential.

Figure 52 shows the path to addressing the university and school mathematics mismatch.

Figure 52

Addressing university and school mathematics mismatch



8.5.7 DIMENSION 7: CURRICULUM

Layer 1	Digital assessment
Layer 2	Technology integration examination
Layer 3	Mathematics period length
Layer 4	Mathematics topics linking and sequencing

Digital assessment (layer 1): Participant observations (2020) showed that the old ways of testing and examination (pen and paper) are prevalent. Digital assessment provides instant feedback and can be good for continuous assessment. However, it is mainly private sector players that have developed the digital assessment platforms, which might be expensive for the public sector given the large numbers and the disparities related to digital infrastructure, as stated earlier.

Technology integration examination (layer 2): E2 (2021) indicated that the use of digital tools for teaching and learning mathematics in secondary schools is not assessed, including the associated pedagogical approaches, resulting in no motivation or effort.

Mathematics period length (layer 3): During participant observations (2020), one specific issue raised was the need to design longer class periods i.e., the ideal period would be 90 minutes, which could happen once or twice a month as 40 or 45 minutes is not sufficient time to enjoy the benefits of learning with dynamic software.

Mathematics topics linking and sequencing (layer 4): GP1 (2020) pointed out that teachers do not link different topics. Participant observations (2020) showed that mathematics topics are taught separately and hence requests for curriculum resequencing had to be made to the education department to enable the linking of different topics.

8.5.8 DIMENSION 8: DIGITAL DIVIDE

Layer 1	Equitable resource allocation
Layer 2	Career guidance

Equitable resource allocation (layer 1): Participant observations (2020) showed that there is no equitable resource allocation amongst schools.

Career guidance (layer 2): Data showed that there is limited career guidance to promote science, technology, engineering, and mathematics (STEM) pathways.

8.5.9 THE ADVANTAGES OF THE REVISED DT-SME 2022 FRAMEWORK OVER THE INITIAL DT-SME FRAMEWORK

The initial DT-SME framework was based on Hanna's (2016) digital transformation ecosystem that was proposed in Chapter 2, which was developed due to the literature's lack of theoretical models and frameworks focused on shifting digital transformation in secondary mathematics beyond the early stage. The initial framework was instrumental in guiding the data collection, analysis, and interpretations using its four dimensions, namely, the digital skills of educators, leadership in the implementation of digitally supported teaching of secondary mathematics in schools, school digital infrastructure, and digital teaching experience. The revised DT-SME 2020 framework (see Figure 46) was developed based on the analysis of data and comprises eight dimensions associated with shifting digital transformation beyond the early stage, namely (i) digital skills of SME educators; (ii) digital transformation levels of SME educators; (iii) pedagogical dimensions of SME educators; (iv) technical architecture of SME schools; (v) formal governance structure during SME digital policy design, implementation, and monitoring; (vi) teacher professional development; (vii) curriculum; and (viii) the digital divide. Additionally, the dimensions are broadly organised under four categories, namely [A] digital learning [human and non-human actors]; [B] digital pedagogy [human actors]; [C] digital infrastructure [non-human actors]; and [D] digital leadership [human actors].

The DT-SME 2022 framework provides a wide coverage of sociotechnical issues and can be used to complement the DBE's (2018b) existing Professional Development Framework for Digital Learning and the Mathematics Teaching and Learning Framework of 2018. In particular, the framework can guide the conceptualisation of the digital skills of secondary mathematics educators (basic, intermediate, and advanced), digital transformation levels or technology integration levels (substitution, enhancement, and transformation), and pedagogical dimensions (teacher-centred, learning-centred, and learner-centred). The intersection of these aspects is key to understanding digital pedagogy as proposed in this study. Additionally, the framework calls for the inclusion of key players in a formal governance structure during digital education policy design, development, and implementation. Furthermore, an evolving technical architecture is needed to address most or all connectivity issues in schools.

