Development of a framework of factors essential to the optimal implementation of the Coding and Robotics subject in South African schools

by
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Declaration

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Abstract

The development of the Fourth Industrial Revolution (4IR) introduced technological innovation, which led to digital transformation in the workplace. This transformation demands that employees be equipped with 21st-century skills to keep up with the fast-paced development. The Department of Basic Education South Africa plans to prepare students for these demands by introducing the subject of Coding and Robotics from grades R to 9 to the national school curriculum. However, there is a lack of research available on the practical aspects that a school should consider in the unique South African school context. This study contributed to the research by developing a framework of factors that a school should consider when implementing the subject of Coding and Robotics in SA primary schools.

The context of the study was provided by investigating the benefits of Coding and Robotics as part of STEM education in the context of the 4IR. The framework was developed by first reviewing relevant literature and policy statements from countries that already teach the subject in their schools. This information was used to identify draft factors that impact the successful implementation of the subject. The draft factors were used as input in the data collection process. Eleven Subject Matter Experts (SMEs) were curated to participate in the study. The SMEs include teachers with Coding and Robotics teaching experience, teaching experts related to the development of computational thinking skills and owners or employees of private robotics education providers. Following a snowball method, interviews were conducted with the SMEs to provide practical insights into the considerations of the implementation in the SA context. Their suggestions and experiences were analysed to populate the framework of factors. The six factors included in the framework are the teacher, infrastructure, artefacts, curriculum, support network, and budget. Each factor was expanded into attributes that provided more detailed considerations and suggestions.

A synthesis of the interviews revealed the existence of specific challenges faced by the participants in the SA context. The possibility of certain relationships existing among the factors was discovered. These hierarchies and influences were explored, although conclusive results could not be drawn due to the limited dataset. Nonetheless, the limited observations suggested that the teacher factor is considered the most influential in the process of successfully implementing the subject of Coding and Robotics, which could suggest prioritising it during the implementation process.

The research was carefully evaluated to ensure the soundness of the findings. The continuous verification and validation strategy confirmed the reliability of the developed framework. The expanded factors present a practical overview of the considerations that will influence the success of the implementation of Coding and Robotics in SA primary schools.

Opsomming

Die ontwikkeling van die Vierde Industriële Revolusie (4IR) het tegnologiese deurbrake teweeg gebring wat gelei het tot digitale transformasie in die werksplek. Hierdie transformasie vereis van werknemers om toegerus te wees met 21ste-eeu-vaardighede ten einde by te bly met die vinnige ontwikkeling. Die Departement van Basiese Onderwys Suid-Afrika beplan om studente voor te berei vir hierdie vereistes deur die vak Kodering en Robotika van Graad R tot 9 in die nasionale skoolkurrikulum in te sluit. Daar is egter beperkte navorsing beskikbaar oor die praktiese aspekte wat 'n skool in die unieke Suid-Afrikaanse skoolkonteks moet oorweeg om hiervoor voorsiening te maak. Hierdie studie het tot die navorsing bygedra deur 'n raamwerk van faktore te ontwikkel wat 'n skool moet oorweeg wanneer die vak Kodering en Robotika in SA laerskole geïmplementeer word.

Die konteks van die studie is van stapel gestuur deur die voordele van die vak Kodering en Robotika as deel van STEM-onderrig in die konteks van die 4IR te ondersoek. Die ontwikkeling van die raamwerk het 'n aanvang geneem deur relevante literatuur en beleidsverklarings van lande te ondersoek wat reeds die vak in hul skole aanbied. Hierdie inligting is gebruik om konsepfaktore te identifiseer wat die suksesvolle implementering van die vak beïnvloed. Die konsepfaktore is as insette in die data-insamelingsproses gebruik. Elf vakkundiges is geselekteer om aan die studie deel te neem. Die vakkundiges sluit onderwysers met Kodering en Robotika-onderrigervaring, onderrigkundiges wat betrokke is by die ontwikkeling van rekenaardenkvaardighede en eienaars of werknemers van private robotika-onderwysverskaffers in. Na aanleiding van 'n sneeubalmetodiek is onderhoude met die vakkundiges gevoer om praktiese insigte te verskaf in verband met die oorwegings ter sprake by implementering in die SA konteks. Hulle voorstelle en ervarings is ontleed om die raamwerk van faktore te ontwikkel. Die ses faktore wat in die raamwerk ingesluit is, is die onderwyser, infrastruktuur, artefakte, kurrikulum, ondersteuningsnetwerk en begroting. Elke faktor is uitgebrei met betrekking tot eienskappe wat meer gedetailleerde oorwegings en voorstelle verskaf.

Die interpretasie van die onderhoude het spesifieke uitdagings wat die deelnemers in die SA konteks in die gesig gestaar het, aan die lig gebring. Moontlike verwantskappe tussen die faktore is ontdek. Hierdie hiërargieë en invloede is ondersoek, alhoewel konkrete gevolgtrekkings nie gemaak kon word nie as gevolg van die beperkte datastel. Nietemin het die beperkte waarnemings aangetoon dat die onderwyserfaktor as die mees invloedryk beskou word in die proses om Kodering en Robotika suksesvol te implementeer wat daarop dui dat dit tydens die implementeringsproses geprioritiseer moet word.

Die navorsing is noukeurig geëvalueer om die betroubaarheid van die bevindinge te verseker. Die deurlopende verifikasie- en valideringstrategieë het die betroubaarheid van die ontwikkelde raamwerk bevestig. Die uitgebreide faktore bied 'n praktiese oorsig van die oorwegings wat die implementeringsukses van Kodering en Robotika as vak in SA laerskole sal beïnvloed.

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And finally, the One that upholds the universe by the word of His power. To Him be the honour and glory forever.

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List of Acronyms

4IR: Fourth Industrial Revolution

CAPS: Curriculum Assessment Policy Statement

DBE: Department of Basic Education

ICT: Information and Communication Technologies

IoT: Internet of Things

IT: Information Technology

NSC: National Senior Certificate

PED: Provincial Education Department

PGCE: Postgraduate Certificate in Education

PIRLS: Progress in International Reading Literacy Study

RO: Research Objective

SA: South Africa

SACMEQ: Southern and Eastern Africa Consortium for Monitoring Educational Quality

SCOR: Supply Chain Operations Reference

SME: Subject matter expert

STEAM: Science, Technology, Engineering and Mathematics

STEM: Science, Technology, Engineering and Mathematics

TIMSS: Trends in International Mathematics and Science Study

WCED: Western Cape Education Department

WRO: World Robotics Olympiads

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CHAPTER 1

Introduction

Contents

The Fourth Industrial Revolution (4IR) introduced fast-paced technological transformation in the workplace, creating a demand for employees to be equipped with 21st-century skills (Kaleci & Korkmaz, 2018). The Department of Basic Education (DBE) in South Africa (SA) plans to prepare students for these demands by introducing the subject of Coding and Robotics from grades R to 9 (BusinessTech, 2020). However, there is a lack of research available on the practical aspects that a school should consider in the unique SA school context. This study aims to investigate the factors that need to be considered when introducing Coding and Robotics to SA primary schools. In this chapter, the problem description and research strategy are elaborated. The research objectives pursued in this study are presented. Next, the research design and the project's scope are discussed. Ethical considerations are highlighted, and finally, the document's structure is described.

1.1 Background

The 4IR introduced a new era of advancement in Science and Technology. 4IR initiated digital transformation through modern smart technologies (Paul et al., 2021). 4IR evolved from the Third Industrial Revolution, also known as the Digital Revolution, due to the development of computers and Information Technology (IT) (Agbehadji et al., 2021). However, Agbehadji et al. (2021) suggest that 4IR is differentiated by the immense impact of new systems and the speed of technological breakthroughs. 4IR is characterised as an era of automation by producing several emerging technologies. Among these technologies is the "Internet of Things" (IoT), which was introduced to many parts of life as we know it (Agbehadji et al., 2021). IoT refers to all systems consisting of devices connected to each other and the internet (Morgan, 2014). These connected objects are able to collect data and transfer it without human intervention (Aeris, 2021). The possibilities for creating and designing new products and services have expanded significantly due to the advancement of IoT technology (Kamble et al., 2018).

The introduction of 4IR IoT has created a technological disruption in business, education and many other sectors of the economy (Agbehadji et al., 2021). These technological advances have created a professional skills gap. Technology is now not only present in most daily activities but is also a key player in the workplace. This means that people must be comfortable using these devices and adapting to new innovations to qualify for competitive job opportunities (Kaleci & Korkmaz, 2018). The demand for advanced engineering talent in the innovative sector further widened the technological skills gap. Skills in robotics and electronics are in high demand due to the new market gap created by 4IR development (GetSmarter, 2021). Patil and Suresh (2019) conducted a study on workforce agility in IoT projects. They found that employees involved with the development of IoT technologies need to be adaptable and self-motivated to keep up with the competitive pressure in the fast-growing IoT industry.

One educational philosophy that ensures the technical literacy required for an innovation-driven occupation is the STEM approach (Kaleci & Korkmaz, 2018). It is an acronym for Science, Technology, Engineering and Mathematics (Bybee, 2010). STEM education is a cross-disciplinary approach incorporating practical applications instead of a purely academic focus. STEM has quickly become the basis of innovation around the world (Dalton, 2019). Education in these fields affords students greater life opportunities and prepares them for the disciplines that have an important role now and in the future (Kaleci & Korkmaz, 2018; Winberg et al., 2019). The STEM philosophy has been expanded to include the "Arts" oriented subjects, known as STEAM (Ponticorvo et al., 2020). STEAM learning highlights the importance of creative thinking and its role in learning other STEAM disciplines. This learning philosophy will henceforth be referred to as STEM for simplicity while acknowledging that the Arts subjects play a vital role in developing 21st-century skills like creative thinking (Dell'Erba, 2019).

Coding and Robotics form an essential part of STEM subjects, linking to the Technology and Engineering branches (Lee et al., 2020). Coding and Robotics is an active application of other STEM subjects and enables the creation of technology. Students benefit greatly from instruction in Coding and Robotics since it ensures that their skills stay relevant in the digital economy as the 4IR progresses (Smith, 2016). Providing Computer Science learning opportunities for all primary and secondary education students will help to ensure a prepared and productive workforce for the 21st century (K–12 Computer Science Framework Steering Committee, 2016). Grover et al. (2019) claim that Computer Science-related skills are not only crucial to computer scientists but also necessary for all citizens to ensure strong STEM foundations in the workforce. All citizens need these skills, such as problem-solving, to thrive in a world driven by computing and digital devices. Sullivan et al. (2015) suggest that children can learn engineering and programming from a very early age. Dejarnette (2012) argues that children exposed to robotics and STEM initiatives at a young age are given a head-start over their peers because it allows them to explore the field at a reasonable pace and cultivate their interest. Early engagement in Computer Science allows students to develop fluency with Computer Science over many years and gives them opportunities to apply it to other subjects and interests as they progress through the school system (K–12 Computer Science Framework Steering Committee, 2016).

The South African education system suffers from many problems, evidenced by the poor quality of STEM tuition offered to students. According to Pols (2019), university graduation rates in STEM-related courses in SA are very poor, emphasising the dire need for skilled professionals in the STEM field. It also highlights the fact that students are not being prepared adequately from a young age for these subjects. Several studies suggested that early exposure to STEM education positively affects the self-confidence of primary school students and helps them cultivate a long-lasting interest in STEM subjects (Kucuk et al., 2021). Tucker et al. (2003) suggest that the same principle applies to computer-related learning subjects, such as Coding and Robotics. The student's success in high school depends highly on access to technology and the achievement of basic computer-related milestones at the primary school level. Therefore, primary schools need to start teaching students the basic building blocks of computer fluency and computational thinking so that more advanced Computer Science programs can be implemented in secondary school.

South African Minister of Basic Education, Angie Motshekga, addressed this shortcoming in 2020 by confirming that a new Coding and Robotics subject will be introduced to schools by 2023 (BusinessTech, 2020). The subject will be incorporated into the curriculum of grades R to nine, with great care taken to ensure seamless progression from one phase to the next. The draft curriculum was drawn up and submitted to Umalusi, the Council for Quality Assurance in General and Further Education and Training, for evaluation. President Cyril Ramaphosa announced in February 2021 that the Department of Basic Education would launch a pilot program during that year. This program was to be implemented to test the draft curriculum to allow possible amendments to be made before all public schools in the country present the material. The curriculum from grades R to three was planned to be piloted in 200 schools across the country, while the grade seven material was to be introduced to 1000 schools (Khoza, 2021). According to BusinessTech (2022), the pilot curriculum was confirmed to be introduced to some schools in the third term of 2021.

The pilot program for grades four to six and grade eight was planned for 2022, and the grade nine pilot for 2023. The full implementation of the Coding and Robotics subject was planned for grades R to three and seven in 2023, with grades four to six and grade eight planned for 2024 and the grade nine full implementation for 2025 (BusinessTech, 2022; Khumalo, 2022).

There have been no further notices on the progress of the pilot program for the Coding and Robotics curriculum. The DBE did, however, confirm that a team of people were to be trained in March 2021 with regard to the teaching of the subject. According to Lang (2021), this team was then to train the respective teachers who were to present the subject in the pilot rollout, but it is unclear to what extent these plans have materialised.

1.2 Problem description

The DBE aims to introduce Coding and Robotics as a subject to the national curriculum from grades R to 9 to expand the range of topics included in STEM learning. The intention is to ensure future STEM-literate citizens with developed computational thinking abilities. Foundations are ideally laid when children are young and form thinking habits as the first building blocks for successful learning. However, according to Bybee (2010), studies show that South Africans are not yet equipped with the IT skills needed to keep up with the 4IR, and the early grades curriculum does not yet include digital skills. Including the Coding and Robotics subject in the curriculum from as early as grade R will aim to rectify these shortcomings (Bezuidenhout, 2021). However, there is still very little information on the practicalities of this subject's rollout and the infrastructure and resources needed to present the subject in a meaningful way.

President Ramaphosa emphasised that introducing this new subject should not be detrimental to the other basic skills taught in schools, such as comprehensive reading and numeracy (Khoza, 2021). However, there is no trustworthy prediction of how much time and effort teachers and school administrators will have to commit to implementing the new subject.

The South African context poses a unique challenge regarding the variety of public schools in the country. Vital disparities exist between schools in rural and urban areas (Samuels et al., 2020). This might present complications in the implementation of the same material across the board. It is a challenge to achieve the same learning outcomes in the presentation of the subject if the availability of the infrastructure varies from school to school. This reality suggests that each school needs to analyse their facilities and support before implementing the new curriculum.

No extensive research could be found on the factors that need to be considered to ensure that the Coding and Robotics subject is introduced properly in a school. Teacher training and qualifications are not defined properly, and required school resources are not clearly stipulated. Different schools' infrastructures need to be considered to determine what adjustments or improvements of facilities are necessary to support the teaching of this subject.

This project proposes to develop a framework of factors that need to be considered when introducing the subject of Coding and Robotics to South African schools. Each factor will be expanded into attributes to provide a practical description of the consideration of each factor. The interaction of the factors and hierarchies among the factors will be explored.

1.3 Research objectives

The aim of this study is to design a framework of factors that provide practical considerations a school should consider before implementing the subject of Coding and Robotics. The following research objectives (RO) are pursued to achieve this aim:

I To *provide* context for the study by conducting a thorough survey of the relevant literature related to:

  (a) the definition of 4IR, Education 4.0 and IoT,

  (b) the definition of STEM and benefits of providing children with a STEM-based education in the context of 4IR,

  (c) the definition and benefits of Coding and Robotics as a subject taught in schools,

  (d) the South African public school context.

II To *identify* proposed factors that a school should consider when implementing Coding and Robotics.

III To *develop* a framework of factors to provide a practical perspective on the implementation of Coding and Robotics in South African schools.

IV To *explore* possible relationships and hierarchies existing among the factors.

V To *evaluate* the comprehensiveness and usability of the framework in the context of South Africa.

VI To *recommend* follow-up work related to the work in this project which may be pursued in future research projects.

1.4 Research design

This study aims to design a framework of factors that are essential to the optimal implementation of the new Coding and Robotics subject in South African schools. According to Jabareen (2009), a conceptual framework is a network of interlinked concepts that provide a comprehensive understanding of a phenomenon or phenomena.

The research process is designed to achieve the ROs described in Section 1.3. Figure 1.1 illustrates the input used, process followed and output produced in pursuit of each RO.

The study is structured into multiple stages, with verification and validation performed throughout the process to ensure the reliability of the research. The study comprises primary and secondary data analysis (Mouton, 2001). The research includes qualitative techniques like interviews, which are not focused on numerical data and results but instead produce words and theories (McCusker & Gunaydin, 2014).

Research Objective	Input	Process	Output
RO1: To provide context for the study by conducting a thorough survey of the literature related to relevant topics.	Literature (Google Scholar, Scopus, SunScholar).	Thematically review articles, journals and other academic publications.	A clear understanding of concepts surrounding the topic and insight into the SA school system.
RO2: To identify proposed factors that a school should consider when implementing Coding and Robotics.	Literature and policy statements from countries teaching Coding and Robotics related subjects.	Thematically review articles, journals and other academic publications.	Proposed factors expanded into attributes that describe each factor.
RO3: To develop a framework of factors to provide a practical perspective on the implementation of Coding and Robotics in South African schools.	Semi-structured personal interviews with credible subject matter experts using the output of RO2 as the starting prompts.	Conduct and analyse interviews following a snowball method to gather practical perspectives.	Framework of factors expanded into attributes that describe the practical considerations of every factor in the SA context.
RO4: To explore possible relationships and hierarchies existing among the factors.	Semi-structured personal interviews with credible subject matter experts.	Synthesise recorded interviews to gain insights into hierarchies.	Possible hierarchies and relationships among the factors.
RO5: To evaluate the comprehensiveness and usability of the framework in the context of South Africa.	Literature, interviews with subject matter experts and conference presentation and publication feedback.	Incrementally conduct evaluation strategy to verify and validate the framework.	Satisfactory evidence ensuring the credibility and plausibility of the developed framework.
RO6: To recommend follow-up work related to the work in this project which may be pursued in future research projects.	Challenges suggested by subject matter experts and limitations noticed during the research process.	Suggest future work building on the findings presented in this study.	A list of suggestions for follow-up work that could expand the body of research.

Figure 1.1: *Output and process followed for each of the research objectives.*

The first stage of the study is an in-depth literature review, which is non-empirical in nature, using a theoretical approach to gather data for the framework's design. This does not include the primary data collection but instead focuses on reviewing existing literature and case studies (Mouton, 2001). The background of Coding and Robotics education in the context of STEM is researched. Policy statements and case studies from other countries that already implement Coding and Robotics-related subjects are reviewed to gain insight into their experiences. Draft factors for the framework are identified from the literature content to use as inputs in the second stage of development.

The second stage is the development of the framework with the South African context in mind, which includes the primary collection of data. According to Mouton (2001), this research design stage is classified as empirical, where data collection is performed through personal semi-structured interviews with credible subject matter experts (SMEs). These interviews followed a snowball method, where participants were selected through suggestions from other credible participants. This method confirms the validity and relevance of an included participant in this research. The draft factors, as identified in the first stage of the study, are used as inputs. The framework's factors are populated by analysing the interviews and extracting considerations from the participants' perspectives. The factors are expanded into attributes that describe the practical considerations of each factor in the SA context. The snowball method ensures that each participant is presented with the entire collection of considerations from the preceding interviews. This allows continuous validation of the description of each factor because the participants continue to offer original considerations until saturation is reached.