8.6 CONTRIBUTION OF THE STUDY – THE NEED FOR THEORISING THE PLACE OF DIGITALLY SUPPORTED SECONDARY MATHEMATICS EDUCATION IN THE 21ST CENTURY DIGITAL ECONOMY

Cryer (2006) mentions various kinds of originality in PhD research, such as originality in tools, techniques, and procedures (methodology); originality in exploring the unknown, unexplored, and unanticipated; originality in data, transfer of mode or place of use; originality in by-products; originality in the experience; and originality as "potentially publishable". This research claims originality on the following grounds: (i) originality in the research data; and (ii) originality as "potentially publishable". This study also claims originality on the grounds of advancing new theory: the DT-SME 2022 framework aims to shift digital transformation in secondary mathematics education beyond the early stage.

Contribution to theory is a process that includes using logic and facts to build on and improve an existing theory (Zhou et al., 2017). This study focused on theoretical contribution by answering research questions through literature and data gathering to build a theory (action research) to propose a theory, the DT-SME 2022 framework that aims to shift digital transformation in secondary mathematics beyond the early stage. The research seeks to contribute to this specific narrow area of understanding and theorising digital transformation, namely using dynamic software in mathematics teaching secondary mathematics. This aspect addresses the grand theory discussion of digital transformation. This is an interdisciplinary social constructivist case study that investigates the interaction between the four dimensions (digital skills of educators, leadership in the implementation of digitally supported teaching, digital teaching experience, and school digital infrastructure) derived from the technology and education fields and their contribution to shifting digital transformation in secondary mathematics beyond the early stage.

Contribution to practice entails the creation of an artefact in case study A (the PP: ADS short course) which was geared towards practice, and which discusses the highly specific digital transformation in education, particularly the use of dynamic software for teaching mathematics in secondary schools (practice). Additionally, this intervention seeks to equip teachers with skills in using dynamic software for teaching mathematics. Overall, the "mature digital ecosystem for digitally supported secondary mathematics education" theory of social success is offered as an explanation from the literature, observations, documents, and interviews. The optimal support of the dimensions of the study, the adoption of pedagogical principles, and the selection and use of appropriate dynamic software tools have the potential to orchestrate a shift beyond the early stage. It is hoped that the findings of this study will help secondary mathematics teachers, principals, policymakers, and academics to understand that the digitally supported teaching of secondary mathematics is a complex and interdisciplinary phenomenon that requires an ecosystem approach. Successful completion of this study may offer insights to secondary mathematics educators, mathematics specialists in the DBE, and TPD programmes at universities on how to use an ecosystem approach when introducing the digitally supported teaching of secondary mathematics in schools.

The DBE should play a key role in the design, development, and implementation of a holistic digital education policy that involves all major role-players via a formal governance structure for accountability on the set targets. The DBE leadership at all levels should also understand the importance of the use of digital technologies in a transformational manner in the teaching of mathematics in secondary schools and the associated digital pedagogy proposed in this study.

8.7 LIMITATIONS OF THE STUDY

This section acknowledges some of the limitations of the findings of this study.

(i) The researcher was a teacher some time ago and then worked in the government digital policy environment in various capacities before starting his doctoral degree. He was partly involved in the conceptualisation and design of the short course that was observed in case study A. The researcher acknowledges that this could have led to bias due to his familiarity with the education sector.

(ii) Digital transformation is a new concept in the education sector. The respondents might not have been aware of the trends (i.e. digital learning, digital pedagogy, learning-centred, etc.) and this might have impacted the ways in which they responded.

(iii) Respondents might have interpreted questions differently from what was expected for the research and might have unintentionally provided incorrect responses.

(iv) The data was collected qualitatively; hence, the focus of the study was mainly a small selection of participants from the population for interview sessions.

(v) Some participants provided various excuses not to participate, citing a lack of understanding of digital technologies or the absence of digital tools for teaching secondary mathematics. Some simply ignored the researcher's communication attempts i.e., not answering emails or telephone calls.

(vi) The Saldanha Bay Industrial Development Zone Licencing Company provided partial funding for this study in respect of the PP: ADS short course in case study A. The researcher believes that it is important to acknowledge this source of funding, as it came from an institution that was also part of the study.

(vii) The study was confined to the context of two case studies in South Africa where data was collected. The study can only make modest claims about the generalisability of the research as the two case studies were conducted in South Africa. Klein and Myers (1999, p. 75) argue that interpretative research provides a philosophical basis for abstractions and generalisations: "unique instances can be related to ideas and concepts that apply to multiple situations. Nevertheless, it is important that theoretical abstractions and generalizations should be carefully related to the field study details as they were experienced and/or collected by the researcher. This is so readers can follow how the researcher arrived at his or her theoretical insights."

These limitations, however, did not impact the validity of this study. Most secondary schools face common challenges that can be broadly categorised into digital skills, digital learning, digital leadership, and digital infrastructure. The findings of this research can be generalised to similar developing countries in the SADC region and beyond.

8.8 CONCLUSIONS

The following conclusions can be reported:

(i) Technology is currently used in a substitutional or enhancement manner in the teaching and learning of secondary mathematics, and is far from transformational.

(ii) Basic digital skills are still prevalent in the public education sector, particularly in secondary mathematics education.

(iii) Teacher-centred pedagogical approaches continue to be used during the digital teaching of mathematics in secondary schools.

(iv) A technical architecture to address challenges related to connectivity in schools is absent.

(v) A formal governance structure for the design, development, and implementation of digital education policies is lacking.

(vi) TPD activities geared towards classroom needs are lacking, for example, technology integration in secondary mathematics and the university and classroom maths gap, among others.

(vii) Digital assessment is lacking, including non-examination technology integration in mathematics teaching and learning in high schools.

(viii) Equitable resource allocation in schools is limited.

8.9 RECOMMENDATIONS

Based on the research findings, the researcher recommends the following:

(i) Regarding technology integration in secondary mathematics, the transformational level use of technology should be clearly understood.

(ii) Given the role of digital skills, the intermediate and advanced digital skills of educators need to be developed.

(iii) A pleasant digital teaching experience that encourages a learning-centred pedagogical approach needs to be created.

(iv) In terms of infrastructure, a technical architecture is needed for schools that considers connectivity, quality of internet connectivity, devices, and applications as well as local support and security (online and physical), among others. In addition, teacher connectivity (i.e., laptops with data for teachers as tablets are not suitable for high schools for content creation) should be factored in during the implementation of digitally supported teaching.

(v) DBE leadership at all levels should be kept abreast of digital pedagogy issues through short courses (capacity building). Additionally, there is a need to establish a formal governance structure for the design, development, implementation, and monitoring of digital education policies to ensure that appropriate digital infrastructure is made available to schools.

(vi) Teacher development programmes should be aimed at addressing the gaps between university and classroom practice. Additionally, the DBE should work closely with universities to ensure that the university training of pre-service teachers is aligned with current classroom needs. Furthermore, pre- and in-service secondary mathematics teachers at universities should be exposed to transformational ways of teaching mathematics using dynamic software tools such as GeoGebra, Geometer's Sketchpad, and Desmos, among others. GeoGebra is freely available and has an online community. Moreover, a secondary mathematics community of practice should be formally integrated into DBE governance and practice in all the districts. The University of Witwatersrand could also establish a GeoGebra institute, like other universities around the world that have done so. Currently, only two institutions in South Africa, one at the University of KwaZulu-Natal and the other at Nelson Mandela University in Gqeberha (Port Elizabeth), support and train teachers in GeoGebra.

(vii) The DBE should consider the assessment or examination of transformational ways of teaching i.e., some aspects of technology integration could be assessed to stimulate adoption and continued use, taking into account the context in which schools operate. Additionally, mathematics class periods should be increased to one hour or more for successful digital learning, including linking different topics in single lessons with associated sequencing of topics. Furthermore, subject groups could be taught on a specific day, for example, physical, mathematical, computer, and life sciences on Mondays; business, commerce, and management sciences on Tuesdays; human and social sciences on Wednesdays; languages on Thursdays; and agricultural sciences on Fridays.