The third stage of the research design is the synthesis of the interviews. Interpreting the primary data collected in the interview process produces specific insights into hierarchies and relationships between the factors. These structures are explored to identify possible rankings and influences that the factors have on one another to suggest which factors a school should prioritise when implementing Coding and Robotics. Continuous verification of the participants' suggestions is performed by assessing whether their opinions could be biased in any way by their relevance to the field.

The fourth stage of the study is verifying and validating the complete framework to ensure its usefulness and reliability. The face validity of the framework is confirmed through personal interviews with the SMEs following the snowball method described in the second stage. The SMEs include teachers with Coding and Robotics teaching experience, teaching experts who conduct research relating to computational thinking development and teacher professional development, and robotics service providers who develop and sell educational robotics solutions in the private sector. The interviewees' varying perspectives and relevance to the field of Coding and Robotics education allow them to comment on the framework's usefulness and the accuracy with which it depicts the SA context of the subject's implementation. The framework was continuously validated since each participant was presented with the framework as populated from the previous participants' perspectives and asked to comment on it and offer additions. The comprehensiveness of the framework was discussed with the participants, and possible challenges in the unique SA context were explored. The frequency of additions to the framework slowed down as the interview process progressed and reached saturation around the interview with the eighth participant.

The final stage of the study will close with a summary and recommendations for future research.

It should be noted that in conjunction with this thesis, the pursuit of ROs I and II was presented and published in the SAIIE33 Conference Proceedings to obtain peer validation of the factors as identified from the literature. The peer-reviewed paper titled "Factors that Influence the Success of Coding and Robotics Implementation in South African Schools" validated the relevance of the study and explained the process of identifying the draft factors (Heyns et al., 2022).

1.5 Scope and limitations

This section describes the study's scope, assumptions and limitations to manage the contribution expectations. The limitations of the study are elaborated on:

- The framework aims to present a practical perspective to public schools in SA. However, teachers from private schools are also included in the study to provide their perspectives and relatable experiences.
- The new subject of Coding and Robotics is to be introduced to the national curriculum from grades R to nine. However, this framework will only focus on the Coding and Robotics subject in the context of primary schools.
- At the time of this research from 2021 to 2023, the subject of Coding and Robotics has yet to be officially included in the national curricula. Therefore, very few schools have started teaching the subject, and those that do have done so in their own capacity. This resulted in no case study being conducted and the number of participants with valid experience being limited.
- This framework is developed in the context of SA, where inequality exists in the school system. However, this study aims not to address these inequalities or comment on the access to quality education in South African schools. The disparities between the resources and infrastructure available at schools from different communities suggest that the Coding and Robotics subject implemented by the DBE will not rely on sophisticated technology. However, this study aims to advocate for students' exposure to sophisticated technology and resources, where possible, to ensure that adequate 21st-century skills are developed. The framework will be developed so that every school can assess their own situation to evaluate their readiness.
- This framework aims to propose the factors that a school should consider when introducing the subject of Coding and Robotics. However, it does not aim to propose a change management strategy or suggest how to adjust certain factors once their state has been assessed. Furthermore, it does not propose a performance measurement scale for each attribute. This study paints the picture of the ideal attributes of each factor, but to what extent the success of the subject will be influenced by the lack of these attributes or poor performance of specific factors has yet to be concluded.
- This study aims to identify and expand the factors by analysing the interviews conducted with suitable SMEs. These findings are presented to provide a practical perspective of the different factors. However, the interview extractions are not interpreted; instead, the participant's voice is preserved. Therefore, the researcher does not claim to advise on which artefacts to use or what to include in the curriculum but instead presents the experiences offered from the participants' perspectives.

The researcher experienced this project to have the potential for scope extension, and clear scope management and limitation had to be conducted throughout the project.

1.6 Ethical considerations

The development of the framework involves the collection of primary data. The SA context of the study requires perspectives from SMEs with insight into the topic to be collected. Personal semi-structured interviews with selected SMEs were conducted. Inputs from teachers from private and public schools, education experts employed by SA universities and employees and owners of private robotics education companies are included in the study. This means that the data collection must be carefully designed to ensure the confidentiality of the participants and their employers. The participants remain anonymous, and although some experience and qualification details are provided to indicate credibility for including the participant, no identifiable information about the participant is revealed. No compromising data from themselves or their employers are revealed. Except for one of the companies whose reputation was significant to include with permission from the founder, the robotics companies also remained anonymous.

Ethical clearance was granted for data collection from the Research Ethics Committee of Stellenbosch University for Social, Behavioural and Education Research (Project number: 24646). Research approval for access to their employees was also received from the Western Cape Department of Education. These research approval letters are attached in Appendix A. In addition, the private robotics education companies granted gatekeeper permission, allowing their employees to participate in this study. The topic of this study includes the education of primary school students. Therefore, it is notable that no persons under the age of eighteen participated in this research.

1.7 Document structure

This section provides the document layout that reflects the study's logical course. In addition, the motivation behind each chapter, as well as the RO pursued, is discussed.

Chapter 1 presents the background of the study. The problem description is explored, and the research objectives pursued in this study are defined. The research design is elaborated to explain how the aim of the study is achieved. Careful limitations are constructed to ensure that the research can achieve reliable results without exceeding the scope of the study. Ethical considerations are highlighted.

Chapter 2 aims to provide the context of the study as described by RO I. Literature related to defining key concepts such as IoT and Education 4.0 in the context of 4IR is reviewed. The definition of STEM and the benefits of STEM education are researched. Coding and Robotics as a subject, as well as other terminology related to the field, is defined in the context of STEM education. The benefits that learning Coding and Robotics will provide a student and the different ways of thinking developed through Coding and Robotics education are explored. Finally, the SA public school context is explored to provide a perspective of the circumstances in which the subject is to be introduced.

RO II is pursued in Chapter 3. Literature and policy statements from countries that already teach Coding and Robotics related subjects are reviewed. Possible factors that a school should consider when introducing the subject of Coding and Robotics are identified. These draft factors are captured to use as inputs in the framework development process described in the following chapter.

Chapter 4 contains the framework development. RO III is pursued by collecting data from SMEs. The snowball method used to identify and interview the verified participants is explained. The draft factors, as proposed in the literature review in the previous chapter, are used as input to the process of populating the framework. The participants' experiences and suggestions are used to expand the factors into descriptions that could provide a school with perspective when implementing the subject.

In Chapter 5, the interviews with the SMEs are synthesised to present insights into the possible hierarchies among the factors. This chapter describes the pursuit of RO IV. Even though the dataset is not large enough to draw fixed conclusions, proposed rankings and relationships between the factors are presented from the interpreted findings.

In Chapter 6, the evaluation strategy is presented to illustrate the reliability and validity of the framework. The verification and validation of the framework are presented to emphasise the soundness of the research. The achievement of RO V is encapsulated by highlighting the processes and techniques used throughout the research process. The SMEs validate the comprehensiveness and usability of the framework in the SA context.

Chapter 7 contains the project summary and conclusion. The summary of the research process and the objectives met are presented. The contributions made in this study are emphasised, and the framework's limitations are reflected upon. Finally, suggestions for relevant future work are made in pursuit of RO VI.

1.8 Conclusion

This chapter provided the study's context by highlighting the background of the research. The problem description was elaborated, and research objectives were defined to address the identified problem. Next, the structure of the research design was explained, and the study's limitations were highlighted to define a clear scope. Finally, ethical considerations regarding the research process were presented, and the structure of the document was discussed.

CHAPTER 2

Literature Review

Contents

This chapter provides the context of the study by conducting a survey of the relevant literature in pursuit of RO 1. Terms related to the problem description, like 4IR, Education 4.0 and IoT, are expanded. The definition of STEM and the benefits of STEM education are highlighted. The definition of Coding and Robotics as a learning area is explored to provide a clear understanding of what is expected from the implementation and provide a scope of literature and resources applicable to this study. The benefits of Coding and Robotics and the ways of thinking that are developed through Coding and Robotics education are researched. Finally, the context of the SA public school system is explored to provide insight into the situation in which the subject of Coding and Robotics is to be introduced.

2.1 Expanding definitions

In this section, specific terms are defined that are relevant to the introduction of Coding and Robotics. Multiple definitions are used among different audiences; therefore, these terms are defined to provide context for the study.

2.1.1 Fourth Industrial Revolution

The current trend of automation and digitalisation of industries is known as 4IR or Industry 4.0. The importance and effects of 4IR are reflected in all aspects of life. 4IR is identified by the rising presence of technology development in many fields, among which the IoT, artificial intelligence, autonomous vehicles, quantum computing, biotechnology, robotics, nanotechnology, and 3D printing (Hariharasudan & Kot, 2018).

Prause and Atari (2017) suggested that the 4IR is a promising evolution where the virtual and real worlds of manufacturing are fused, which enables concepts like smart manufacturing and logistics using cyber-physical systems. Moreover, smart production brought about by the 4IR can enable resource and energy efficiency, increased productivity and shortened time-to-market cycles.

The 4IR is characterised by introducing disruptive technologies, processes, and practices. González-pérez and Ramírez-montoya (2022) suggested that some of the most transformative technologies introduced by the 4IR are machine learning and artificial intelligence. Hariharasudan and Kot (2018) offered that the rapid rate at which the 4IR produces changes in all fields, is remarkable.

The 4IR empowers digital technology with the prevalence of interconnection through IoT, virtual and augmented reality, Big Data, artificial intelligence and other IT paradigms that affect most industries. The positive impact of the 4IR provides an opportunity for many industries to increase productivity, not only in the manufacturing sectors but also in the education sector (Abdul Bujang et al., 2020). Chaka (2020) agrees that education is among four sectors in which the 4IR vision has gained significant traction, along with production (factories and industries), technology and the employment market.

2.1.2 Education 4.0

According to Chaka (2020), the 4IR development caused inevitable changes in all sectors, including within the education context, which introduced "Education 4.0" as a buzzword among educationists.

Education 4.0 refers to a trend in education. The term originated in response to the 4IR or Industry 4.0, which created a need for the future workforce to be prepared to adapt as the 4IR develops. Education 4.0 aims to introduce ways and approaches to teaching that prepare citizens for the workplace (Bonfield et al., 2020). The concept of Education 4.0 responds to the pressing demands created by the 4IR, where the constant interaction between humans and machines introduced the need for skilled employees to troubleshoot problems, seek solutions and deliver new possibilities for innovation. Each individual must be prepared to live and work in the ever-developing society (Suhaimi et al., 2019).

Hariharasudan and Kot (2018) added that Education 4.0 is a technology-based teaching and learning method inspired by the 4IR. Education 4.0 helps learners and employees develop competencies following societal changes. The rapid growth of the 4IR prompts education systems to transform and include information and communication technologies (ICT) in teaching and learning to prepare students to meet the demands of the 4IR (Abdul Bujang et al., 2020).

Education 4.0 allows students to develop 21st-century skills that are imperative in meeting the demands of the 4IR. The 4IR includes disruptive technologies, meaning the education systems and class management need to be updated to include these technologies. Research supports the correlation between 21st-century skills and digital competence. This suggests that Education 4.0 should include computational thinking development in the classroom by introducing educational robotics. Teachers should adopt a design-thinking mindset to help students develop creative thinking and innovation skills in Education 4.0 (González-pérez & Ramírez-montoya, 2022). Abdul Bujang et al. (2020) added that students are shaped to develop critical thinking, self-learning and problem-solving abilities through the characteristics of the Education 4.0 concept. ICT platforms and tools allow students to learn at a self-directed and flexible pace. Education 4.0 emphasises collaborative skills and lifelong learning, in addition to computer and ICT abilities (Suhaimi et al., 2019).

Hariharasudan and Kot (2018) claimed that Education 4.0 also introduces a new mindset in teaching. In the digital world of information overload and fast-changing technology, students must be trained and not taught. Information needs to be made accessible, and students need to be guided through how to find it rather than the teacher simply offering the information to them in a rigid structure. It is understood that students do not have the same basic knowledge and master and absorb different areas of focus differently. Therefore, they need to be guided to solve problems and develop their abilities rather than be taught predefined topics. According to Hariharasudan and Kot (2018), Education 4.0 also intends to prepare students to be adaptable and confident to face the next industrial revolution, which will happen in their lifetime.

2.1.3 Internet of Things

Many definitions of IoT exist within the research community, which affirms the strong academic interest in the topic (Atzori et al., 2010).

IoT is a novel paradigm that is rapidly becoming prevalent in the field of modern wireless telecommunications. The basis of the IoT concept is the presence of things or objects that interact with each other and can collaborate with their neighbours to achieve a common goal through unique addressing schemes. These interconnected objects or “things” include devices like sensors, actuators, Radio-Frequency Identification tags and mobile phones (Atzori et al., 2010). Giusto et al. (2010) added that IoT refers to physical objects that connect to the internet to share information about themselves and their surroundings.

According to Saravanaguru and Govinda (2016), the term IoT also refers to the thing-to-thing or human-to-thing communication in embedded networks through standard internet protocols. IoT creates a virtual footprint of all the devices and people connected to one another. It allows a new way of communication between people and things and between objects themselves.

Hariharasudan and Kot (2018) agreed that IoT expands the interdependence of humans and is one of the most important introductions of the 4IR. In this digital society, IoT occupies a constant presence in human life. Hariharasudan and Kot (2018) claimed that the everyday life of humanity could not have mobility without IoT, likened to the way a vehicle cannot move without wheels. It allows people to connect on a peer-to-peer basis all over the world.

The most significant advantage of the IoT idea is its impact on many aspects of everyday life and the behaviour of the users. From a private user’s perspective, the effects of IoT will be evident in both the working and domestic environments. Examples of possible application scenarios in which IoT will lead include assisted living, home automation, e-health and enhanced learning. However, from the business user’s point of view, the most noticeable effects will be visible in fields like industrial manufacturing, automation, logistics, business management and intelligent transportation of people and products (Atzori et al., 2010).

2.2 STEM education

Different definitions exist for STEM education. Literature relating to the definition and benefits of STEM is reviewed to provide a clear understanding of the education approach.

2.2.1 Definition of STEM

The term STEM was coined in the 1990s by the National Science Foundation to refer to the subjects of Science, Technology, Engineering and Mathematics (Bybee, 2010).

Tippett and Milford (2017) offered that a vital attribute of STEM education is the interdisciplinary approach to learning the various subjects. Students are encouraged to apply Science, Technology, Engineering, and Mathematics in real-world contexts to make the connections between theory and multiple aspects of their lives. Cinar et al. (2016) agreed that STEM education allows students to understand the world as a whole rather than in parts by removing the barriers between the different disciplines. STEM education emphasises the synthesis of knowledge. It is a constructive education approach that includes models like problem-based learning and Project Based Learning (Asiroglu & Akran, 2018).

STEM is used widely to represent a range of applications of the different disciplines (Nadelson & Seifert, 2013). Tippett and Milford (2017) agreed that there is some ambiguity around using the term. STEM may refer to any of the four disciplines individually, it might indicate the integration of all four disciplines, and sometimes, it is used to refer to a combination of two or more of the individual disciplines. Nadelson and Seifert (2013) added that STEM could also refer to the instructional practices and appropriate learning activities associated with teaching Science, Technology, Engineering, and Mathematics. Therefore, the term STEM can have different meanings based on the context.

Tippett and Milford (2017) suggested that if students are exposed to appropriate STEM learning experiences in early childhood, they often achieve greater success in STEM fields in later phases of education. Early childhood education presents the opportunity for teachers to instil in students a lasting interest in the STEM fields by engaging them in Science and Engineering activities through purposeful play. Harnessing students' interests, experiences, and prior knowledge through structured play can nurture their potential from an early age.

Students need to be equipped with 21st-century skills due to the fast pace of economic, scientific, social, and technological developments of the 4IR. These skills include creative and critical thinking, problem-solving, and decision-making, as well as knowledge about scientific reading and writing to prepare students for the demands of the future. However, developing these skills does not seem possible with traditional teaching practices. It challenges the educational system to keep up with the continuous change in society while empowering students as autonomous future citizens with the self-confidence to create their own future. The integrated approach of STEM education allows students to develop 21st-century skills like innovation and collaborative working skills that are difficult to develop through classical education approaches (Cinar et al., 2016).

Asiroglu and Akran (2018) agreed that STEM aims to equip students with 21st-century skills like creativity, critical thinking, cooperative working and problem-solving. Individuals are encouraged to use their creativity and theoretical knowledge to produce a product or an innovation to solve real-life problems. In this way, permanent and meaningful learning is ensured.

The STEM philosophy was expanded to include the subject of Art, renaming it STEAM. The motivation for incorporating Arts and Design concepts in STEM was to develop a more comprehensive education model. The unique value of STEAM education is in the trans-disciplinary thinking that occurs simultaneously when creative and analytical thinking is employed. Analytical thinking, often associated with STEM subjects, and creative expression, often associated with the Arts, combine to foster innovation (Dell'Erba, 2019).

Adding Art to STEM does not intend to reduce any aspect of STEM areas but brings them into a stronger and more attractive form by encouraging creative thinking (Kaleci & Korkmaz, 2018). Boy (2013) argued that disciplines should not be taught in isolation from one another and that the STEM subjects should include the Arts field to promote creativity alongside rationalisation.

According to Land (2013), traditional STEM fields focus on convergent skills, while Art focuses on divergent skills. Ensuring citizens can employ both skill sets alternately can improve a country's global competitiveness. Land (2013) stated that an argument favouring the STEAM vision in primary education is to counter the lack of innovation and creativity noted in college graduates in the United States. He elaborated that the current education system teaches students how to execute prescribed tasks fluidly but often neglects to foster curiosity and self-motivation. Technology and innovation through Art and Design should be integrated into education to support creative thinking and practice.

Advocates for STEAM education believe it equips students for life and employment in the 21st century, where workers are expected to be creative and culturally competent and qualified to solve new global problems through innovative thinking. STEAM education focuses on the process of learning through new experiences and perspectives. The Arts and STEM are necessary to support this process since they expose students to various thoughts, concepts and sensory experiences when implemented together. The inclusion of Art introduces new competencies and skills, including active learning, social, emotional and interpersonal skills, divergent thinking and cultural competency. The impact of the Arts on students' social and emotional development is significant, including increased motivation, engagement, perseverance, empathy and emotional regulation (Dell'Erba, 2019). This study recognises the addition of Arts subjects to develop 21st-century skills, but the learning philosophy is referred to as STEM for simplicity.

2.2.2 Benefits of STEM education

Education in the STEM fields presents the opportunity to develop 21st-century skills in the context of 4IR-driven innovation (Gunduz, 2020). Students develop complex communication and social skills as well as self-management. STEM education also teaches students to be adaptable and to solve non-routine problems. Systems thinking is one way of thinking developed by STEM education (Bybee, 2010).

Nadelson and Seifert (2013) suggested that citizens need to be STEM literate to address global challenges in the ever-developing and technology-driven economy. There is a need for specialists in the field of STEM to solve 21st-century problems. STEM education positively affects certain elements like students' attitudes, motivations, and scientific process skills (Asiroglu & Akran, 2018).

The skills developed through the STEM approach not only prepare students for the workforce but also equip them with insight to make decisions in social, economic and political matters. In addition, students are trained to be self-confident problem solvers and logical thinkers through STEM education (Cinar et al., 2016).