(viii) To address digital divide issues, equitable resource allocation strategy and career guidance should be put in place. To address social issues such as poverty, lack of parental involvement, and alcohol and drugs in schools, the DBE should work closely with other relevant stakeholders, for example, the Department of Social Development.

8.10 AREAS FOR FUTURE RESEARCH

The qualitative nature of this study meant that documents, participant observations, and participants' perspectives on the use of digital technologies in the teaching of mathematics in secondary schools were examined and analysed. The researcher would like to outline the following four suggestions for further research:

(i) Further research could be undertaken with the same philosophy, but focusing on the primary education sector. Conducting the same research in the primary mathematics education sector might have different outcomes.

(ii) An ethnographic study of the use of digital technologies for teaching mathematics in the secondary school sector in South Africa is an important area to consider.

(iii) As this research examined two complementary case studies in South Africa, the same research could be repeated in other developing countries in the SADC region and beyond.

8.11 FINAL WORD

Digital transformation or the use of technology in the education sector, particularly for the teaching and learning of secondary mathematics in schools, has the potential to promote deep conceptual understanding for the improvement of learning outcomes when used in a transformational manner. However, close examination has shown that while various technologies are used in the classroom, this use is mainly for enhancement, and is scarcely transformational, particularly in the teaching of mathematics in secondary schools. Additionally, the transformational use of digital technologies for teaching mathematics requires digital pedagogy, conceptualised in this study to be optimal at the intersection of pedagogy dimension (learning-centred), transformation level of the substitution-enhancement-transformation (SET) model, and digital skills level (intermediate and advanced). Furthermore, TPD programmes should go beyond providing basic digital skills and rather provide integrated training on intermediate and advanced digital skills, the use of learning-centred approaches, and the ability to exploit the transformational affordances offered by dynamic software applications that are linked to the deepening of conceptual understanding for improved outcomes. Otherwise, teachers will continue to use technology as an enhancement tool. It can be argued that South African teachers are currently in the learning phase and are not using technology for teaching secondary mathematics in schools, which is demonstrated by a lack of resourcefulness when there are problems such as load shedding, as there are no existing mitigation measures as in other industries. Some teaching and learning activities do not necessarily need electricity and can be carried out during power outages; powered devices can be used when the power is restored or alternative power sources such as solar, for example, can be used. Small-scale comparative studies have shown that technology integration in mathematics teaching and learning improves results, compared to the traditional means of teaching (chalk and talk). It remains to be seen if dynamic software such as GeoGebra – if widely adopted by all schools in South Africa – will contribute to the improvement of the matric maths results and the country's international rankings in the subject.

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Appendices

Appendix A
Ethics Clearance Certificate

Research Office

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

ACKNOWLEDGEMENT OF RETROSPECTIVE APPLICATION FOR ETHICS CLEARANCE
R14/49

CERTIFICATE OF RETROSPECTIVE ACKNOWLEDGEMENT
PROTOCOL NUMBER H20/04/14

PROJECT	Exploring early stage digital transformation in secondary mathematics education
INVESTIGATORS	Mr S Mata
DEPARTMENT	School of Literature, Language and Media
DATE CONSIDERED	24 April 2020
EXPIRY DATE	06 August 2023
DECISION OF THE COMMITTEE*	Retrospective Acknowledgement Risk Level: Minimal

NOTE:
- **The HREC (Non-Medical) acknowledge receipt of this retrospective ethics clearance application.**
- **The HREC (non-medical) found no ethics problems.**
- **This acknowledgment is valid for three (3) years.**

DATE 07 August 2020 CHAIRPERSON ....
(Professor J Knight)

cc: Supervisor: Dr L Abrahams

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.

I/We acknowledge that appropriate permission should have been sought, this acknowledgement does not entitle the applicant to conduct further research under this protocol number.

Signature

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix B
Informed Consent Form

INFORMED CONSENT FORM FOR INTERVIEWS

Title of project: Exploring early-stage digital transformation in secondary mathematics education

Name of researcher: Songezo Mata

I, ………………………………………. agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please tick the relevant box below)

	YES	NO
I agree that my specific contribution to the data will be written up under a pseudonym.		
I agree that the researcher may use quotes in his/her research report using a pseudonym for me.		
I agree that the interview may be audio recorded.		
I agree that the information I provide may be used for academic purposes, by other researchers, subject to their own ethics clearance being obtained and subject to the use of a pseudonym.		
I agree to the use of anonymised quotes in any publications.		
I agree that data gathered from me in this study may be stored (after it has been anonymised) and may be used for future research.		

Name of participant	**Date**	**Signature**

Songezo Mata

Name of researcher	**Date**	**Signature**

Appendix C
Observation Guide

OBSERVATION GUIDE: EXPLORING EARLY-STAGE DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION

Broad designation and institution of Key Informant (for analysis purposes only):

Date of observation: The observation guide is used to record both historical and future information related to digital skills cases A1 & A2 on course design and delivery respectively.

Length of Activity: Twelve weeks due to the shift to hybrid mode of learning	
Descriptive Notes	**Reflective Notes**
1. Course content design: Teaching approaches and tools *1a. Pedagogical principles*: (i) What are the pedagogical principles that teachers are being encouraged to use in the mathematics classroom, and why? *1b. Technology as input (static/dynamic)*: (i) How are static and dynamic technologies used in combination in the design process? • Excel/GeoGebra • Pencil and paper • Website, e-mail, skype, MOOCs, etc • Other (ii) What other focus is given to technology as input in the course design?	
2. Artefacts: The design of the classroom environment for the course. • Characteristics and benefits of online (website, e-mail, skype, MOOCs, etc.) and offline course delivery methods (telephonic). • Strengths and weaknesses of classroom set up including presentation laptop, overhead projector, venue and seating arrangements • Strengths and weaknesses of curriculum structure and content • Strengths and weaknesses of textbooks, materials, hand-outs and applets • Strengths and weaknesses of assignment responses and lesson plans	
3. Course delivery *3a. Pedagogical principles*: (i) How do teachers engage with/respond to the relevant pedagogical principles and related teaching approaches? (ii) How are the exercises/assignments contributing to understanding the pedagogy of digitally supported teaching? (iii) How are the exercises/assignments contributing to understanding the practice of digitally supported teaching? *3b. Technology as input (static/dynamic)*: (iii) How are static and dynamic technologies used in combination by teachers? 4. Excel/GeoGebra 5. Pencil and paper 6. Website, e-mail, Skype, MOOCs, etc 7. Other	

(iv)	What is the nature of the discussion amongst teachers of the benefits of dynamic software over static teaching tools?	
(v)	Any other relevant points raised by teachers.	

Appendix D
Interview Guide

SEMI-STRUCTURED INTERVIEW GUIDE: EXPLORING EARLY-STAGE DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION

Broad designation and institution of Key Informant (for analysis purposes only):

Date of interview:

Please note that these are guiding questions. The researcher is interested in noting and understanding issues related to early-stage digital transformation in secondary mathematics education, particularly those elements that foster digital transformation.

Dimension A0 – General opening question

A0.1 How do you refer to digital transformation in the education sector (e.g. the use of digital technologies for teaching, learning, administration, other)?

Dimension A1 – Digital skills of educators for course design (prompt: where teachers create their own lesson plans, applets, other, for digital learning)

A1.1 Which digital skills of educators should be developed for successful course design in schools, specifically for mathematics education?

A1.2 Comment on the state of digital skills for course design, specifically for secondary mathematics education in the current context?