STEM education is an approach that develops skills that are in high demand, such as critical thinking and collaboration. STEM education is an interdisciplinary approach. It teaches students to look at problems in the context of other fields and apply information and skills holistically. STEM education enables students to apply theoretical knowledge to real-life problems (Kaleci & Korkmaz, 2018). Arifin et al. (2021) agreed that STEM education focuses on preparing students to become skilled workforce members in a scientifically and technologically advanced society. STEM integration in education is encouraged since the ways of thinking enabled through the silo approach in traditional learning are inadequate to understand and solve real-world problems. Design thinking is developed through STEM education, which increases creativity, problem-solving solving and innovation.

STEM education prepares students for job opportunities in innovation and Sciences. This education provides knowledge in a leading field, creates employment possibilities, and increases the student's chances of job security. Critical thinking is a skill that is highly sought after in the workplace. In addition, STEM learning builds resilience and perseverance. The subjects involved with STEM learning require high cognitive skills, and the student is challenged to embrace mistakes and keep going when a concept is difficult to grasp (Lynch, 2019).

2.3 Coding and Robotics

Department of Basic Education South Africa (2021a) named the new subject "Coding and Robotics", but it is essential to define the subject and the topics included in the content matter of the subject to understand better what literature and studies are relevant to this project.

2.3.1 Department of Basic Education's definition of the subject

In the draft curriculum released on 19 March 2021, the DBE defined the subject as follows (Department of Basic Education South Africa, 2021a):

"The Coding and Robotics subject is central to function in a digital and information-driven world; apply digital ICT skills and transfer these skills to solve everyday problems in the development of learners. It is concerned with the various interrelated areas of Information Technology and Engineering. The subject studies the activities that deal with the solution of problems through logical and computational thinking."

The specific aims of the subject are also described in the draft curriculum to provide an overview of the general skills that a student is intended to develop through the course content. The aim is for students to be prepared to solve problems, work collaboratively, think critically and creatively and adapt in a digital and information-driven society. The subject will also equip students to apply digital and ICT skills to solve everyday problems (Department of Basic Education South Africa, 2021a).

The specific study areas of the subject, as proposed in the draft curriculum, paint a clearer picture of the distinct scope of the subject. From grades four to nine, the content is organised into four study areas, namely Algorithms and Coding, Robotic Skills, Application Skills and Internet and E-communication Skills. In the foundation phase (grades R to three), there is an additional study area, Pattern Recognition and Problem Solving, to ensure that foundational skills and concepts are developed adequately before advancing to the content covered in the intermediate phase. These study areas suggest that this subject includes more than the simple act of writing code as indicated by the term "Coding" (Department of Basic Education South Africa, 2021a, 2021b, 2021c).

The expanded topics covered under the different study areas further elaborate that the aimed scope of the subject, as stated in the draft curriculum, is indeed quite broad. In the foundation phase, the study areas are expanded as follows (Department of Basic Education South Africa, 2021a):

- **Pattern Recognition and Problem-Solving :** An important step in the Design and Computational Thinking process is learning to recognise abstract and geometric patterns. Students learn to identify and analyse repetitions, regularities, and changes in patterns consisting of drawings, physical objects, and symbolic forms to practice making predictions and solving problems. They also learn to use symbolic expressions and grids to describe these patterns and relationships.

- **Algorithms and Coding:** Fundamental principles and constructs of programming are introduced through coding activities on block-based programming platforms. These platforms involve arranging drag-and-drop coding instructions to allow learners to focus on the program's design without requiring perfect syntax knowledge. In addition, students learn computational skills and concepts, such as identifying and analysing solutions for fundamental problems. They also practice converting simple algorithms to block-based code.

- **Robotic Skills:** Students are introduced to the fundamentals of Electrical and Mechanical engineering systems and circuits relevant to the field of Robotics. Concepts of computational thinking are included in the Engineering Design Process. Students are taught to create logical steps for a robot to follow. They are also introduced to basic Mechanical systems such as gears, pulleys and linkages. Students are introduced to basic electrical circuits.

- **Internet and E-Communication Skills:** Students are equipped with skills required to interact responsibly and safely in a digital world in this study area. Concepts like digital identity and security, as well as the safety around the use of digital platforms, are taught. Different types of e-communication platforms and technologies are introduced. Students learn about basic networks and the internet and are equipped to use web browsers safely to search for information.

- **Application Skills:** In this study area, students learn end-user skills required on various digital platforms. Different platforms are introduced, and students are oriented around the user interfaces and functions of the application. Some of the skills taught in the foundation phase include using digital devices and user interfaces and applications like text editors and spreadsheet applications.

In the intermediate phase (grades four to six), the four study areas are expanded into specific topics according to the draft curriculum as follows (Department of Basic Education South Africa, 2021b):

- **Algorithms and Coding:** Programming skills are developed primarily using block-based coding platforms. This allows students to be introduced to basic coding concepts in an environment that is easy to understand. Some of these concepts include integers, strings and variables, as well as operational, mathematical and relational operators. Students are also introduced to conditional and nested conditional statements, looping mechanisms, event triggers and broadcasting.

- **Robotic Skills:** This study area consists of two merging fields, coding and engineering. In the intermediate phase, the content builds on the knowledge gained in the foundation phase by introducing microcontrollers that are coded using block-based platforms. Students practice creating logical steps that a robot can follow using these block-based coding platforms. The student's knowledge of basic mechanical systems is also expanded.

- **Internet and E-Communication Skills:** The focus is to teach students about safe interaction in the digital world, both online and off. Students are introduced to the basic components of digital devices. Safe internet use and digital citizenship is taught, as well as concepts like plagiarism, piracy and copyrights. In addition, topics such as IoT, automation, cloud computing and digital communication are taught.

- **Application Skills:** In the intermediate phase, learners engage with programs that develop their digital presentation, numeracy, text and drawing skills. Students gain exposure to programs requiring specific end-user skills, namely, text editing applications, presentation applications, spreadsheet applications, multimedia editing applications and computer-aided drawing applications.

According to the draft curriculum, the topics covered in the senior phase (grades seven to nine) are organised into four study areas as follows (Department of Basic Education South Africa, 2021c):

- **Algorithms and Coding:** In the senior phase, programming skills are developed mainly by using line-based programming interfaces. A hybrid programming platform consisting of block-based and line-based coding is used to introduce students to line-based coding. This hybrid platform allows syntax-free programming to help students focus on the concepts instead of the details. These concepts build on knowledge attained in the intermediate phases. For instance, looping mechanisms, conditional and nested conditional statements, as well as mathematical operational, logic and relational operators, are taught on a more complex level. New concepts like flow diagrams, truth tables and logic gates are introduced. Students learn about variables, integers, floats, booleans and lists. Learners are introduced to the concepts of functions and parameter passing, as well as programming libraries.

- **Robotic Skills:** In this study area, the content builds on the skills taught in the intermediate phase. Where microcontrollers were coded using a block-based coding platform in the intermediate phase, they are programmed using line-based platforms in the senior phase. Students are taught to create logical processing steps using hybrid and line-based programming. Learners are familiarised with microcontroller components for input and output as well as mechanical systems that include gears, linkages and pulleys. CAD drawing skills are also introduced.

- **Internet and E-Communication Skills:** In this study area, security issues such as cyber threats, authentication measures, viruses, and malware are covered. Students learn about augmented and virtual reality, machine learning, Big Data and IoT. Students are introduced to data processing techniques. Social media operation and safety are also covered.

- **Application Skills:** In the senior phase, end-user skills engaging with applications that involve website development and data analysis are taught. In addition, students are introduced to HTML and develop further spreadsheet application skills.

At the time of this study, the topics suggested in the draft curriculum were not elaborated to specify the depth and detail to be covered or what level of mastery would be expected from the student. BusinessTech (2021a) claims that as the pilot program for the rollout of the subject proceeds, amendments will be made to finalise the curriculum content and layout. It has yet to be confirmed whether all of these topics included in the draft curriculum will be included in the final curriculum. Still, it does provide an idea of the spectrum of topics included in the subject. This author's assumption from studying the topics in the draft curriculum is that literature related to Computer Science, IT, ICT, software development, electronics and robotics education is relevant to the aims set out in the draft curriculum of Coding and Robotics.

2.3.2 Terminology definitions related to the subject of Coding and Robotics

The British Royal Society (2012) identified the issue of terminology definition as a potential barrier to the progress of advancing a subject such as Computer Science. Misunderstanding the scope and definition of a subject area can cause many problems. There are many terms in use, and they are used in diverse ways to indicate different concepts in different contexts. For instance, the term "IT" is frequently used in industry, while "ICT" or "Computing Science" is used by teachers, and "Computer Science" or even "Informatics" by academics. A computational thinking-related subject may be called "Computer Studies" or simply "Computers" by parents or students. In the context of education and skills, these terms could describe a range of abilities, from being able to use a mouse, building a computer from hardware components, developing software, or understanding the abstract foundational principles of a computer. The British Royal Society (2012) stated that consistent language is lacking between industry, academia and educators, which results in business needs and curriculum content not being communicated effectively.

Ching et al. (2018) recognised that the terms "coding" and "programming" are often used interchangeably in daily conversations and academic literature. Ching et al. (2018) adopted a few definitions in an article on educational technologies. They referred to "programming" as "the craft of analysing problems and designing, writing, testing, and maintaining systems to solve them". A "program" is understood as "a set of instructions that the computer executes to achieve a particular objective". The term "coding" focuses explicitly on "the act of writing computer programs in a programming language".

K–12 Computer Science Framework Steering Committee (2016) claimed that the subject of Computer Science is more than the act of coding. It involves physical systems and networks as well as the collection, storage, and analysis of data and the impact of computing on society. This broad view of Computer Science emphasises its range of applications in other fields. However, Computer Science is frequently confused with the everyday use of computers, such as learning how to use the internet and create digital presentations. Parents, teachers, and principals often mistakenly ignore the difference between traditional computer literacy activities and Computer Science, and parents often believe that doing an internet search is Computer Science. The British Royal Society (2012) interpreted Computer Science as referring to the scientific discipline that covers principles like data structures, algorithms, systems architecture, design, programming, and problem-solving. Tucker et al. (2003) defined Computer Science as the study of computers and algorithmic processes. This includes hardware and software designs, their applications, and their impact on society.

Computer Science builds on computer literacy, digital citizenship, educational technology, and IT. "Computer literacy" refers to the general use of computers and programs (K–12 Computer Science Framework Steering Committee, 2016). According to The British Royal Society (2012), "digital literacy" is understood as the basic ability or skill to use a computer safely, effectively and confidently. This includes the ability to use office software like email, word processors and presentation software. Digital literacy also refers to the ability to create and edit audio, images and video content, as well as the ability to use a web browser and conduct internet searches. K–12 Computer Science Framework Steering Committee (2016) claims that "computing" focuses on using computer technologies instead of understanding how to create those technologies.

"Digital citizenship" refers to the appropriate and responsible use of technology, like choosing an appropriate password and keeping it secure (K–12 Computer Science Framework Steering Committee, 2016).

"Educational technology" involves computer literacy applied to school subjects, where the technology use aids the learning activity of another study field's content without being the main aim of the activity. For example, the use of an application to create and store an essay in an English class (K–12 Computer Science Framework Steering Committee, 2016).

"Information technology" overlaps with Computer Science but is mainly focused on industrial applications of Computer Science, like installing software rather than creating it. IT professionals often have a background in Computer Science (K–12 Computer Science Framework Steering Committee, 2016). The British Royal Society (2012) accepted the term IT to mean the assembly, deployment and configurations of digital systems to satisfy user requirements for specific purposes. While Computer Science and IT have much in common, neither is fully substitutable for the other (Tucker et al., 2003).

The British Royal Society (2012) claims that digital literacy, IT and Computer Science form a broad spectrum of skills and knowledge, from the most software-specific digital literacy skills to the most abstract aspects of Computer Science. Every aspect of this spectrum is important in modern society, from office skills to specialised software development. Therefore, a holistic approach to teaching IT and Computer Science in schools is vital to ensure that the full range of relevant skills and content are covered. However, the The British Royal Society (2012) emphasises that the implementation strategy for IT and Computer Science should not include an integrated approach. Instead, government agencies should distinguish between IT and Computer Science when designing the curricula and deciding on funding and specialised teacher development to ensure that all topics in these areas receive adequate attention.

2.3.3 Benefits of Coding and Robotics

The British Royal Society (2012) claimed that every child should have the opportunity to learn computing concepts and principles, including IT and Computer Science study areas, from primary school age onwards. Hu (2011) claimed that there "is inherently a C (Computing) in STEM". Learning STEM without learning computing is fundamentally inadequate. Learning computing skills while solving STEM problems develops computational thinking skills in a student, regardless of the title of the subject.

Fragapane and Standl (2021) pointed out that programming is much more than writing code; it also involves the ability to analyse a situation, identify crucial components and create a solution by taking a design-thinking approach. Fessakis et al. (2013) suggested that from a pedagogical viewpoint, computer programming is considered to improve higher-order thinking. From an instructional perspective, programming is a key skill that enables students to enhance their understanding of various knowledge fields related to Computer Science. Computer programming learning has a positive effect on the cognitive development of children. Liao and Bright (1991) conducted a study and found that children with computer programming experience achieved higher scores on several cognitive-ability tests than those without computer programming experience.

Robotics and programming can support the development of many cognitive and social milestones in early childhood education. Some cognitive skills developed through programming activities include language skills, number sense and visual memory (Sullivan et al., 2015). In addition, learning Computer Science increases student engagement, confidence, communication and problem-solving skills. Performance and learning of other STEM subjects are also improved by learning Computer Science (Mason & Rich, 2019).

Fragapane and Standl (2021) highlighted that creative thinking is one of the primary skills developed through programming. Programming aspects that empower creative thinking include pattern recognition, observation, imagination, abstraction and visualisation. Ching et al. (2018) elaborated that students' creativity is stimulated through programming activities where they must solve problems by commanding computers. Programming is seen as an extension of writing, where students practice their skills to "write" and create new things. Students are empowered through programming to express themselves and their ideas using various tools. Therefore, a student's achievement in Science, language skills, Mathematics and creative thinking can be increased by learning computer programming.

Mason and Rich (2019) claimed that students could benefit economically and academically from learning Computer Science skills. For example, employment opportunities in the computer and IT fields are projected to grow 13% between 2020 and 2030 in the United States (Bureau of Labor Statistics, n.d.-a), which is a promising figure compared to the overall projected job opportunity growth of 7.7% (Bureau of Labor Statistics, n.d.-b). Furthermore, the projected employment growth for software developers, software quality assurance analysts, and testers is 22.2% between 2020 and 2030 in the United States. This suggests that students benefit significantly from exposure to Coding and Robotics related instruction by increasing their employment opportunities.

K–12 Computer Science Framework Steering Committee (2016) suggested that Computer Science will be used in STEM-related occupations as well as non-STEM fields. Students who receive Computer Science education in school will be computationally literate members of society. Instead of being passive consumers of computing technologies, learning Computer Science empowers students to become active producers and creators.

Teaching robotics to young students throughout their schooling can increase their ability to be creative and innovative thinkers and more productive members of society. However, teaching young students the abstract subject of programming can be challenging. Programming is often too complex for inexperienced students to grasp. Robotics provides a tangible introduction to programming. When students program physical robots, they can see real-time feedback on the software they develop. They learn the skills needed to create precise and accurate instructions while the robot introduces an element of fun. Building and programming a robot can be a complex and challenging process. Many students often get frustrated when they struggle with the concepts. Robotics in schools can motivate these students to turn their frustration into creativity and innovation. This valuable life lesson teaches students perseverance and determination when faced with challenges. Not only does teaching students robotics teach them how to persist and solve problems, but it also helps them increase their maturity levels and prepare them for real-world situations (Lynch, 2017). Ponticorvo et al. (2020) added that school robotics education effectively develops skills such as computational thinking, problem-solving, complex systems management, and collaborative learning. Robotics education also promotes 21st-century skills like initiative, autonomy, teamwork, and creativity, together with social skills and communication. Robotics activities can lead to increased self-esteem and motivation in a student.

2.3.3.1 Ways of thinking

Although the specific topics and content that students will learn in the subject of Coding and Robotics in SA schools have yet to be confirmed, there is a clear emphasis that the subject aims to develop certain ways of thinking. The draft curriculum dictates that the common thread across the different content areas is the focus on developing computational thinking skills. Other thinking skills that the subject intends to develop, as mentioned in the draft curriculum, include algorithmic thinking, critical thinking, creative thinking, logical thinking, and design thinking. Students will benefit from developing these ways of thinking since these skills are useful not only in many career opportunities but also for well-adjusted citizens of a digital society (Department of Basic Education South Africa, 2021a). Wing (2006) supports the argument that the activity of programming or studying Computer Science involves the development of various ways of thinking, of which computational thinking is considered the most prominent. To understand the implementation of the subject, these ways of thinking are elaborated on.

2.3.3.1.1 Computational thinking

There is a link between involvement in programming activities and the development of computational thinking skills (Wing, 2006). Fragapane and Standl (2021) admitted that there is no single definition of computational thinking but offered that many definitions of the term include concepts like algorithmic thinking, problem solving, data handling and abstraction. Computational thinking is also implicitly connected to the design of programmable objects, including hardware and software.

The Coding and Robotics draft curriculum emphasises applying computational thinking concepts throughout the subject. Computational thinking is defined in the draft curriculum as a set of problem-solving methods that involve expressing problems and their solutions in simplified steps in the same way that a computer executes instructions. Furthermore, computational thinking is considered to be a dynamic process that consists of four aspects: decomposition, pattern recognition, algorithm design and abstraction (Department of Basic Education South Africa, 2021a).

Computational thinking is not a new concept. Alan Perlis argued in the 1960s that college students of all disciplines should learn the "theory of computation" and programming (Grover & Pea, 2013). According to Wing (2006), computational thinking draws on concepts from Computer Science and involves system design, problem-solving and the understanding of human behaviour. Computational thinking uses reduction, transformation, embedding and simulation to reformulate seemingly complicated problems into simpler ones. Computational thinking includes skills such as recursive thinking, parallel processing and the ability to analyse not only the correctness and efficiency of a program but also the elegance and simplicity of the system's design. Aho (2012) added that computational thinking is the thought process of formulating problems so that their solutions are represented as computational steps and algorithms. The British Royal Society (2012) defined computational thinking as "the process of recognising aspects of computation in the world that surrounds us, and applying tools and techniques from Computer Science to understand and reason about both natural and artificial systems and processes".

Ching et al. (2018) accept "computational thinking" as a framework that includes processes, skills and approaches to solve problems, while "programming" is the key practice to support and develop those cognitive tasks that comprise computational thinking. Wing (2011) revisited the topic to clarify that computational thinking refers to the thought processes required when a problem and its solution are formulated in such a way that the solution is represented in a form that can be carried out effectively by an information-processing agent. Bezuidenhout (2021) explained computational thinking as a problem-solving process that includes logically ordering and analysing data to create solutions. Computational thinking involves concepts like abstraction, pattern recognition, decomposition, data representation, generalisation and modelling.

Wing (2006) suggested that computational thinking is not just a skill fit for a computer scientist but is a fundamental skill for everyone. She claimed that computational thinking should be added to every student's analytical ability, along with reading, writing and arithmetic. Students should be exposed to computational thinking methods and models in school education. Innovation in fields such as Science, Humanities, Medicine, Arts and Engineering is enabled by computational thinking (Grover & Pea, 2013). Wing (2006) agreed that the influence of computational thinking had been witnessed in many disciplines by using the example of statistics that have been transformed by machine learning. Statistical learning can now be implemented on problems with large data sizes and dimensions. Smith (2016) stated that computational thinking skills are developed when children are educated in Computer Science-related subjects and added that these computational thinking skills are relevant to many careers and disciplines, equipping students to break complex problems into smaller ones and to focus on the core of a problem to identify clear steps to a solution. Hu (2011) added that computational thinking is likely a hybrid thinking ability that people gain through various means.