A1.3 Please add any other influencing skills not mentioned above. (prompt: from the DBE professional development framework for digital learning, or any other)

Dimension A2 – Digital skills of educators for course delivery (prompt: e.g. use of PowerPoint and other presentation software; use of excel spreadsheets, GeoGebra applets and other dynamic software; relationship of digital pedagogies to use of digital tools)

A.2.1 Which digital skills of educators should be developed for successful course delivery in schools, specifically for secondary mathematics education? Why?

A.2.2 Comment on the current state of digital skills for course delivery, specifically for secondary mathematics education.

A.2.3 Please add any other influencing skills not mentioned above.

Dimension A3 – Digital teaching experience and outcomes (prompt: digitally supported teaching is viewed as being important for improving the teaching experience and outcomes in secondary mathematics education. Comment about the following issues related to digitally supported teaching)

A3.1 In your opinion, which of these teaching strategies, namely, teacher-centred, learner-centred, and learning-centred is prevalent during the early digital learning environment? Why?

A3.2 What do you think are the strengths and weaknesses of linking different branches of mathematics in a single lesson, or series of lessons?

A3.3 What school culture will need to be met during digitally supported teaching?

A3.4 What can be done to improve teaching experience and outcomes during the implementation of digitally supported teaching of secondary mathematics in schools?

A3.5 Please add any other teaching experience and expected outcome issues not mentioned in this list.

Dimension B – Leadership in the implementation of digitally supported teaching of mathematics in secondary schools

Please refer to or mention how national, provincial, and local (district/school) administrators provide guidance to schools to implement digitally supported teaching:

B.1 In what ways is the national government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools?

B.2 In what ways is the provincial government providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools?

B.3 In what ways is the local education district administration providing guidance in the implementation of digitally supported teaching of secondary mathematics in schools?

B.4 What are other leadership concerns the necessary during the implementation of digitally supported teaching of secondary mathematics in your school?

Dimension C – School digital infrastructure

Please mention or comment on the following issues related to school digital infrastructure:

C.1 What kind of internet connectivity do teachers have at school and/or at home to enable digitally supported teaching of secondary mathematics and is it operational? Why?

C.2 What is the quality of your internet connectivity (sufficient/low/intermittent bandwidth) for digitally supported teaching of mathematics in secondary schools? Why?

C.3 What type of devices and digital resources are important for ensuring teacher connectivity for digitally supported teaching of secondary mathematics? why?

C.4 Which mathematics applications do you use or are aware of?

C.5 Comment on any other relevant school digital infrastructure issue.

Dimension D – Social issues affecting teaching and learning in schools

D.1 What kind of social issues are affecting educators in schools? Why?

D.2 What kind of social issues are affecting learners in schools? Why?

D.3 Comment on any other social issues affecting schools.

If we were not able to capture all the information and insights you have, would you be willing to send a follow-up note on the above points?

Ends.

Appendix E
Interview Guide – Revised for Sponsor

SEMI-STRUCTURED INTERVIEW GUIDE: EXPLORING EARLY-STAGE DIGITAL TRANSFORMATION IN SECONDARY MATHEMATICS EDUCATION

Broad designation and institution of Key Informant (for analysis purposes only):

Date of interview:

Please note that these are guiding questions. The researcher is interested in noting and understanding issues related to early-stage digital transformation in secondary mathematics education, particularly those elements that foster digital transformation.

Question 1: Why did the SBIDZ-LC start the Open Saldanha Project? (prompt: what is the objective of the open Saldanha Project?)

Question 2: Why did the SBIDZ-LC get involved in teacher development in general and in mathematics education in particular?

Question 3: What short-term and long-term plans does the SBIDZ-LC have for engagement with the Open Saldanha schools, relevant to the innovation and development taking place at the SBIDZ? (prompt: how does the Open Saldanha project fit into generating workers, professionals and entrepreneurial participation from surrounding schools)

Questions 4: How does the SBIDZ-LC envisage providing future support to the schools in the Saldanha Bay circuit to overcome the challenges related to internet connectivity, devices, and use of mathematics teaching applications, amongst others?

Question 5: What are other issues relevant to the schools in the Saldanha Bay circuit that the SBIDZ is involved in addressing? Why?

If we were not able to capture all the information and insights you have, would you be willing to send a follow-up note on the above points?

Please share with me any documents (short, or longer documents), that are relevant to the questions posed above, if they are not confidential to the organisation. These documents will be reviewed, and relevant data will be extracted for research purposes.

Ends.

Appendix F

ATLAS.TI Early-Stage Stage Digital Transformation in Secondary Mathematics Education – Dimensions, Categories, and Codes/Subcategories

DIMENSIONS	CATEGORIES	CODES (SUB-CATEGORIES)
D1: Digital skills of educators	Course design	Lack of digital skills for course design; partial use of digital tools; underdeveloped digital skills for course design; preparation of lessons at home; encourage training on digital tools.
	Course delivery	Limited exposure to digital tools; limited use of digital tools; ability to use digital tools; inadequate devices for course delivery.
	Pedagogical practices	Adopting a range of pedagogical approaches improve the potential of digital tools and resources; lack of digital pedagogy; lack of learner-centred teaching due to large class sizes; knowledge of learning centred approaches; need for pedagogy shift to learning-centred approaches; need for training to improve digital pedagogy; need to deepen digital pedagogy; prevalence of teacher-centred approaches; use of learning-centred approaches.
	Linking branches of maths	Knowledge about linking branches of maths; lack of linking different branches of maths; linking branches of maths important; make it easy to understand the other topics; problems if one topic was not understood.
	School culture	A supportive culture is need during maths digital teaching; affected by large school enrolments; discipline needed during maths digital teaching; exploration should be allowed; lesson periods are short for maths digital teaching; negative and unsupportive environment; related to learner achievement.
	Teaching experience	Lack of time to learn and use digital tools
	In-service training	Misalignment of the university maths training to the classroom needs; require training on the use of digital tools;
	Partnerships	Collaboration of government department for STEM; involvement of the private sector.
D2: Digital skills initiatives	Interfacing with communities	Penetrate communities; promote of social cohesion.
	Investment, skills development, and job creation	Promotion of economic growth; ensuring economic opportunities for the local communities.
	Human value	Restoring the dignity of individuals in the Saldanha Bay area to see possibilities in life for themselves and their children

	4IR technologies in the school curriculum	Create awareness about careers that the digital era presents and the role of subject such as mathematics; development of human resource pipeline; infrastructure for advanced digital skills; lack of advanced digital skills; need for funding; stimulating interest in mathematics to increase uptake of STEM fields.
	Teacher support	Continuation working with schools; maths programs must start with teachers; need to practice building knowledge and capacity; in-class practice.
	Continuation of engagement with maths teachers	Not leave maths teachers on their own after only a very basic; require a maths community of practice for continuous engagement.
	Access to devices	Need for access to devices for both teachers and learners
D3: Digital learning	Definition of digital transformation in education	Referred to be digital learning; referred to be digitally enabled learning; referred to be e-learning; referred to be ICT; referred to be online teaching; referred to be using technology for mathematics teaching.
	Digital transformation levels	Levels of digital transformation in education [substitution, augmentation, modification, redefinition]; evidence of the substitution level.
	Digital learning components	Uses learner-centred approaches.
	Digital learning competencies	Ability to use digital tools and resources; facilitate teacher's professional growth and knowledge about the value of digital tools and resources; appropriate use of digital tools and resource to attain curriculum objectives; demonstrate leadership vision for digital learning.
	Transition to digital learning	Develop a rubric for schools; requires a change management strategy.
D4: Teacher professional development	Mathematics teaching and learning issues	Awareness about creativity; awareness about critical thinking; awareness about deep learning; awareness about project-based learning; knowledge of the language of learning; need to incorporate digital technologies; promotion of good teachers to upper grades; require a learning-centred classroom; ways of teaching mathematics for understanding; ways of teaching reasoning skills for mathematics.
	Curriculum issues	List of aims of the NCS for Grades R-12, applicable norms and standards for digital technologies in education.
	Community of practice	Need for budget for community of practice
	ICT in mathematics education issues	Lack of time to teach concepts