2.3.3.1.2 Computational thinking linked to other ways of thinking

Doleck et al. (2017) illustrated that computational thinking could best be understood as an umbrella term that relates a subset of related cognitive skills involved in computational tasks and activities. Hu (2011) agrees there are links and overlaps between ways of thinking and that a way of thinking conceivably consists of a set of thinking elements. Commonly cited examples of computational thinking skills include abstraction, algorithmic thinking, cooperativity, creative thinking, critical thinking, data analysis, debugging, decomposition, heuristic reasoning, problem-solving, and recursive thinking (Doleck et al., 2017).

Katai (2015) refers to computational thinking and algorithmic thinking interchangeably by claiming that they can both be viewed as special problem-solving skills that involve techniques such as decomposition, pattern recognition, pattern generalisation and abstractions, algorithm design, and data visualisation. Doleck et al. (2017) agrees that algorithmic and computational thinking are both developed during the process of solving problems through programming activities and advocates for the development of these ways of thinking during primary and secondary education. Algorithmic thinking is based on the concept of an algorithm, which refers to solving a problem by developing a set of operations performed in a specific order to achieve the desired outcome. Algorithmic thinking is the thought process behind the formulation of these steps, similar to the computational thinking process. However, Doleck et al. (2017) suggests that algorithmic thinking does not require a computer and is dependent on the human's capacity for abstraction. Futschek (2006) agrees that algorithmic thinking is a key ability in informatics but can be developed independently from learning programming skills. Doleck et al. (2017) agrees that many areas in modern life involve processes where procedures are followed, protocols are applied, and techniques are implemented where not the computer, but the human, is considered the processor.

Hu (2011) suggested that computing is inherently a mathematical activity. Aspects of programming such as analysis, pattern recognition and recursive thinking are mathematical in nature. Hu (2011) continued that programming ability can be improved by developing strong mathematical thinking ability. Mathematical thinking is the process of deconstructing tasks, making assumptions, identifying similar processes and appropriate knowledge, looking for patterns and designing strategies to solve a problem. Mathematical thinking is directly correlated with recursive, abstract, logical and procedural thinking skills, which are all essential to performing computing tasks successfully. This suggests that computational thinking is a form of mathematical thinking.

According to Hu (2011), a person's capacity for critical thinking is applicable in any problem-solving context. Doleck et al. (2017) noted that in addition to problem-solving, critical thinking is also one of the skills comprising computational thinking. Critical thinking can be understood as the capacity or skill by which a person willfully transcends their subjective selves to reach rational conclusions supported by valid information, even if such findings are not necessarily favourable to them. Critical thinking is considered multidimensional, for it requires a deeper level of thinking to solve problems, adding a layer of complexity. Critical thinking incorporates skills like evaluation, selection, abstraction, prediction, deductions and generalisations. Critical thinking promotes skills like problem-solving and creative thinking.

The computational thinking skills employed in software development also require design thinking skills to be applied to solve a problem. Constructing new algorithms that solve given problems in programming challenges requires a strong creative aspect (Futschek, 2006). Hu (2011) offered that design thinking enables the developer to tolerate uncertainty during divergent-convergent thinking cycles and maintain sight of the big picture while communicating solutions in various design languages. Creative thinking forms part of critical thinking, which is a crucial dimension of computational thinking (Doleck et al., 2017).

2.4 SA context

According to Spaull (2019), the life chances of an average South African child are not determined by their ability or the result of their dedication or hard work, but instead by the province of their birth, the wealth of their parents and the colour of their skin. Therefore, the historical context and barriers in the education system need to be considered to understand the complex playing field of education and schooling in SA.

2.4.1 Inequality

SA remains among the most unequal nations in the world. The richest 10% of South Africans lay claim to 90% of national wealth and 65% of national income, one of the largest 90–10 gaps in the world (Spaull, 2019). The Gini coefficient, a measure of inequality, rose from 0.61 in 1996 to 0.63 in 2015, signalling an increase in inequality (World Bank, 2021). These inequalities are mirrored in the education system, where the situations in rural and urban areas differ significantly. These disparities can largely be attributed to the country's historic context (Spaull, 2019). Since the end of apartheid in 1994, there have been many efforts to reduce inequality and poverty, but inequality has remained high and persistent and has increased since then. Although progress has been made to reduce poverty since 1994, between 2011 and 2015, the trajectory of poverty reduction reversed, posing a threat to the advances made. Low intergenerational mobility and inequality are two issues that hamper poverty reduction (World Bank Group, 2018). The reality of inequality in the country is particularly evident in the school system. Samuels et al. (2020) offer that apartheid has left South African schools with unequal distribution of facilities and resourcing. The quality of basic infrastructure and resources varies widely, and many schools do not reach the national minimum standards. The unequal distribution of facilities means the right to quality education remains unrealised in many SA schools.

Angie Motshekga pointed out that in addition to overall academic under-performance in the school system, significant performance disparities tend to follow the poverty lines, as evidenced by poorer performance in rural schools and schools at the lower end of the socio-economic scale (Moloi & Chetty, 2011). According to Köhler (2020), teachers in less affluent communities tend to have less experience and qualifications. Only about one in every three teachers in quintile one to three schools that generally serve the poorest communities have a postgraduate degree, as opposed to quintile five schools, generally in the wealthiest communities, where there is more than one in every two teachers. The average teacher in quintile five schools has more than five additional years of experience teaching than the average teacher in quintile one schools. This highlights the need to prioritise interventions in farm, rural, and township schools and ensure they are operational and appropriately equipped to provide high-quality education to the populations that they serve in a predominantly rural society with limited resources (Moloi & Chetty, 2011).

The state of the education system must be viewed within the broader context of one of the most socio-economic unequal countries worldwide. Nearly half of the black population in SA is regarded as living below the poverty line compared to fewer than 1% of the white community. Moreover, black households earn, on average, less than 20% of what white households do. The situation for the most vulnerable and underprivileged has worsened due to recent austerity measures. At the same time, corruption is a significant issue affecting both the available resources and the public's trust in the government, culminating in the establishment of the Zondo Commission on State Capture and Corruption in August 2018 (Amnesty International, 2020).

Education could positively affect the reduction of inequality if the quality of the instruction given to all students in the country is adequate. Although there has been a tremendous improvement in access to education since apartheid ended, this has not necessarily resulted in all students receiving a quality education. The system is still plagued by stark inequalities and persistent underperformance rooted in apartheid's legacy. The government's failure to apply available funds to effectively address these challenges has resulted in the education system continuing to mirror the country's socio-economic inequalities (Amnesty International, 2020).

2.4.2 South African school history

SA's education history continues to influence the current system, from elite private schools established during the colonial period by religious institutions to the schools developed under the apartheid policies (Amnesty International, 2020).

With the founding of mission schools associated with the church in the late 17th century, formal education in SA began to develop. By the end of the 19th century, three different categories of state schools had been established: small rural schools that generally employed one teacher; district schools, which provided primary education to multiple towns in an area; and a few secondary schools in bigger cities. Some of the prestigious private schools that exist today were founded during this time (Amnesty International, 2020).

By the beginning of the 20th century, black African children were essentially no longer enrolled in government schools, leaving them dependent on mission schools with little assistance from the state (Byrnes, 1996). English and Afrikaans became the official languages of instruction in schools in 1948 (Ocampo, 2004). Different departments for education were established, mirroring the apartheid policy. These used different curricula and provided education of various standards. They included national departments for black people, so-called coloured (multi-ethnic) people and Indians; a department for independent schools; and provincial departments for white people. Some territories set aside for black Africans had their own education departments. Under this discriminatory system, universities were banned from accepting black students unless special permission was obtained, and specific universities for black, coloured, and Indian students were established. All racial groups were required to attend school, but at different ages and the law was enforced differently. By 1970, the per capita government expenditure on black education was a tenth of that on white education. As a result, Black schools had inferior facilities, teachers and textbooks. Despite making up 70% of the population, just 20% of university students in 1978 were black. The ratios of teachers to students varied greatly. There were 1:18 students per teacher in white schools, 1:24 in Indian schools, 1:27 in coloured schools, and 1:39 in black schools for primary education. Differences in teacher qualifications enhanced discrimination.

Consequently, this affected outcomes, and pass rates for black students were less than half of those for white students (Roodt, 2011). The Soweto Uprising, a student-led protest against the regulation that half of the secondary school classes be taught in Afrikaans, occurred in 1976 and changed the trajectory of education (Ocampo, 2004). Eight years later, the National Policy for General Affairs Act gave the Minister of National Education authority to determine the policy for curricula, assessments, and certification requirements across all institutions. This led to some improvements in black education, but it was challenging to manage because education was scattered across racially separated and homeland education agencies. Negotiations between President P.W. Botha and Nelson Mandela of the African National Congress (ANC) in 1986 resulted in narrowing the gap in funding for education between racial groups (Roodt, 2011).

The ANC government-in-waiting was tasked by the policy guidelines adopted at the 1992 National Conference of the ANC to "equalise the per capita expenditure between black and white education" and to make sure that "resources are redistributed to the most disadvantaged sectors of our society, in particular, women, rural and adult students, and mentally or physically disabled children and adults." The ANC administration reorganised the basic and higher education departments under the Interim Constitution, with duties being split between nine recently established provincial education departments and one national education department. It also started removing all out-of-date, discriminating content and implementing continuous assessment in schools. Ensuring every child had access to education was one of the top priorities. This strategy persisted in the post-apartheid era, and as a result, SA has a respectable record regarding access to education. All government-run primary and secondary schools were officially racially integrated in 1995, and schooling was made compulsory from the age of seven to fifteen for all students (Roodt, 2011). The government paid teachers, while schools had to charge for supplies and equipment (Ocampo, 2004). All 21 of South Africa's top universities, which the government supported, accepted students of all races (Roodt, 2011).

South Africa has done well in the past 20 years to increase black children's access to school at all levels, but this hasn't always translated into high-quality education for everyone. As a result, the socioeconomic disparities in the nation are still reflected in the educational system. SA is failing far too many of its young people in terms of education. Despite positive developments, apartheid's legacy still contributes to ongoing inequality (Amnesty International, 2020). Roodt (2011) insisted on a strong perception that education still fell short for everyone, especially for black children who live in poverty 25 years after the end of apartheid.

2.4.3 Student performance

Minister of Basic Education at the time, Angie Moshekga, stated in response to the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ) report that the levels and quality of educational outcomes achieved by our learners are evidently still far below our national target (Moloi & Chetty, 2011).

The Progress in International Reading Literacy Study (PIRLS) published in 2017 found that 97% of grade four students in SA scored the lowest of all 50 participating nations, with 78% of grade four students unable to read for meaning. The worst performers were the rural regions, with 91% of grade 4 students in Limpopo and similarly high percentages in the Eastern Cape (85%) and Mpumalanga (83%) unable to read for meaning. The results were 69% in Gauteng and 55% in the Western Cape (Centre for Evaluation and Assessment, 2017).

Another standardised regional survey based on mathematics and literacy testing of 61396 grade six students from 2779 schools across 15 southern African countries placed SA eighth for mathematics and tenth for reading (Amnesty International, 2020).

South Africa's performance in the SACMEQ tests and the Trends in International Mathematics and Science Study (TIMSS) assessments were also reportedly poor (Amnesty International, 2020). Mullis

TABLE 2.1: *Mean scores of grade six students' achievement in the SACMEQ II, III and IV surveys (Department Basic Education, 2017).*

Reading			Mathematics		
SACMEQ II	SACMEQ III	SACMEQ IV	SACMEQ II	SACMEQ III	SACMEQ IV
492	495	538	486	495	552

et al. (2020) provided an interpretation of the TIMSS grade four Mathematics and Science achievement results. The achievements are described by four benchmark points on the scale of achieved marks concerning the student's assessment performance. The Advanced International Benchmark, High International Benchmark, Intermediate International Benchmark and Low International Benchmark describe the standard of the student's ability. Only 1% of SA grade four students reached the Advanced International Benchmark (above 625) in Mathematics, while 63% could not even reach the Low International Benchmark (400). In the Science assessments, only 2% of grade fours reached the Advanced International Benchmark, and 72% were unable to reach the Low International Benchmark.

The SACMEQ IV survey was conducted in SA in 2013 to assess the quality of education. Grade six students' mathematics and reading skills were tested, and these scores were compared to the SACMEQ III and II results of 2007 and 2001, respectively. Table 2.1 shows an improvement in the mean scores for reading and mathematics tests. The National Development Plan specified that the target score for the SACMEQ survey is a mean score of 600 in both language and mathematics by 2022, which seems achievable if the trend of improvement continues (Department Basic Education, 2017). However, the breakdown of the scores into achievement levels shows more meaningful results. The SACMEQ test scores are grouped into eight achievement levels, with level four and above being the acceptable benchmark (Moloi & Chetty, 2011). The overall percentage of students reaching proficiency in reading (level four and above) was 51.7% in 2007 and 75.3% in 2013. In 2013, Limpopo was the province where the lowest number of students reached acceptable skill levels, with 56.1% of students reaching levels four and above, while in the Western Cape, 94.4% of students reached this benchmark in the reading test. The mathematics test showed less favourable results. The percentage of students reaching acceptable levels of four and above was 30.9% in 2007 and 50% in 2013. Similar to the reading test results, the Western Cape had the highest percentage of students achieving acceptable scores for mathematics in 2013, with 85% of students reaching level four and above, while in Limpopo, only 34% of students reached levels four and above (Department Basic Education, 2017).

In terms of quality of education, South Africa has one of the most unequal school systems in the world, with the widest gap between the test scores of the top 20% of schools and the rest (Amnesty International, 2020). In a study conducted by Köhler (2020), the pass rates for the 2017 National Senior Certificate (NSC) and the 2017/18 School Monitoring Survey were compared. It was discovered that there was a more than 30 percentage point difference between the quintiles. Only 56% of students in quintile one to three schools passed grade twelve with an NSC, compared to 87% of students in quintile five schools. Furthermore, Spaull (2019) reported that 3% of SA secondary schools produce more Mathematics distinctions than the remaining 97% put together.

Motala and Pampallis (2005) suggest that the outcome of teaching can be measured by continuous learner assessment, by entering international comparative tests, and by simply taking NSC results as a norm of teaching efficiency. According to Motala and Pampallis (2005), matric pass rates, especially passes with an endorsement for university entry, correlate with the school's socio-economic status. Schools in the top 40% socio-economic group perform significantly better than those in the bottom 60% group.

The SACMEQ tests also reported on the "non-readers" or "non-numerate" achievers. These are students who scored in the lowest two levels of the SACMEQ tests, meaning that they cannot "interpret meaning in a short and simple text" in the reading test or "have not moved beyond the mechanical skills related to basic calculation and simple shape recognition" in the mathematics assessment (Moloi & Chetty, 2011). In SA in 2013, 14.9% of grade six students were non-numerate, and 8.9% were non-readers. This is a significant improvement from the 40.2% non-numerate and 27.2% non-reader statistics of 2007. However, significant disparities between student subgroups are hidden by these averages. In stark contrast to the Eastern Cape and Limpopo, where 15.7% and 16.5% of pupils, respectively, were non-readers, only 1.7% of students in the Western Cape were. Similar disparities were noticeable in the mathematics tests, with a significant difference in skills between the provinces. The Eastern Cape and Limpopo had non-numerate percentages of 20.5% and 23.9%, respectively, compared to the Western Cape's non-numerate percentage of 2.7%. The mean test scores of students in quintile one schools also proved significantly lower than those of quintile five schools. 10.8% of students in quintile one schools were considered non-readers, while only 5.9% of quintile five students were non-readers. The non-numeracy percentages revealed the same phenomenon, with 18.1% of quintile one students classified as non-numerate compared to the 10.6% of students in quintile one schools (Department Basic Education, 2017).

2.4.4 Barriers to education

Several issues in SA schools hinder students from receiving quality education (Amnesty International, 2020). A few of these barriers are discussed to provide context for the situation in SA schools.

2.4.4.1 Condition of infrastructure in schools

SA schools have an unequal distribution of resources and facilities as a result of apartheid. Many schools in the country do not reach the minimum standards, and the quality of basic infrastructure varies dramatically. Many pupils still do not enjoy the benefits of light, heating or modern teaching tools (Samuels et al., 2020).

In 2018, 20071 of the 23471 public schools did not have a laboratory (including a computer laboratory), 18019 had no library, 16897 had no internet, and 9956 had no sports facilities. In the same year, there were still 4358 schools with illegal pit latrines for sanitation and 37 schools that had no sanitation facilities at all. In addition, 269 schools were reported to have no access to electricity (Department of Basic Education, 2018). Electricity is an energy resource that directly affects the equipment available to create an environment suitable for effective learning and teaching, such as lighting, computers, photocopiers, television sets or projectors (Moloi & Chetty, 2011).

Department Basic Education (2017) reported from the SACMEQ IV study that in 2013, the average grade six learner was in a school where 65.6% of the learners had Reading books and 66.1% had Mathematics textbooks. This means that grade six learners were in schools where 34.4% of them either had no Reading book or shared a book with another student. Between 2007 and 2013, the overall percentage of schools where the average grade 6 learner had exclusive access to a Reading book increased from 45% to 65.6%, while access to Mathematics books increased from 36.4% to 66.1% (Department Basic Education, 2017; Moloi & Chetty, 2011). The SACMEQ study also reported on the operation facilities available in SA schools. In 2013, 61.3% of school buildings were in usable condition, and 33.2% of schools had a suitable meeting hall. 76.9% of schools had offices appropriate for principals, and 67.7% had staffrooms. The percentage of schools with class cupboards and class bookshelves was 84.9% and 56.7%, respectively. The availability of television sets and computers in 2007 was 87% and 97.6% respectively (Department Basic Education, 2017).

A notable observation from the SACMEQ IV study is the discrepancy between the infrastructure conditions in the provinces. For instance, the state of school buildings differed significantly. In the Western Cape and Gauteng, 82.1% and 81.8% of schools were in a usable condition, while in the Eastern Cape and Limpopo, these numbers were 48.9% and 46.6%, respectively. Similarly, 90.7% of schools in the Western Cape had staff rooms, while only 50.0% of schools in Limpopo had (Dell'Erba, 2019).

Amnesty International (2020) agrees that inadequate infrastructure and facilities hinder a school's ability to provide quality education and contribute to the poor academic performance of students. In many cases, school buildings do not protect teachers and learners from adverse weather conditions, which also negatively impacts learning. These conditions range from rainwater leaking into classrooms to buildings being unable to protect from extreme temperatures. The SA government has failed repeatedly at upgrading the infrastructure in schools to meet its own Minimum Norms and Standards, despite attempted efforts. The government enacted binding regulations in 2013 to ensure that all schools would have access to water, sanitation and electricity; pit latrines would be replaced; and schools built from inappropriate materials such as asbestos and mud would be replaced by 2016. However, these targets were not met. The DBE's policy on school infrastructure, the National Policy for an Equitable Provision of an Enabling School Physical Teaching and Learning Environment, highlights that a poor schooling environment negatively affects learners. These include higher dropout rates and irregular attendance. The policy also recognises the detrimental effects of inadequate infrastructure on teachers, citing high rates of teacher absenteeism and turnover due to their challenging work environments.

2.4.4.2 Security

Another hindrance to students' education experiences in SA is the matter of school security. The lack of proper security measures and poor infrastructure maintenance found in many schools in SA increases the problems of vandalism and burglary (Amnesty International, 2020). The SACMEQ study found that only 87% of schools were fenced off in 2007, and this percentage increased to 94.9% in 2013 (Department Basic Education, 2017). Properly securing the premises of a school to restrict unpermitted access is crucial in providing a safe learning environment (Moloi & Chetty, 2011). According to Moloi and Chetty (2011), it is unacceptable for any students to be in schools that are not fenced off since it is such an essential requirement. South African Police Service (2018) released a statement condemning the persistent incidents of violent crimes occurring on the school premises. These incidents negatively impact students' learning experience (Amnesty International, 2020).

2.4.4.3 Transport challenges

One of the challenges that students face that affects their access to quality education is the lack of transport to school. This does not only hinder their access to education but also puts their safety at an increased risk. According to the 2013 National Household Travel Survey, about 11 million of the 17.4 million learners who attended educational institutions get to school by walking. 22% of these children (more than 2.4 million) walk between 30 minutes and an hour to get to their school. This means it is likely more than 3km that they have to walk to get to their educational institution. It was also found that children in the lowest income group were likelier to walk to school than those in the highest income group. More students walk to school in KwaZulu-Natal than in any other province. More than 210000 students walk for more than an hour each way, and 659000 walk between 30 minutes and an hour each way in the province (Amnesty International, 2020).

2.4.4.4 Overcrowded classes

In many schools in SA, the number of students per class is a barrier to the student's learning experience. Amnesty International (2020) reported that the insufficient number of trained teachers results in overcrowded classrooms and an increased workload on the teacher. This high ratio of students per teacher has a negative impact on the student's learning as well as the morale of the teacher. Amnesty International (2020) reported that they found some schools in SA had more than one grade taught together in a class due to a shortage of classrooms. They also found that some students received as little as 2.5 hours of tuition per day, with class sizes of up to 70 pupils, due to a lack of available staff. In a joint survey with the National Association of School Governing Bodies, 48% of respondents reported that the average class size was more than the official stipulated figure of 1:35 in all or most schools in their areas, and 41% responded that either no or few schools in their areas had sufficient numbers of teachers. The challenge of recruiting new teachers in rural areas, as well as frequent teacher absenteeism, remains a hindrance to overcrowded classrooms.

2.4.4.5 Teacher challenges

The poor teacher skills and ability level in SA present major challenges to students' learning experiences. Specialist fields like Mathematics and Science have particular challenges in teacher skills, with thousands of teachers being underqualified or unqualified. According to Amnesty International (2020), 24% of teachers in SA have not completed any tertiary education. A study in March 2018 found that many SA teachers could not pass simple Mathematics and English tests, with some scoring as low as 10% for English as a first additional language and 5% for Mathematics. Another study by Stellenbosch University found that intermediate-phase Mathematics teachers in under-resourced schools in the Eastern Cape were not proficient in English even though they were supposed to teach in English and they also lacked adequate knowledge of Mathematics (Amnesty International, 2020).

According to a series of interviews conducted by Amnesty International, one of the most significant reasons for the poor teaching skills is the SA teacher training system not being fit for its purpose. New teachers are reportedly not equipped with adequate content or pedagogical knowledge when they enter the profession. School principals reported that new teachers required significant on-the-job training, for their pre-service training focussed too much on the subject content and not enough on practical pedagogical skills needed to teach students effectively (Amnesty International, 2020).

One of the many challenges teachers face in SA is the lack of support. Multiple changes to the national curriculum have introduced more content for teachers to teach, placing pressure on their preparation requirements and lesson planning. Furthermore, insufficient professional development opportunities place more pressure on the teachers to master the content themselves. There is also a lack of engagement and support from curriculum subject advisors. For many teachers, this has resulted in increased stress and decreased motivation, which negatively impacts the student's learning experience. As expected under these conditions, teacher retention and recruitment are significant challenges, especially in poorer provinces. Vacancy numbers are reported to be more pressing in the Eastern Cape, Limpopo and Mpumalanga, which reinforces the disparities in education received by students from different communities (Amnesty International, 2020).

2.4.4.6 Funding challenges

According to Samuels et al. (2020), funding for basic education needs is under pressure, even though SA spends more than 20% of the government budget on education. The schools' budget spent per pupil decreased by 8% between 2010 and 2017. The problem is not limited to the availability of funds but also relates to how the money is allocated to certain expenses. The historical inequities in the South African education system were aimed to be reduced by the Amended National Norms and Standards for School Funding. Schools are classified into five quintiles according to the socioeconomic status of the community in which they are located for government funding purposes (Ogbonnaya & Awuah, 2019). Socioeconomic status is measured by the unemployment rate, average income and general literacy in the school's geographical area. Quintile one schools, which still mainly serve black pupils, are the poorest, and quintile five schools, many of them formerly white schools, are the most affluent. Quintiles one to three are the non-fee-paying schools. They receive the highest allocation per pupil from the government, while quintile five schools receive the lowest. This is due to the assumption that the parents of quintile five school children can afford to pay school fees. Studies have shown that despite this attempt to distribute the funding to the benefit of less fortunate schools, inequalities persist regarding access to good education (Samuels et al., 2020).

The way funds are distributed often fails to address the inequalities in the school system and sometimes even reinforces them. The funding formula often discriminates against poorer provinces instead of reflecting the longstanding existing demographic and structural issues. For example, Limpopo and Eastern Cape, the two most impoverished provinces, spent a larger portion of their equitable share on basic education in 2016/17 but still ended up with the lowest allocations per student. Compared to the Western Cape and Gauteng, the two wealthiest provinces, that spent more per learner while having among the lowest proportion of their population enrolled in school. This significant defect in the formula is escalating inequality. For example, the Limpopo Education Department stated that according to its current budget, it would take 14 years minimum to replace all pit latrines that are still in use in the province's public schools (Amnesty International, 2020).

2.5 Conclusion

In this chapter, the achievement of RO I is described. Terminologies such as 4IR, Education 4.0 and IoT that are relevant to the study are defined. STEM education is researched to present the benefits that STEM education holds for a student. The subject of Coding and Robotics is defined according to the DBEs draft statement, and definitions of terminology related to Coding and Robotics are presented to provide an understanding of the concepts and topics the subject is to cover. The benefits of Coding and Robotics as a subject are explored to motivate the introduction of the subject to SA schools. The SA public school landscape is explained to provide an understanding of the realistic situation in schools that are to present the proposed subject. In this chapter, the literature is reviewed with the aim of providing context for the framework, while in the next chapter, Chapter 3, the literature survey is conducted to identify possible factors to include in the framework.

CHAPTER 3

Factors identified from literature

Contents

In this chapter, the literature is reviewed to identify proposed factors that a school should consider when introducing Coding and Robotics. These theoretical factors are explored to achieve the outcome described by RO II. The six factors that are expanded in this chapter are teacher, infrastructure, artefacts, curriculum, support network and budget. The deductions are made from literature primarily dominated by research on Computer Science due to its similarities with the proposed subject of Coding and Robotics.

3.1 Introducing a subject to schools

The chief director of Mathematics, Science, Technology and Curriculum Enhancement Programmes in the SA DBE, Sileki Tlhabane, commented that various elements need to be considered and managed carefully when including a new subject in South African schools (BusinessTech, 2021b). The implementation strategy of the subject must be flexible due to the evolving nature of Computer Science education. Schools will need to be adaptable in their introduction of the subject and potentially explore multiple implementation strategies before deciding upon the right fit for their specific situation to serve their students best (K–12 Computer Science Framework Steering Committee, 2016). This suggests that the factors identified in this study must be carefully considered and managed to ensure a successful introduction.

3.1.1 Change management in schools

The demands of education improvement are constantly changing, which requires careful change management as response (Cobo & Rivera Vargas, 2018; Hoşgörür, 2016).

Educational change is multi-dimensional and involves several different dimensions within the school system, including, among others, resources, management, content, administration and attitudes (James & Connolly, 2000). This complexity suggests that educational change needs to be managed carefully (Wallace, 2004)

Effective change management requires an investment in both technological and human resources, as well as the careful management of the process (James & Connolly, 2000). Cobo and Rivera Vargas (2018) offered that transformations regarding the introduction of technology in schools do not necessarily develop at the same pace; for instance, it might take longer to develop a teacher's technological capacities than it does to install these technologies.

Hoşgörür (2016) conducted a change management study to determine the opinions of primary school administrators. Change was regarded as any renewing, changing or updating of situations that create challenges in implementation, such as the introduction of technological equipment and the increased use of technology. The researcher found that there is great resistance to these changes in schools, often from the teachers since they are the ones largely responsible for the implementation of introduced changes in education practices.

One of the changes that need to be carefully managed is time allocation. In order to find time for a new subject's instruction, a school might need to cut time spent on another subject (K–12 Computer Science Framework Steering Committee, 2016). However, in the SA public school context, this falls outside of the scope of decisions that a school's management needs to take responsibility for because learning time allocation is determined by the DBE. The final approved Coding and Robotics Curriculum Assessment Policy Statement (CAPS) document will specify timetable allocations, but the assumption is that the content might be introduced in the existing technology subject's timeslot (Mtshali, 2019). The demands of education improvement are constantly changing, which requires careful change management as response (Cobo & Rivera Vargas, 2018; Hoşgörür, 2016).

3.1.2 Equal access considerations

Equal access needs to be considered when introducing the new subject into schools. Due to the possibility of perpetuating disparities, it is crucial to take into account implementation for all students, regardless of race, socioeconomic background, disability, gender, or level of English proficiency. Throughout the implementation phase, equity should be actively monitored (K–12 Computer Science Framework Steering Committee, 2016).

However, the intention of equity in the subject should not be to equip all students to become software engineers. Instead, it should focus on granting every student the opportunity to develop 21st-century skills applicable in a technology-driven workplace while laying an adequate foundation of knowledge for the few students who do wish to pursue further education in a technical field (K–12 Computer Science Framework Steering Committee, 2016).

Cobo and Rivera Vargas (2018) offered that accessibility is a critical aspect to consider in educational technology projects. Strategies need to be in place to include differently-abled students to ensure "equality of opportunities". The specifics of each disability, such as auditory, visual, motor or developmental disorders, must be acknowledged to ensure that suitable support is provided. Students with special needs can, for instance, be supported through adapted computers or designed software. For example, desktop access screen readers could be made available to students with visual impairments to allow for inclusivity in the subject's introduction. Alternatively, specific teaching strategies can be implemented to increase access to computing activities for learners with cognitive disabilities (K–12 Computer Science Framework Steering Committee, 2016).

The field of robotics is readily accessible to a range of students with various skills and talents. For instance, robots are effective in capturing the attention of autistic students. Children with autism can easily react to the predictable, calm, and orderly interactions that robots provide (Lynch, 2017). Werry et al. (2001) agree that education involving mobile robots can enable students on the autism spectrum to develop a range of interaction skills.

Dealing effectively with diversity in schools is a significant challenge (Katai, 2015). Regarding equity, it is not only about whether classes are offered but also about how those subjects are taught. The classroom culture is important in terms of support for diverse learners, retention of interest and addressing unconscious biases (K–12 Computer Science Framework Steering Committee, 2016). Educational programmes must bridge the gap between Sciences- and Humanities-oriented learners, ensuring that all students feel empowered to learn (Katai, 2015).

3.2 Factors to consider when introducing Coding and Robotics

In this section, factors that impact the implementation of Coding and Robotics are identified from the literature. As elaborated in Section 2.3.1, the learning areas and aims specified in the draft curriculum for the Coding and Robotics subject suggest that the subject will have significant overlap with Computer Science and IT, even though the exact scope of topics have not yet been confirmed. Therefore, literature related to Computer Science education was also used to make deductions about draft factors to include in this framework, to append the limited research available on Coding and Robotics in SA.

3.2.1 Teacher

Teacher quality is one of the most important factors in student learning (Buchter et al., 2017). Classroom teachers play a particularly vital role in the student's learning experience in Computer Science curricula (Grover et al., 2019). Similarly, the availability of suitable teachers to teach the new subject of Coding and Robotics is crucial to ensure the success of the subject's introduction. Sileki Tlhabane insists that these teachers must be well-orientated and trained to teach the curriculum effectively (BusinessTech, 2021b). Proper certification pathways will need to be designed for the subject to ensure teaching standards and long-term sustainability, which will require time, resources, and collaboration with teacher preparation institutions (K–12 Computer Science Framework Steering Committee, 2016).

According to Tucker et al. (2003), Computer Science is often taught by teachers certified in Mathematics. These two subjects have significant overlaps in content, such as abstraction and pattern recognition, and both promote computational thinking development. There are also significant similarities between Computer Science and Science education, such as data analysis and problem-solving (K–12 Computer Science Framework Steering Committee, 2016). This suggests that a Mathematics or Science teacher might be a suitable candidate to be trained for Coding and Robotics teaching. However, Tucker et al. (2003) found that numerous teachers who are interested in the field have self-educated to teach Computer Science at various levels, regardless of their original teaching certification. K–12 Computer Science Framework Steering Committee (2016) agree that teachers from various backgrounds could be trained to teach the new subject. For example, subject area teachers, like Science, Technology, Maths, Music, Art or Media teachers, could teach the subject successfully if properly prepared.

The DBE insisted that no additional teachers would need to be employed to teach the subject of Coding and Robotics. Instead, existing teachers identified in schools would be presented with training that will be sufficient in equipping them to guide students through the material (Lang, 2021).

The British Royal Society (2012) offered that determining a teacher's suitability to be a specialist teacher is more complicated in an ICT-related field because many in-service ICT and Computing teachers have relevant industrial experience but no formal qualification in these subjects. This suggests that a teacher's qualification does not provide the most accurate measure of subject specialist potential.

There is a need for conclusive research regarding the competency aspects required to teach the relatively new subject of Computer Science (Bender et al., 2015). This suggests that a system for evaluating a teacher's suitability to teach the new subject of Coding and Robotics could also be useful. Drawing inspiration from the Supply Chain Operations Reference (SCOR) Model for People, a method for managing talent in the supply chain, certain performance metric elements could be defined to determine the adequacy of a potential teacher. In the SCOR method, experience, training and competence are evaluated. The SCOR system recognises five competency levels, as follows (APICS, 2017):

- Novice: Untrained beginner without experience; requires and follows detailed documentation or instructions.
- Beginner: Performs the work with limited situational perception.
- Competent: Understands the work and can determine priorities to reach certain goals and outcomes.
- Proficient: Oversees all aspects of the work and can prioritise based on situational aspects.
- Expert: Intuitive understanding. Experts can apply patterns from experience to new situations.

A similar strategy could potentially be followed to determine the readiness of a teacher to apply themselves to the implementation of the new subject.

3.2.1.1 Suitable teacher profile

Since the argument is made that Coding and Robotics teachers will be identified from within schools (Lang, 2021), this framework aims to present attributes by which a suitable teacher could be recognised. This study proposes that an appropriate teacher should preferably possess as many of these attributes as possible. These proposed attributes are explored from the literature in this subsection.

3.2.1.1.1 Interested

Bell et al. (2014) suggested that the teacher selected to teach Computer Science should be personally interested in the subject, and they must be motivated to provide better opportunities for their students. The teacher needs to believe in the new subject's advantages for the students. If the teacher does not believe that the inclusion is necessary, they will not be motivated to apply themselves adequately to the teaching of the subject (James & Connolly, 2000). Since teaching the subject has unique demands due to the ever-changing nature of the field, the teacher will have to spend time researching and evaluating new resources (Tucker et al., 2003). Bell et al. (2014) agree that the teacher will have to be self-motivated by their interest, for Computer Science-related topics require self-study from the teacher to keep up with developments, and the same condition could apply to the field of Coding and Robotics.

3.2.1.1.2 Digitally literate

The subject of Coding and Robotics will have a significant technical component (Department of Basic Education South Africa, 2021a). It is understood that teachers must have the appropriate depth of knowledge and skills for the subject that they need to teach. Therefore, the teacher needs to be digitally literate to teach this subject that relies significantly on the use of digital devices (Tucker et al., 2003).

It is essential that the Coding and Robotics teacher has confidence in their technical abilities in order to teach effectively. When teachers unfamiliar with computers are required to use them in their teaching, their authority as teachers is compromised, and the content they aim to teach is not presented adequately (James & Connolly, 2000).

3.2.1.1.3 Willingness to learn

A suitable Coding and Robotics teacher must have a keen aptitude for learning. The nature of a subject like Computer Science involves continuous change, which requires the teacher to continue learning (K–12 Computer Science Framework Steering Committee, 2016). Teachers must devote time to invest in professional development opportunities to keep up with the constant developments in technology and resources. The teacher will need to be keen to seize opportunities for professional development and upskilling in order to teach the subject (Tucker et al., 2003).

3.2.1.1.4 Capacity

A suitable teacher for the subject must have capacity. Attending professional development opportunities and getting familiar with the course content could consume a significant amount of time (Bell et al., 2014). Tucker et al. (2003) agree that the newness of the subject will require the teacher to devote suitable time to activity planning and lesson preparation.

3.2.1.2 Teacher training

Appropriate teacher training programmes are vital to ensure the successful teaching of the new subject of Coding and Robotics (Mtshali, 2019; Tucker et al., 2003). Du Plessis and Webb (2012) agree that teacher training is one of the most important factors in the sustainable integration of digital devices and learning resources in education. High-quality teacher professional development has proven to improve performance and assessment results in young students (Buchter et al., 2017). Clear certification pathways need to be implemented to ensure that teachers are equipped to teach the subject (K–12 Computer Science Framework Steering Committee, 2016).

The sole availability of digital devices will not increase the digital competence of the student if the educators are not properly trained to facilitate learning (Cobo & Rivera Vargas, 2018). Mtshali (2019) agrees that supplying schools with tablets or laptops without addressing the teacher training will not result in a sustainable implementation.

An aspect that should be covered in training is addressing misconceptions. Many misconceptions and inaccurate perceptions surround Computer Science, computational thinking and computing topics (Sáez-López et al., 2016). Falkner et al. (2015) offered the importance of addressing these misconceptions during teacher training. The definitions of topics in the new field need to be established to ensure teachers are confident with the content. The British Royal Society (2012) suggest that the training sessions should provide the teacher with relatable context for the learnings by showing real-world applications of ICT from the teacher's frame of reference to ensure they are comfortable with the concepts. Bell et al. (2014) offered that professional development opportunities could make a big difference in teachers' views of the subject. Teachers should be informed of the true intent of the subject to communicate the value that the subject will add to the student's education (K–12 Computer Science Framework Steering Committee, 2016).

Appropriate professional development will be essential to the success of introducing a new computing learning area since it will give teachers the skills and the confidence necessary to successfully incorporate the new content into their lesson plans (Falkner et al., 2015). Bell et al. (2014) offered that teachers have to be prepared to teach a wide range of material that few of them have encountered before to enable them to teach Computer Science. This suggests that the training opportunities should attend to novice teachers' anxiety over their lack of experience and knowledge. Teachers are often nervous about having to teach new topics outside of their experience and often do not have an accurate understanding of the range of terminology surrounding the discipline (Du Plessis & Webb, 2012). Due to the unfamiliarity that many teachers may face surrounding computational thinking or Computer Science topics, the training material should be suitable for someone learning these concepts for the first time. The barrier to entry should be low so that teachers from a range of backgrounds can benefit from the training opportunities. The logical structure of the content should also be prioritised to ensure careful scaffolding (K–12 Computer Science Framework Steering Committee, 2016). Du Plessis and Webb (2012) and The British Royal Society (2012) suggested that teacher professional development be continuous so that teachers are thoroughly prepared to teach the new material.