	Professional development	Availability of teacher development centres in districts; funding for training of teachers and resources; must accompany access to digital tools and resources; need for training on advanced digital skills.
D5: Leadership in the implementation of digitally supported teaching	National guidance	Provide resources but not training; public policy documents only; a framework must be accompanied by resources to implement; Aspires technology integration at all levels; development of the PDFDL document; develops integrated strategies; do no organise training on technology integration; lack of guidance on the use of dynamic software; leadership at all levels required; limited implementation a school level; limited resources for digital teaching and learning; limited support; organise training for mathematics content; organise training on use of technology; promote stakeholder involvement; provide guidance on online safety in schools.
	Provincial guidance	Are at different stages of technology integration; do not organise training on technology integration; lead awareness, training, monitoring, and support to districts; limited guidance to schools; organise workshops for teachers; plan and budget for resource allocation.
	District	Participation of district officials; training of district officials on digital skills for using digital tools.
	School	Need for a school champion; training of school leadership on digital skills
D6: Digital education policy issues	Recent digital education policy issues	Stakeholders involved in policy design, implementation, and monitoring; aimed at improved infrastructure and teaching capacity; focus on different levels of primary, secondary, and tertiary education; integrate evaluation and monitoring into the policy design; promote innovative teaching and learning; provide multiple pathways for supporting teachers.
	Low stakes	Digital teaching and learning not assessed
	Digital assessment	Prevalence of old ways of testing and examinations.
	Career guidance	Lack of career guidance to promote STEM pathways
D7: Digital divide	Digital divide issues	About availability of digital content; socio-economic context do not affect use of digital tools and resources.
	Bridging the digital divide	Development of digital content initiatives; regulatory framework for connectivity in schools.
	Marginalisation	Alcohol, drugs, and violence; challenges related to historical inequalities.
	Parental involvement	Lack of parental involvement
	Migration	Movement of people to the Western Cape
	Internet connectivity	Availability of internet connectivity; availability of internet for grades 11 and 12 only; availability of internet for grade 12; availability of IT support;

D8: School digital infrastructure		broadband internet connectivity recommended for a virtual class; lack of IT support; leveraging the digital reality or cyberspace through the use of platforms; teachers self-provide for internet connectivity at home; establishing internet that works in schools; internet available for admin and teachers; lack of problem-solving skills.
	Quality of internet connectivity	Unsuitable internet connectivity for teachers at school or at home; poor quality of internet connectivity; need to improve quality of internet connectivity.
	Devices	Absence of technical architecture; addressing teacher connectivity; advocates for devices for every teacher and learner in schools; availability of a lab; availability of data to teachers for connectivity; availability of devices; availability of laptop, projector and smartboard; availability of laptops for teachers; availability of projectors; availability of smartboards; availability of initiatives to address infrastructure in schools; computer laboratory available for grades 11 and 12; lack of devices; lack of safety and security; lack of teacher connectivity; laptop recommended for virtual class; need to projectors; need for setting up time for devices; not all classes have devices; provide a teacher with one computer and a projector; securing funding for infrastructure.
	Digital content	Development of national education portal; lack of digital content; prioritisation of development of mathematics digital content.
	Digital tools and resources	Develop knowledge about integration of digital tools and resources; knowledge about apps like GeoGebra; lack of knowledge about affordances of digital tools; laptops; availability of laptops for Grades 10, 11 and 12 teachers; list of digital tools and resources; need for awareness about the use of digital tools and resources; need for development of digital skills to use all applications; need for investment in time and effort to learn using digital tools and resources; no devices for grades 8 and 9; potential to improve teaching in a wide range of socio-economic context; require training on apps like GeoGebra; self-learning of GeoGebra; smartboards for grade 12 classes; tablets available for grades 11 and 12; use of apps like GeoGebra.
	Technical architecture	Absence of a technical architecture to address connectivity challenges in schools.