Falkner et al. (2015) emphasised the necessity of teacher development that addresses both content and pedagogical knowledge. In order to use digital technology responsibly and critically as an educational tool, it is vital to promote and build new pedagogical methods. Not only should the teachers be equipped with the content knowledge that they need to teach, but they should also know the appropriate pedagogical methods to teach certain concepts with the use of technology (Cobo & Rivera Vargas, 2018). Cobo and Rivera Vargas (2018) claim that educating teachers on pedagogical concepts such as constructionism will allow them to draw inspiration from the philosophy when designing and facilitating activities. Constructionism emphasises the idea that learning is not simply the consumption of external knowledge but instead an active process of constructing knowledge drawing from a relevant context. According to Bender et al. (2015), the better a teacher's pedagogical content knowledge, the better the support for the student during lessons and the higher the student performance. Teachers should master both the subject matter and the pedagogical practices to facilitate learning at appropriate levels (Tucker et al., 2003). Equipping teachers to introduce Computer Science related topics like computational thinking and problem-solving into other subjects will further promote inter-disciplinary learning (K–12 Computer Science Framework Steering Committee, 2016).

According to Cobo and Rivera Vargas (2018), teachers in Uruguay were trained to teach robotics as part of a pilot program to develop students' computational thinking skills. This training followed a blended model with face-to-face training time as well as remote sessions and online resources. The face-to-face sessions in a specialised lab were vital in equipping teachers to use tools such as robotics kits, lab sensor kits and 3D printers and to give them practical experience with teaching coding. Teachers also received remote teaching via video conferencing as well as access to online resources and additional documentation to ensure ongoing training and efficient time management. Du Plessis and Webb (2012) reported on ICT professional teacher development opportunities in the SA context and confirmed that successfully training teachers to teach with the use of computers requires a significant hands-on component, for it is important that new teachers get adequate practical exposure to these devices. Sileki Tlhabane confirmed that the teachers trained for the pilot rollout of the Coding and Robotics curriculum will be trained in face-to-face and online sessions to optimise time management (BusinessTech, 2021b).

According to The British Royal Society (2012), one of the primary considerations with teacher training is the associated costs and schedule conflicts. Training often happens during busy term times, but teachers are reluctant to lose contact time with the students when attending these training opportunities. This means that the school has to organise a substitute teacher for the conflicting classes. In addition, the geographical distribution of training events is a particularly discouraging consideration for teachers who work in rural areas. For this reason, The British Royal Society (2012) suggests that more local and regional training opportunities be organised. They also encourage remote learning opportunities.

3.2.1.2.1 Pre-service and in-service training

It is crucial that adequate pre-service, as well as in-service training programs, be designed and implemented (Cobo & Rivera Vargas, 2018).

A senior lecturer in the Department of Information Systems at the University of Western Cape, Dr Mmaki Jantjies, commented that teachers in SA were not trained to teach coding in pre-service training at the current time (Mtshali, 2019). Cobo and Rivera Vargas (2018) suggested that it is critical that pre-service training includes working with high-quality technology to ensure that teachers are equipped to use these resources in the classroom. Appropriate standards for teacher certification must be established to ensure that teachers are appropriately prepared before entering the profession (Tucker et al., 2003). Schools of education should introduce pre-service programmes to teach prospective teachers the necessary skills to teach the subject (Cobo & Rivera Vargas, 2018). Teachers must be equipped with a solid foundation in educational technology (Tucker et al., 2003).

Current educators must also be equipped to adopt and integrate the new subject. The school system will need to meet the immediate need for Coding and Robotics teachers by building capacity amongst existing teachers (K–12 Computer Science Framework Steering Committee, 2016). In-service training programmes should provide the required professional development to the teachers who will teach the new subject to ensure that teachers already in the school system are retrained (Tucker et al., 2003). Sustainable integration of technology into the classroom requires permanent teacher development. Not only should the new generation of teachers be trained to teach using these technologies in their pre-service education training, but teachers who are already in service need to be equipped to adopt these new teaching tools and methods. Teachers who have already adopted technology in their classrooms should attend continuous development opportunities so that they stay informed of the latest developments in educational technology (Cobo & Rivera Vargas, 2018). Educators need to attend continuous professional development opportunities to ensure their skills and knowledge stay relevant in a rapidly evolving field (Tucker et al., 2003).

3.2.2 Infrastructure

According to Dr Jantjies, one of the most significant factors needed for an effective rollout of the new Coding subject is adequate infrastructure to support learning (Mtshali, 2019). Bell et al. (2014) suggested that existing infrastructure be utilised as far as possible for Computer Science education. A few elements of infrastructure that a school will need to consider when introducing the subject of Coding and Robotics are explored in this subsection.

3.2.2.1 Teaching space

When any new subject is introduced into a school, it is vital to ensure that an appropriate teaching space is available where the subject can be taught. The specifics of the classroom or lab will depend on the resource requirements of the subject (BusinessTech, 2021b). According to Tucker et al. (2003), an accessible learning space is crucial to enable the learning of Computer Science, which is influenced by the physical arrangement of resources in the classroom. The classroom layout must cater for the optimal use of the subject's teaching tools, like computers and artefacts, which will be discussed further (Mtshali, 2019).

3.2.2.2 Internet

Cobo and Rivera Vargas (2018) explained that one of the requirements of providing students with the necessary tools to develop digital literacy and technological competence is the availability of internet access. Access to educational platforms, online libraries and other online resources depends on internet access. Dr Jantjies agrees that internet connectivity needs to be available on the school premises to support the teaching of Coding and Robotics (Mtshali, 2019).

Bell et al. (2014) added that much of the software that supports learning can be run in a browser, making it much easier for teachers and students to deploy the software. However, this requires a reliable internet connection. Some of these software resources can be downloaded for offline use if the school has limited bandwidth. However, this would still require some degree of connectivity to have the software installed. Cobo and Rivera Vargas (2018) offered that the expansion of smartphone connectivity offers a low-cost internet access solution in cases where public Wi-Fi infrastructure is not available in the school.

Although internet access could support students' development of self-confidence, critical thinking and initiative by allowing them to investigate independently and use online resources, Cobo and Rivera Vargas (2018) insist that students must be carefully guided when given access to the internet. With internet access, concepts such as cyberbullying, online security and cyber wellness must be considered. The teacher and IT teams need to ensure that students are guided to evaluate the information they find and use resources safely. Careful network restrictions should be in place to ensure safe and secure operation. However, The British Royal Society (2012) found that network security restrictions often impede legitimate teaching activities. For example, if a particularly restrictive policy is in place in a school, the academic staff often have little control over the computers used for subject teaching. Teachers have reported difficulties in providing students with access to interpreters and compilers. The installation of specific software development environments could also be hindered.

Computational thinking could be taught through unplugged approaches. The basic concepts of Computer Science could be introduced to younger students through physical, kinesthetic experiences without a computer or internet access (K–12 Computer Science Framework Steering Committee, 2016). However, the intention of providing students with adequate digital skills suggests the need for proper exposure to digital devices with internet access (Mtshali, 2019).

3.2.2.3 Computing devices

Computer Science has a significant technology component, which supports the need for technology support in the classroom (The British Royal Society, 2012). Access to hardware and software resources is crucial to support the learning goals of the subject (Tucker et al., 2003). Dr Jantjies also emphasised the importance of having computers available on the school premises to provide a good foundation in digital skills (Mtshali, 2019). Minister Motshekga confirmed that the subject of Coding and Robotics would equip learners to apply digital and ICT skills to solve everyday problems, which confirms that the subject's implementation would require the availability of computers or computing devices (BusinessTech, 2021a).

Cobo and Rivera Vargas (2018) explained that the aim of bridging the digital divide in the population and promoting students' competence using technology requires adequate exposure to digital devices. The school should have appropriate digital devices, namely computers, laptops or tablets, to give students the exposure to develop digital skills. These digital devices must be carefully evaluated and reviewed before being acquired to ensure they adequately support learning. For example, the specifications of a chosen computer will significantly enable or limit the type of software that can be supported (Tucker et al., 2003).

The ratio of computers to students also needs to be considered. In cases where computers are lacking, one possible strategy could be to have students work collaboratively. Alternatively, students could be exposed to these devices on a rotational schedule (K–12 Computer Science Framework Steering Committee, 2016). However, these strategies must be managed carefully to ensure all students receive adequate experience. Teachers play a critical role in the social organisation of the participants if multiple children are engaged in a classroom setup (Fessakis et al., 2013).

3.2.2.4 Electricity

Dr Aineamani commented that although the inclusion of Coding and Robotics to the SA curriculum will hold many benefits, the technology component might pose challenges in the unique SA school landscape. She referred expressly to the infrastructure element of electricity availability necessary to support computer usage. Due to geographical and socio-economic factors, many schools in SA do not have access to electricity. Furthermore, schools that do have electricity access are often disrupted by the unreliable electricity provision in the country (Majiba, 2023).

3.2.2.5 Safety and security

According to Dr Jantjies, another consideration of introducing the new subject to the South African school context is safety and security. The subject will require technical infrastructure. Expensive resources like computers will be introduced to the school premises and must be stored securely (Mtshali, 2019). Security measures are necessary to prevent vandalism and burglary in SA schools (Amnesty International, 2020).

3.2.3 Artefacts

The introduction of the new subject will require the availability of appropriate learning resources (BusinessTech, 2021b). According to the draft curriculum, the subject of Coding and Robotics will not only focus on coding skills but will have a component of robotics to develop logical and computational thinking (Department of Basic Education South Africa, 2021a).

3.2.3.1 Robotics kits

Children benefit from having direct experience with artefacts like programmable toys that allow programming logic to be executed through simple interfaces. The development of computational thinking through robotics education is supported by the integration of appropriate teaching tools, namely robotics kits (Cobo & Rivera Vargas, 2018). Young students benefit from experiencing the feedback of their developed code in a tangible manner, such as with a programmable robot (Fessakis et al., 2013). Young learners have been found to be more motivated and committed to solving a problem when they can witness immediate feedback from their programming decisions through activities involving robots (Sáez-López et al., 2016). The British Royal Society (2012) suggests that teachers guide primary school students to play with a robot, such as the Bee-Bot, to complete certain challenges. The small bee-like robot can be used to encourage students to create progressively more complex sequences of instructions to travel to particular points or perform specific actions. Another popular example of a robotics kit used in education is the LEGO Mindstorms (Lee et al., 2020). These two examples of robotics kits can be seen in Figure 3.1

Although the benefits and social encouragement of using robots in education are significant, these artefacts are expensive. The robot's price is often a school's main consideration when introducing robotics to their classrooms (Lee et al., 2020). The choice of the artefact should be carefully considered,

(a) *Bee-Bot (Editmicro, 2014)*

(b) *LEGO EV3 Mindstorms (LEGO, 2022)*

FIGURE 3.1: *Examples of robotics kits.*

for the robotics kits have significant financial implications. Sullivan et al. (2015) suggest that these tools need to be developmentally appropriate and should encourage open-ended play.

In the case where the number of robotics kits is lacking, group work should be encouraged. Teachers will have to manage the situation carefully to ensure that all students are engaged and show adequate participation in a teamwork setup (Fessakis et al., 2013).

3.2.3.2 Limited robotics kit availability

If there is no availability of tactile artefacts, there are specific coding environments where the simulated result of the student's code can be seen (K–12 Computer Science Framework Steering Committee, 2016). A few of these environments are Scratch, Microworlds JR, Squeak Etoys, ToonTalk, Stagecast Creator, as well as various implementations of Logo language (Fessakis et al., 2013). The British Royal Society (2012) reported that many primary schools use visual programming environments like Scratch or Kodu to create interactive simulations, complex animations and games. An environment like Scratch is child-friendly because it uses a block-based drag-and-drop interface to create models and games graphically. Foundational coding concepts like variables, loops, conditional statements and subroutines are successfully developed.

3.2.4 Curriculum

Successfully teaching a subject depends on the existence of an appropriate curriculum that captures the standards for the subject (Tucker et al., 2003). A well-defined curriculum that explains the expectations that students need to master will provide the vision for schools from various communities and circumstances to guide the process of introducing the subject (K–12 Computer Science Framework Steering Committee, 2016).

According to Sileki Tlhabane from the DBE, suitable curricular material must be written and approved before the new subject of Coding and Robotics is officially included in CAPS. He explains that the draft curriculum is made public to allow for feedback from teachers as well as the public to be taken into consideration to confirm the standard of the curriculum content before all schools start offering the subject (BusinessTech, 2021b).

Although the content of the final Coding and Robotics to be included in CAPS is still to be finalised, the framework developed in this study aims to suggest some considerations that need to be taken into account when designing course content and lesson plans regardless of the final confirmed study areas. These considerations are expanded in this subsection.

3.2.4.1 Scaffolded

The curriculum must be well designed to define the expectations at every level in a scaffolded manner. The need to promote Computer Science and digital literacy learning areas from early childhood education through high school has become evident (Falkner et al., 2015). The content should increase in difficulty at an appropriate pace in every year group and build on the previous year in a scaffolded manner. The milestones a student is expected to reach at every level should be reasonable while ensuring progress is made (Tucker et al., 2003). Fessakis et al. (2013) suggested that programming learning activities for young children should be challenging to keep the student's interest but achievable to ensure that the student does not become discouraged.

For instance, the complexity of programming activities should be developmentally appropriate. For younger students, concepts should be introduced by making use of visual, block-based programming languages and environments designed for education. These drag-and-drop coding methods allow beginner programmers to execute logic and practice problem-solving without the obstacle of syntax errors. As students progress, they could gradually be introduced to traditional text-based programming languages to advance their skills (K–12 Computer Science Framework Steering Committee, 2016).

3.2.4.2 Unplugged elements

The curriculum cannot rely entirely on technology. The availability of resources will vary from one community to the next. This must be considered when creating the curriculum, especially if schools from rural areas are expected to participate. This implies that while opportunities for students to be exposed to sophisticated teaching technologies are necessary, alternative unplugged sessions should also be developed (Falkner et al., 2015).

According to The British Royal Society (2012), Computer Science education does not necessarily require computers; fundamental concepts can be taught without the use of technology. For example, primary school students can explore encryption ideas by playing games in groups where secret messages are coded and decoded for one another to instruct certain actions. The concept of sequencing can be introduced by creating flow charts in the context of interactive adventure stories, where specific decision points lead to different chapters or actions (The British Royal Society, 2012). These unplugged activities can teach students how to cooperate, formulate instructions, and arrange actions logically (Falkner et al., 2015). The British Royal Society (2012) continued that especially at the complexity level of primary school, topics such as binary numbers, searching algorithms, image representation and text compression, all of which are core Computer Science topics, can be taught through unplugged methods. However, it is suggested that from age 11, students should be encouraged to work in a more sophisticated technology environment.

3.2.4.3 Carefully curated scope

The British Royal Society (2012) recommended that the curriculum recognise and prioritise the core foundational knowledge. They advocate that the key skills students need to succeed in their future digital workplaces be included in the national curriculum and that any other subjects be left up to the school's discretion. Where possible, the teacher should be encouraged to supplement the core curricular requirements. However, the content of the compulsory curriculum should give pupils the fundamental knowledge and abilities they require from a young age to ensure that they can pursue jobs in technical domains by selecting specialised subject pathways in high school. Bell et al. (2014) agreed that keeping the amount of content demanded by the new subject to a minimum will increase the likelihood of successful widespread adoption. It will also reduce the complexity of teacher professional development and the time spent on preparation.

3.2.4.4 21st-Century skills

The core of the curriculum should focus on the development of 21st-century skills. Computational thinking skills, problem-solving skills, as well as Computer Science knowledge should be promoted (K–12 Computer Science Framework Steering Committee, 2016). Students need to learn how to solve problems logically and holistically, taking into account societal issues and sustainability (Falkner et al., 2015).

3.2.4.5 Pedagogy

The curriculum should include pedagogical knowledge as well as content knowledge to describe the most effective ways of presenting and orchestrating activities to enable learning (Bender et al., 2015). Cobo and Rivera Vargas (2018) mentioned that there should be a focus on pedagogy and not only technology when designing implementation plans to develop students' technological skills. The curriculum should include appropriate pedagogical models and approaches to support the learning of Computational thinking content (Sáez-López et al., 2016).

The semantic wave theory is one pedagogical approach to ensure effective cumulative learning in the STEM fields. A semantic wave represents the relation between theory and practice, with increasing levels of complexity over time. Wolff et al. (2021) suggest that the teacher could demonstrate the connection between theoretical concepts and practical examples by starting with a focus on the theoretical concept and moving toward the practical to anchor the concept in a particular context and then again to the theoretical to build on the cumulated knowledge. Alternatively, learning may start from a particular practical context, like a demonstrated example or physical site visit, and then the educator uses this context to explain a specific theoretical concept. This method enriches teaching in order to enable students to make the connections between theory and real-world practice (Wolff et al., 2021).

Sáez-López et al. (2016) suggested that the Computer Science learning environment design should include constructionism activities. Constructionism is based on the belief that the most effective learning experiences are related to active construction, interactions with others, socially meaningful elements, and elements that support thinking about one's own thinking (Sáez-López et al., 2016). Computational thinking learning activities inspired by constructionism will focus on learning as a contextualised, active process. Activities could involve technological tools to allow students to construct knowledge from first-hand experience instead of presenting students with information from external sources (Cobo & Rivera Vargas, 2018). Self-directed projects should be encouraged to ensure that critical thinking and communication skills are developed in line with 21st-century skill requirements (Sáez-López et al., 2016).

3.2.4.6 Teamwork prioritised

Denner et al. (2014) found that pair programming promoted better computational thinking and knowledge development than working alone, especially for less experienced students. Activities involving collaboration need to be included where students work together to solve problems to develop teamwork skills. However, careful classroom management is required from the teacher to ensure that students rotate through defined roles and develop a well-rounded set of skills.

3.2.4.7 Assessment

When the new subject of Coding and Robotics is introduced into schools, there should be clear guidelines on the assessment of the subject. It is vital to ensure clarity on the standards that students need to meet with regard to the new subject (BusinessTech, 2021b). The inclusion of computational thinking skills in education has not only created a demand for new pedagogical approaches but also for the reconsideration of the assessment structure (Cobo & Rivera Vargas, 2018). The British Royal Society (2012) added that appropriate assessment methods for qualifications in digital literacy, IT and Computer Science are crucial to ensure the integrity of the subject is maintained. Bell et al. (2014) offered that the assessment of the subject needs to be carefully designed to ensure that the unique outcomes of the subject are met.

3.2.4.8 Integration with other subjects

Schools are often faced with difficult choices due to the crowded curriculum. An introduction of a new subject will be at the expense of another unless the length of the school day is increased. Additionally, unless the school budget is increased, resources will have to be decreased elsewhere. These considerations explain why some schools would prefer to integrate new computing concepts into other existing subjects (The British Royal Society, 2012).

Bell et al. (2016) agreed that since instructors have limited time to cover all the courses necessary in the already "crowded curriculum", new computational thinking content may be incorporated with other subjects in primary school education. Integrating computational thinking with other courses can enhance learning in these areas and increase the relevance of these courses for the digital world. According to Bell et al. (2016), teachers from various subject areas, including Mathematics, physical education, literacy, numeracy, creative writing, and art, highlighted that cross-curricular learning had been accomplished. They reported that students exercised teamwork and social skills in unexpected ways.

The British Royal Society (2012) suggested that including a cross-curricular implementation approach for digital literacy at primary and early secondary school could be effective. This is because some schools prefer not to allocate an entire period in the timetable to these computing skills. However, teaching these concepts separately will ensure that each strand is always adequately developed.

3.2.5 Support network

The integration of educational technologies and new pedagogical models in a school will require support from various parties apart from the teacher (Cobo & Rivera Vargas, 2018). This subsection explores roleplayers that could influence the introduction of Coding and Robotics in a school.

3.2.5.1 School management

School management plays a vital role in smoothly integrating any transformation or policy in a school. Introducing new technologies in a school will create tension that needs careful negotiation (Cobo & Rivera Vargas, 2018). The leading parameter in change management within a school organisation is school management and administration. The principal's managerial competence significantly impacts the sustainability of changes and improvements introduced in the school (Hoşgörür, 2016). The importance of the subject needs to be acknowledged by persons in leadership to promote the introduction of the subject in a school (Tucker et al., 2003).

It is paramount that close coordination by school management is practised to ensure sustainable integration of technology (Cobo & Rivera Vargas, 2018). Strong leadership with a clear vision is vital to ensure successful implementation of a subject like Computer Science, in the long run (Tucker et al., 2003). The British Royal Society (2012) suggested that the school management should instil positive culture toward continuous professional development in a school. The teachers of ever-evolving disciplines should be incentivised and supported by their school management to attend continuous professional development opportunities. Du Plessis and Webb (2012) agree that the principal should create opportunities for the necessary teachers to develop ICT skills.

3.2.5.2 IT support

The implementation of the subject will also involve support staff (K–12 Computer Science Framework Steering Committee, 2016). The introduction of technology in the classroom requires technical support and maintenance. The division of labour is important to ensure that the responsibility of updating devices and monitoring connectivity does not fall on the teacher, who should devote their attention to pedagogical and content development. This calls for an IT team in the school to provide technical support (Cobo & Rivera Vargas, 2018). Dr Jantjies agrees that the IT department needs to be available to assist both the teachers and learners with problems that may arise from Coding and Robotics teaching. They should also manage the IT infrastructure and ensure that the necessary upgrades are made (Mtshali, 2019). IT support may need to be provided by external parties since many schools in SA do not have IT support available on the premises (Amnesty International, 2020). The British Royal Society (2012) suggested that IT departments need to work closely with the school management and teachers to ensure that the network restriction policy serves the best interest of the students and ensures safe and secure internet use.

3.2.5.3 Parents

Parents play an important role in educational change policies (Chiong & Lim, 2022). According to K–12 Computer Science Framework Steering Committee (2016), implementing Computer Science education requires involvement and support from the parents and the local community. Cobo and Rivera Vargas (2018) found that community support for the integration of digital devices and technological education in schools is important. In low socio-economic communities, the student's exposure to computers in school was often the first time that a member of their family got to interact with computers. Cobo and Rivera Vargas (2018) continued that in these communities, support and enthusiasm from the parents were crucial in influencing teachers to embrace opportunities offered by these technologies and platforms. Teachers were motivated to deepen their knowledge of integrating technologies to enrich the student's education when they realised the benefit to the student and, ultimately, the community at large.

The school community should be educated in order to inform and foster support for the adoption of Computer Science. Back-to-school nights, school board meetings, parent-teacher conferences, or academic showcases are all occasions at which schools might communicate the particulars of their Computer Science curriculum (K–12 Computer Science Framework Steering Committee, 2016). Cobo and Rivera Vargas (2018) also mentioned the benefit of offering parents and supporting communities the tools and competencies to support and guide students with homework when they use these technologies at home.

3.2.5.4 Teacher peer support

Cobo and Rivera Vargas (2018) offered that education has to stay relevant to students' lives outside of school. They encourage ideas and education innovations in technology-enriched contexts to be exchanged among teachers and decision-makers. Forming a network for teachers to share experiences could assist them in making sure that content stays meaningful and relevant. It is important to prioritise the creation of community networks to share insights and pedagogical approaches. According to Falkner et al. (2015), Computer Science teachers expressed the need for a network and community to support resource development to improve education.

Teachers benefit from networking opportunities with regard to the adoption of technology in the learning environment (Du Plessis & Webb, 2012). Regular meetings and gatherings of educators are considered effective in presenting opportunities for teachers to learn from each other and share good practices. Teachers participating in virtual or face-to-face training and development events can share experiences of successful and failed approaches regarding technology adoption in the classroom (Cobo & Rivera Vargas, 2018). The British Royal Society (2012) agrees that ICT training events offer valuable networking opportunities. Mutual issues and challenges could be discussed, and solutions could be offered.

Falkner et al. (2015) suggested that these knowledge-sharing communities could also be found and formed online, where access to resources and participants are not bound by physical proximity. Teachers could gain confidence by having solutions and new approaches suggested by their peers. The British Royal Society (2012) recommended that training opportunities include a mentor program to ensure teachers have a contact for continued assistance after the training has been completed. Du Plessis and Webb (2012) offered that the ICT training programme facilitator should follow up with teachers after the training is complete to assist them with further support should they need it.

3.2.6 Budget

The biggest constraint in implementing Computer Science as a subject is often the money it requires to start a program in school (K–12 Computer Science Framework Steering Committee, 2016). The British Royal Society (2012) agreed that one of the most significant barriers to new initiatives in schools is the availability of funds.

The infrastructure and technology required to support the learning of Computer Science have significant financial implications (K–12 Computer Science Framework Steering Committee, 2016; Majiba, 2023). The expenditure on equipment and software will need to be managed carefully. The resources to support learning are expensive, and continuous maintenance of technological infrastructure will require ongoing financial support (Tucker et al., 2003). The maintenance and continuous updates of software and hardware resources to support the evolving content of the subject implies a continual expense (The British Royal Society, 2012).

The introduction of appropriate robotics kits to support the learning of Coding and Robotics will have substantial financial impacts since many of these robotics kits are expensive (Lee et al., 2020).

Bell et al. (2014) offered that another expense to consider is acquiring a lesson plan or teacher guide. An inexperienced teacher might need help designing their lesson plan from the learning requirements of the new subject. Purchasing a developed lesson plan that includes the content and pedagogical guidance to meet the required learning outcomes would be advisable. However, this could be expensive.

One of the elements a school should make sure to budget for when implementing a new educational initiative is the professional development of teachers and relevant management staff. They recommend setting a significant portion of funding for the new educational initiatives aside for professional development due to its importance (The British Royal Society, 2012). However, it is up to each school to decide how to deploy these funds, particularly given that administrators might not understand how much help particular teachers might need to teach the new subject (Bell et al., 2014).

Dr Jantjies agrees that introducing Coding and Robotics to SA schools will depend on funding. Not only will the resources and infrastructure require a significant once-off investment, but the IT department that continuously maintains the infrastructure will translate into an addition to the annual budget as a recurrent cost item. Professional development opportunities to train the teachers to teach the new subject will also add another cost (Mtshali, 2019).

Bell et al. (2014) suggested that a school should utilise their existing infrastructure as far as possible to minimise expenses. Many schools fully rely on state funding, which is often insufficient to cover their basic expenses, let alone catering for new acquisitions (Amnesty International, 2020). Acquiring software and resources to support a subject like Computer Science could be quite costly if not managed carefully. An implementation plan should be designed to utilise available resources creatively to support the learning of the subject (Bell et al., 2014).

The financial demands of including the subject in a school could be alleviated by introducing a robotics club. Cobo and Rivera Vargas (2018) mentioned that students could benefit significantly from technological exposure in class and after-school activities. Many STEM club initiatives have been effective in ensuring sustainable interest is cultivated in the students. Computer Science learning could be presented as an extracurricular activity after school for students who show particular interest in the subject (K–12 Computer Science Framework Steering Committee, 2016). This could allow students the opportunity to foster an inclination to continue with further study in the subject while allowing the teacher time to develop strategies and gain experience without the demands of a full classroom. This could also alleviate the immediate pressure of purchasing many computing devices and robots at once to support the entire classroom. However, the extracurricular approach could create a challenge of discrimination because all students may not be able to join the club if it is outside of school hours, and many parents may not be able to afford to pay for their children to attend. Eventually, the subject must be included during school hours to ensure equal opportunity, even if a more advanced club is also hosted after-hours (The British Royal Society, 2012).

3.2.6.1 Sources of funding

The school management is responsible for managing their school budget to cover their expenses (Amnesty International, 2020). Some public schools in SA supplement government funding by charging fees, while others rely entirely on funding from the state (Veriava et al., 2017). This suggests that the costs regarding introducing the new subject will have to be worked into the school budget (K–12 Computer Science Framework Steering Committee, 2016).

Funding needs to be allocated from the government to support the introduction of the subject. For instance, certain teacher professional development opportunities should be presented and funded by the education department (Bell et al., 2014). Professional development opportunities for the preparation of teachers, as well as course material and technical infrastructure, will require financial support from the government (K–12 Computer Science Framework Steering Committee, 2016).

The introduction of the subject in a school could be supported financially by local community partners. Bell et al. (2014) offered that sponsorships from external companies or stakeholders should be sought out if the school budget cannot support all the elements involved in introducing the new subject. Du Plessis and Webb (2012) confirmed that in the SA context, schools often rely on sponsorships from external partners to provide computers and additional technology requirements. It is important to foster support for Computer Science from local businesses. If there is buy-in from the local community, initiatives from partnered businesses could support the financial requirements of the subject's introduction (K–12 Computer Science Framework Steering Committee, 2016).

3.2.6.2 SA budget system

The introduction of the new subject will, to some extent, be supported financially by the SA government. This subsection provides some insight into the SA education funding system.

The DBE governs SA's primary and secondary school system. Public education, which accounts for 95% of all education provided in SA, is funded by the government budget. Depending on the quintile classification of the school, some public schools supplement this funding by charging school fees (Veriava et al., 2017).

Determining the budget allocated to basic education by the government every year is a lengthy process. Many stakeholders are involved in determining the budget spent at the national, provincial and school level (Veriava et al., 2017).

Every year, the DBE and Provincial Education Departments (PEDs) are responsible for submitting their expected expenses for the following year. Once the provincial treasuries, education departments, National Treasury, DBE and the public have deliberated and agreed on the predicted expenditure, the Finance Minister is presented with the figure for the total basic education budget. Once all the other government departments have done the same, a final budget for the whole government is prepared by the Finance Minister and presented to parliament (Veriava et al., 2017).

The total government budget is split between the national departments, provincial government, local government and debt-service costs. Since basic education is a concurrent function between the national DBE and PEDs, funding for basic education is provided from both the provincial equitable share and the national equitable share. However, most of the education expenses in a province are covered by the provincial equitable share (Veriava et al., 2017).

The allocation of each province's equitable share is determined by a formula that considers specific criteria in an attempt to support the province's individual education needs and address inequality in education. This criteria includes, among others, the number of learners enrolled in public schools, the size of the school-age population in the province and the province's share of the national population. The number of people in the province who fall in the lowest 40% of household incomes also influences the provincial equitable share to provide more support where needed (Veriava et al., 2017).

However, despite attempts to reduce inequality in education, funding often reinforces inequality. It is more than just the amount of funding that is an issue. It is the way that funds are distributed which often fails to tackle inequalities. The formula intends to provide more funding where it is needed. However, in reality, the two poorest provinces, Limpopo and Eastern Cape, have the lowest education funding allocations per learner, which fails to reach the goal of providing extra support. By contrast, Gauteng and Western Cape, the two wealthiest provinces with some of the lowest proportion of their population in school, actually spent more per learner (Amnesty International, 2020).

One of the issues in calculating the equitable share formula is that the school enrolment numbers are not updated every year as they should be, which underestimates the number of learners in most provinces. The formula also does not consider the unequal starting points of historically underfunded schools, which results in a further disadvantage. The formula also does not consider the unequal cost of providing education in rural and urban communities. Urban areas benefit from economies of scale, with more resources available, making them cheaper to procure. Therefore, building and maintaining schools that provide education in urban areas is generally cheaper. Resources like textbooks, IT equipment and internet access are more easily acquired in urban areas (Veriava et al., 2017).

The expenditure of funding in every province depends on the source of the funds. The funds from the DBE grant are spent on admin costs and curriculum policy, support and monitoring. These grants also fund teacher professional development. The funds from the provincial equitable share are spent according to the PED's discretion. This includes teacher and employee compensation and non-personnel costs like learning materials and facilities (Veriava et al., 2017).

Veriava et al. (2017) offered that changes to the curriculum policy are supported financially by grants from the DBE. This suggests that the DBE will make provisions for improving teacher capacity and delivering Learning and Teaching Support Materials to support the introduction of the new subject. The DBE also provide grants for the upgrades and maintenance of infrastructure.

3.3 Conclusion

In this chapter, the completion of RO II is described. Possible factors that could be included in the developed framework are identified from the literature. Six factors, namely teacher, infrastructure, artefacts, curriculum, support network and budget that a school should consider when introducing the subject of Coding and Robotics are explored. These theoretical factors will be explored further from a practical perspective to confirm their validity in the development of the framework described in Chapter 4, and their interaction will be investigated in Chapter 5.

CHAPTER 4

Framework Development

Contents

In this chapter, the development of the framework is explained in pursuit of RO III. The purpose of the framework is to provide a practical overview of the factors a school should take into account when introducing the subject of Coding and Robotics. The framework was developed by analysing 1073 minutes of recorded interviews with SMEs. In this chapter, the SME's perspective is presented objectively, carefully preserving the voice of the participant. The researcher's deducted insights from the interviews will be presented in Chapter 5.

4.1 Methodology of data collection

This study aims to set out the practical considerations that the school management needs to consider before attempting to implement the new subject of Coding and Robotics in their school. These considerations are structured into themes called factors that group together associated elements. Each factor is expanded to describe the elements that make up the factor. The methodology followed to populate this framework of factors is described in this section.

4.1.1 Methodology description

The literature, as presented in Chapter 3, and the semi-structured interviews with SMEs were used to develop this framework. The factors suggested by the literature were used as starting prompts. However, due to the framework's highly practical aim, the literature dominated by research on similar subjects like Computer Science and STEM subjects cannot be taken at face value to provide an accurate account of the Coding and Robotics subject in the context of SA. Valuable deductions were made from the literature, but the application of the Coding and Robotics subject, as discussed in this study, suggests that a more specialised implementation is to be expected. Due to the limited research conducted on the Coding and Robotics subject and Coding and Robotics in the South African context, inputs from SMEs with practical experience in the South African education sector were required to present this perspective.

Semi-structured personal interviews with selected SMEs were conducted to gather data on the practicalities of the South African context. The interviews were conducted by following a snowball approach. The number of participants included in the study was not fixed before the process started. Participants were asked to suggest other suitable participants from their respective industries to identify more relevant SMEs to include in this study. The topics discussed, and specific questions asked in the interviews also evolved and increased as the process progressed and the factors expanded.

The process was started by identifying six possible factors from reviewed literature as presented in Chapter 3: teacher, infrastructure, artefacts, curriculum, support network and budget. These draft factors, as illustrated in Table 4.1, were then used as prompts in the exploratory interview with the first participant to validate and motivate the inclusion of each factor and introduce some defining attributes of each factor. Participant One was selected as a relevant SME based on their experience as a Coding and Robotics teacher. Participant One not only has experience teaching Coding and Robotics to primary school children but is also their school's vice-principal and could give valuable insight into the management perspective of a school when implementing a new subject. The first interview with Participant One did not follow a pre-designed set of questions; the discussion was aimed at confirming the validity of each draft factor as identified from the literature. The following interviews with Participant Two onward were semi-structured after the initial draft factors were confirmed through the unstructured discussion with Participant One. The interview guide used can be seen in Table 4.2.

TABLE 4.1: *Draft factors from literature presented to Participant One.*

Factor	Attributes
Teacher	**Suitable teacher profile:** • Interested • Digitally literate • Willingness to learn • Capacity **Teacher training:** Appropriate pre-service and in-service training is important to prepare teachers to teach the new subject.
Infrastructure	• Teaching space • Internet • Computing devices • Electricity • Safety and security
Artefacts	• Appropriate teaching tools are vital. • Robotics kits are expensive and should be chosen carefully. They should be tangible and versatile. • If no robot is available, coding environments that simulate results could be used.
Curriculum	• Scaffolded • Unplugged elements • Carefully curated scope • 21st-century skills • Pedagogy • Teamwork prioritised • Assessment • Integration with other subjects
Support network	• School management • IT support • Parents • Teacher peer support
Budget	**Sources of funding:** • School budget • Government • External funding from local business .

TABLE 4.2: *Interview guide.*

Category	Questions
SME qualification	1. What subjects do you teach? 2. To what age group of children do you teach Coding and Robotics? 3. How many years of experience do you have in teaching? In Coding and Robotics education specifically? 5. What qualifications or training do you have? 6. What is your approach to continuous professional development? Do you attend training often? 7. What is your job title? 8. Rank your own competence in teaching Coding and Robotics from one being little to no knowledge of the field and five being very experienced and knowledgeable in the field. 9. What makes you qualified to add to and validate this framework? 10. At what quintile school do you teach?
The comprehensive-ness of the framework	1. Are any factors missing from the framework that might prove relevant to add? If yes, what would these factors add to the usefulness of the framework? 2. Are any of these factors included in the draft framework redundant? If yes, why is this factor dispensable?
Teacher	1. What are the attributes of a successful Coding and Robotics teacher/candidate teacher? 2. Can any teacher teach Coding and Robotics? How do you identify a possible teacher for Coding and Robotics? 3. Are all the attributes assigned to this factor relevant? 4. Have you received any training to teach Coding and Robotics? 5. What training/qualification should a teacher attend/attain before being equipped to teach Coding and Robotics? 6. Do you know anything about the DBE training for the pilot school teachers?
Infrastructure	1. Describe the specifications of adequate infrastructure to enable Coding and Robotics teaching. 2. Which of those specifications is most important? 3. Are all the attributes assigned to this factor relevant?
Artefacts	1. What artefacts and robotics kits do you use? Why? 2. What age group can be taught with these kits? 3. Describe the specifications of adequate artefacts to enable Coding and Robotics teaching? 4. Which of those specifications is most important? 5. What would you recommend if a school does not have good Wi-Fi? 6. Are all the attributes assigned to this factor relevant?
Curriculum	1. Possibly comment on the draft curriculum of the DBE. 2. What lesson plans do you use? 3. What should be taught if you have no robotics kit? 4. Name important inclusions in a Coding and Robotics curriculum.
Support Network	1. What other stakeholders influence your/the ability to teach Coding and Robotics? 2. Is the principal's support important? 3. Is parents' support important? 4. Comment on the necessity of IT support at the school. 5. Comment on the value of the network of fellow teachers who also teach Coding and Robotics. 6. Support from the community. Any external stakeholders that play a role?
Budget	1. How did you fund the subject and robotics kits? 2. What do you suggest if your school cannot fund the artefacts or kits from the school budget? 3. Are there cheaper options? 4. What should be taught if you have no robotics kit? 5. What are budget elements? What is money spent on? 6. What should be prioritised when the budget is restrictive?

The reality of SA's complex landscape of inequality suggests that resources like LEGO robots will not be available to all students in the country. However, this study still argues and motivates that a technologically advanced approach to the subject be taken to ensure that students are equipped with the skills necessary to contribute in a digitally driven workplace or to pursue careers in technological fields like engineering. The complexity of concepts that will be included in CAPS is yet to be determined, but this study assumes that a sophisticated approach will be followed to ensure 21st-century skills are developed.

4.1.2 Subject matter experts

The profiles of the SMEs who participated in this study are summarised in Table 4.3. The participants were grouped into three categories based on their relevant experience in the field of Coding and Robotics education. These categories are teachers with Coding and Robotics teaching experience, teaching experts related to the development of computational thinking skills and owners or employees of private robotics education providers. The SMEs' credibility and competence are described using elements from the SCOR method as suggested for the Teacher evaluation in Section 3.2.1. The SMEs' skills are described as perceived by the researcher during the interview process. These performance metric elements, namely experience, training and aptitude of the participant, are elaborated to give an overview of the participant's background, skills and extent of their contribution to the study. The first element, experience, was included to give the context of the participant's background. The teachers' years of general teaching experience and Coding and Robotics teaching experience are specified to motivate their credibility. The teaching experts' years of experience in research regarding teacher professional development and computational thinking are mentioned, and other significant experiences of involvement with Coding and Robotics initiatives or developments are described. The robotics providers' years of experience in the private robotics solution field are given, as well as other background experience in the education sector. The training of the participants describes their formal education or their philosophy towards continuous teacher professional development and self-study of the topics related to Coding and Robotics education. The aptitude metric describes the participant's aptitude in their particular category as perceived by the interviewer. The researcher used these descriptors to motivate the participant's ability to contribute to the study and the extent of topics on which they are credible to comment.

TABLE 4.3: *SMEs summary.*

Category	**Participant**	**Experience**	**Training**	**Aptitude**
Teacher	One	10+ years teaching, 2 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities. Continuous online self-training.	Expert
Teacher	Two	10+ years teaching, 4 years Coding and Robotics.	Receives continuous training from private robotics coach.	Proficient
Teacher	Three	11 years teaching, 2 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities. Continuous online self-training.	Competent
Teacher	Five	9 years teaching, 3 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities. Continuous online self-training. MEd candidate on Coding and Robotics engagement.	Expert
Teacher	Seven	9 years teaching, 9 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities. Continuous online self-training. Honours in Education on teacher's perception of Coding and Robotics teaching.	Expert
Teacher	Ten	15 years teaching, 2 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities. Continuous online self-training.	Beginner
Teacher	Eleven	2 years teaching, 2 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities. Continuous online self-training.	Proficient

Table 4.3 continued from previous page

Category	Participant	Experience	Training	Aptitude
Education expert	Four	10 years computational thinking development research, 5+ years involvement with teacher professional development for primary school robotics initiatives.	PhD in Education	Expert
Education expert	Nine	20 years Computer Science education, 5+ years robotics solutions development.	Regular attendance of Coding and Robotics development opportunities to promote their own product. PhD in Computer Science and Information Systems.	Expert
Robotics service provider	Six	6 years private sector, 19 years teaching, 9 years Coding and Robotics.	Regular attendance of Coding and Robotics development opportunities to promote their own product. Postgraduate Certificate in Education (PGCE)	Expert
Robotics service provider	Eight	4 years private sector, 5+ years primary school tutor experience.	Regular attendance of Coding and Robotics development opportunities to promote their own product. BEng Industrial	Proficient

The participants are numbered chronologically in the order that the interviews were conducted. The interviews were semi-structured and varied to the situation; the researcher specifically included participants with different perspectives on the field of Coding and Robotics education to avoid having many interviews where participants offer the same viewpoint and suggestions. The order of the participants was also influenced by suggestions made by previous participants in a snowball method, while the first participant was a connection suggested by one of the research supervisors.

Participant One has more than ten years of teaching experience and two years of experience teaching Coding and Robotics to grade four to seven students at a double-medium quintile five public primary school in Paarl. Participant One takes a proactive stance on teacher professional development and attended multiple Western Cape Education Department (WCED) courses on the introduction of Coding and Robotics. Participant One believes in the importance of continuous learning and makes time regularly to find resources and articles online in the field of Coding and Robotics. Participant One also adds credibility as an SME by holding a leadership position as deputy principal at their school. This position allows Participant One to add value to the study by contributing the perspective of school management regarding the practicalities of introducing Coding and Robotics as a subject.

Participant Two is a grade eight and nine Coding and Robotics teacher at a quintile five public high school in Cape Town and has more than ten years of experience in teaching. They run Coding and Robotics in a two-fold structure with all students receiving Coding and Robotics teaching during school hours once a week as well as an extracurricular robotics club for the students that are more serious about Coding and Robotics. The students in the robotics club train and participate in the First LEGO League and the World Robotics Olympiad. Participant Two has four years of experience teaching Coding and Robotics to grades eight and nine and assists their partnering primary school with implementing Coding and Robotics in the foundation and intermediate phases. This experience allows Participant Two to add value to this study by commenting on the scaffolding of the content and introducing the content in a “top-down” structure.

Participant Three is a primary school teacher with eleven years of teaching experience and two years of Coding and Robotics teaching experience. They teach Coding and Robotics as an extracurricular club to grades three to six students at a quintile five public primary school in Stellenbosch. Participant Three has a BSc Honours degree and a PGCE but no formal Coding and Robotics teaching qualification. However, Participant Three is very eager to learn, takes a proactive stance on teacher professional development, and regularly attends development opportunities. They learned to teach Coding and Robotics by attending seminars and conferences and through the continuous self-study of online resources. Participant Three also holds the position of Head of Technology and Learning at their school and has experience in the management of infrastructure and resources, which affords them credibility to comment on the digital skills and challenges of introducing ICT infrastructure in a school.

Participant Four is the Engineering Teaching and Learning Advisor at one of SA's leading universities. Their PhD in Education was on negotiating disciplinary boundaries in engineering problem-solving practice, and their Post-Doctoral research was on building a repertoire of engineering problem-solving case studies for use in engineering curriculum development. Their most recent work is on the preparation of future engineers by focusing on the basic knowledge and ways of thinking developed in early childhood education. Their relevance to this study is strengthened by their involvement with teacher professional development and computational thinking pedagogy design for primary school robotics initiatives. Due to Participant Four's extensive experience and research in the field of computational thinking teaching in various communities, they fall under the category of teaching experts.

Participant Five is a teacher and acts as Head of Innovation at a private school in Cape Town. They have nine years of teaching experience and three years of teaching Coding and Robotics. They first introduced Coding and Robotics to grades seven to nine and gradually introduced the subject to the younger grades. Their position as Head of Innovation requires them to spearhead the process of including Coding and Robotics in the primary and preschool. They work with the preschool teachers to help them to incorporate Coding and Robotics lessons into what they call their "E-Steam" initiative. They are also heavily involved with the primary school to help equip the teachers to successfully introduce the subject of Coding and Robotics into the lower grades to support what they have accomplished with grades seven to nine. They have experience in finding innovative ways to teach Coding and Robotics but have not completed any formal Coding and Robotics qualifications. Their formal qualification is in Education with a BEd Honours in language studies. They are currently working on their Master's in Education in curriculum studies focusing on game-based learning to engage pupils during Coding and Robotics learning. This research makes them qualified to comment on the benefits that Coding and Robotics education affords to a student.

Participant Six owns a private robotics education company in SA that offers education solutions to schools and individuals. They have programs and clubs that students can join as extracurricular activities. They also offer implementation plans, training and guidance to schools and teachers who wish to start introducing Coding and Robotics lessons. Participant Six has also been actively involved in developing the draft CAPS for Coding and Robotics since 2019. Their company developed a set of Teaching and Learning Support Materials that includes Student Workbooks and Textbooks with accompanying Teachers Guides that align with the latest draft version of the Coding and Robotics CAPS. They present a lesson plan that covers the necessary learning outcomes suggested in the draft curriculum. This robotics solution is a blended approach, not heavily reliant on technical infrastructure, to make it accessible to as many schools as possible. However, Participant Six's affiliation with their largely unplugged product could influence their responses toward this framework that advocates for a more technologically sophisticated approach. Participant Six also has a teaching background, having been a full-time teacher before leaving the profession to enter the private sector. They have 19 years of experience as an intermediate phase teacher and nine years of experience as a Coding and Robotics teacher to primary school students at a quintile five public school in the Western Cape. They have a Master's Degree in Theology with a PGCE and believe in continuous teacher professional development but have no formal Coding and Robotics training.

Participant Seven has nine years of teaching experience. Their first five years of teaching were to foundation phase students at a no-fee public primary school, where they incorporated computational thinking and sequential thinking concepts into the existing curriculum. They also taught Coding and Robotics as an extramural activity to grade three students. For the following four years, they taught at a quintile five boys' primary school where they acted as Digital Integration Specialist and trained the other teachers to integrate technology into their teaching. They also taught Coding and Robotics to grades one to seven students. Another significant attribute of Participant Seven is their qualification. They have a BEd in foundation phase teaching and an Honours in Education Development and Democracy. Their Honours research was on foundation phase teachers in the Western Cape and their perspective towards teaching Coding and Robotics to grades R to 3. Participant Seven equipped themselves to teach Coding and Robotics by completing self-study courses through edX and Udemy. Participant Seven adds value to this study due to their experience with teaching and conducting research in the field and their knowledge about innovative technologies and systems to be implemented in schools.

Participant Eight is a qualified industrial engineer who works for a private robotics education company in SA. They offer Coding and Robotics programs for individual students at robotics clubs and resources and support solutions for school integration from grades R to 12. Participant Eight has many years of experience as a tutor to young students, which gave them the necessary background for their position as Head of Academics at the robotics solution company. Participant Eight manages and adjusts the robotics curriculum continuously to ensure that the content stays relevant and aligns with the content suggested in the latest CAPS draft version to ensure that the program stays appealing to schools. Participant Eight also manages the training programs for the teachers of schools that implement their robotics solution and has helped teachers from various communities to integrate the subject.

Participant Nine is an associate professor and Head of the Department of Computing Sciences at a leading university in SA with more than 20 years of experience teaching Computer Science modules to university students. Participant Nine is particularly valuable to this study due to their involvement with Tangible Africa. They started promoting and demystifying the topic of Coding and Robotics in the Eastern Cape in the mid-2000s. They realised that one of rural and township schools' most significant barriers is the lack of available computers and computing devices. Consequently, they founded Tangible Africa in collaboration with their Computing Sciences Department in 2017 to start teaching children in SA Coding and Robotics and the 21st-century skills that accompany it. The team from Tangible Africa developed the TANKS, BOATS and RANGERS mobile games as well as the Tangible coding kits and lesson plans that go along with it to introduce learners to coding concepts without the use of computers. They have reached more than 50 000 school children through workshops with their Tangible Africa coding solutions in all nine provinces of SA. Participant Nine's experience with teaching these primary school students and training teachers from all communities has equipped them to comment on the practicalities of teaching Coding and Robotics in various communities with different levels of infrastructure available. They focus on schools that do not have computers available and offer a solution and lesson plan that teaches sophisticated higher-order thinking skills with smartphone apps and accompanying coding cards that can be scanned to translate specific coding instructions.

Participant Ten is a primary school teacher with 15 years of experience. They have two years of experience in teaching Coding and Robotics to grade four to six students at a quintile five primary school in Stellenbosch. Participant Ten has a BEd qualification, but their Coding and Robotics abilities are self-taught through attending demystifying conferences hosted by the WCED and completing self-study courses through Udemy.

Participant Eleven is a primary school teacher with two years of experience teaching Coding and Robotics at a private school in Cape Town. They teach grade four to nine students for one hour per week during school and run the extracurricular robotics club. Participant Eleven's formal education includes a BA degree in film and media production and a PGCE qualification. Their prior experience as a tech support consultant at Apple prepared them for the world of Robotics and ICT and sparked their interest in Coding and Robotics education. They take a proactive stance regarding training and continuously investigate available technologies and resources online.

4.1.3 Conclusion

The data was gathered following the methodology described in this section. The findings extracted from the interviews were used to populate the framework's factors. These factors constructed from the SMEs' experiences and suggestions are presented in Section 4.2 to 4.7.

4.2 Teacher

The first factor expanded in this framework is the teacher. A suitable teacher must be identified to present this subject to ensure that students receive a quality education. The school management will need to assess their staff critically to decide on the appropriate teacher or teachers that will take on the responsibility of teaching the new subject. In most schools, there will not be a teacher who already has experience with Coding and Robotics education; therefore, the suitable teacher could be identified by noting specific attributes and qualities that will make them appropriate to train to present the subject. The factor of the teacher was discussed with the participants to collect possible attributes of a teacher that could be used as a benchmark to identify whether a teacher would be suitable to teach the new subject. Participant Five agreed that for the initial introduction of the subject, teachers from within a school would have to be identified and start teaching the subject. They continued that placing teachers from outside the school would be too complicated on a large scale. There is not enough time or resources to train teachers quickly and have them placed in all schools once the subject is formally included in the national curricula. A teacher from within the school will have to step up and prepare to start teaching Coding and Robotics. Participant Ten agreed on the importance of identifying a suitable teacher to teach the subject. They added that the teacher's enthusiasm would influence the subject's success. They have found that teachers are willing to walk the extra mile for a subject they are passionate about but will not commit adequate effort to a subject in which they are not particularly interested.

4.2.1 Suitable teacher profile

Identifying a suitable teacher for the subject could prove to be a challenge. Participant Nine agreed that there is no existing metric or test yet to evaluate a teacher's competence or readiness to teach the subject of Coding and Robotics in the South African context. They continue that because the subject is still relatively new in the SA education sphere, there are no standards against which a teacher's suitability can be measured. However, they continue that identifying specific attributes in a teacher could act as indicators to suggest that the teacher would be fit to be trained or equipped to teach the new subject. These attributes should not be considered strict disqualifiers. However, they could instead be used to suggest which of the existing teachers in a school should be trained to start introducing the subject.

The participants agreed that the Coding and Robotics teacher position should not only be considered for teachers with a STEM background, such as Maths or Technology teachers. Participant One offered that any teacher could teach Coding and Robotics, for the topics at the primary school level are simple enough for any willing and enthusiastic teacher to master, regardless of their prior experience. Participant Five offered that at their particular primary school, the language teachers were the ones who volunteered and were fit to teach Coding and Robotics. Through working with those teachers and training them successfully, Participant Five strengthened their conviction that any teacher can be taught to teach the subject, not necessarily only those with STEM backgrounds.

The participants were asked to propose possible attributes or descriptors of a suitable Coding and Robotics teacher to compile a list of possible identifiers. The collected findings are grouped into proposed attributes.

4.2.1.1 Motivation and enthusiasm

All the participants agreed that a suitable teacher for Coding and Robotics education must be motivated and enthusiastic. Participant One was adamant that the teacher's attitude toward the new subject is crucial to ensure the successful introduction of the subject. Participant Two offered that at their school, they generally found that the younger teachers were more suitable for the Coding and Robotics position but explained that it has less to do with age and more enthusiasm. They explained that older teachers are sometimes less open to learning to teach a new subject, especially if they are close to retirement. However, they admitted that openness to change is a matter of temperament, not age, which proves it an unreliable observation. Participant Three agreed with Two on the statement of age not being a valid measurement of a teacher's suitability for Coding and Robotics teaching, but rather that the teacher's enthusiasm is the most important benchmark. Participant Three added that any eager teacher should easily be able to master the content and pedagogy required to teach the subject at the primary school level. Participant Seven also mentioned that from their experience training teachers to include technology in their teaching methods, they noticed significant resistance among a specific age group. They admitted that this is not the case across the board but noted that teachers close to retirement often were not enthusiastic about learning to include technology. Participant Seven continued, "those are often the teachers who tend not to be digitally literate or competent and who give too much credit to the learners, thinking that the learners know more than they do." These teachers are often scared of being exposed. Participant Seven continued that one does not want to discriminate by excluding a teacher as a potential Coding and Robotics teacher due to an attribute such as age. Participant Seven suggested that enthusiasm should instead be the describing attribute, for a teacher who is enthusiastic about the subject will be willing to work on any other skills they may lack. Participant Ten suggests that it comes down to whether the teacher believes in the importance of the subject.

Participant Seven added that the teacher must be interested in the subject of Coding and Robotics to be a successful teacher, or they must at least grasp the subject's relevance. They need to understand what Coding and Robotics is; Participant Seven continues that teachers often have no idea of what it practically entails or where students would benefit from those skills. Participant Eight agreed that the teacher should also be interested in the subject and understand the definition and aim of the subject to recognise the value it will add to the student's life. Participant Five offered that enthusiasm for the subject will only be possible if the teacher has a solid understanding of what the subject entails. However, they admitted that this could be achieved by sending a willing teacher to the appropriate conferences and training to ensure they grasp the full extent of the topics. Participant Nine feels that one should not make "interested" a disqualifying attribute, for teachers often do not know precisely what Coding and Robotics as subject means, resulting in disinterest. Being disinterested could often be due to ignorance or fear of incompetence. Participant Nine continues that once all teachers have been exposed to the proper application and meaning of Coding and Robotics education, only then can the teachers who still do not show any enthusiasm be disqualified.

Participant One offered that they suspect the availability of enthusiastic teachers willing to teach Coding and Robotics would be one of the main obstacles in the South African context.

4.2.1.2 Willingness to learn

The participants agreed that willingness to learn is a non-negotiable attribute of a suitable Coding and Robotics teacher. Participant One argued that since the subject is still relatively new in the South African education context, the teacher will have to be willing to commit a lot of effort and time to familiarise themselves with the content and resources available to teach the subject successfully. Participant One continued that willingness to learn is a critical quality of a suitable teacher due to this not being a subject for which teachers are currently trained in most pre-service training and teacher education programs. This requires the appointed teacher to be willing to get familiar with the concepts and related pedagogy that are involved in the teaching of Coding and Robotics in their own time. Participant Three resolved that eagerness to learn is the essential attribute of a potential Coding and Robotics teacher. They continued that the field is rapidly developing, and while there are promises of a curriculum on the horizon, there is no formally structured textbook or collection of content for the subject yet. This suggests that the teacher will have to be willing to put in the effort to familiarise themselves with available content and design their own lessons. Participant Five concluded that at this stage, where the subject is still largely self-taught, the teacher's willingness to learn is non-negotiable.

4.2.1.3 Digital literacy

The participants agreed that digital literacy is a necessary attribute of a suitable Coding and Robotics teacher. However, the exact skills and experience required for a teacher to be considered digitally literate is not a unanimous topic. Participant One feels that a suitable teacher should be digitally literate in the sense that they must have basic digital skills but, more importantly, have confidence in using digital devices. Participant Two continued that the teacher should be computer literate, even though they do not need to have advanced coding experience. Participant Three offered another argument for the teacher to be a skilled and experienced computer user by offering that technical difficulty often arises in the classroom when the students use digital devices during the Coding and Robotics lessons. They continued that an IT staff member cannot always be available on demand to fix all technical difficulties, requiring the teacher to have the digital competence to sort out problems independently. Participant Six agreed that digital literacy would be an essential attribute of the teacher but agreed that the requirement should be defined explicitly. They continued that "being able to identify a computer, being able to create, save and print a document and being able to develop software and debug code are all considered digital literacy, but imply very different abilities". They suggested that standardised tests should be used to determine a teacher's digital literacy to evaluate their abilities and how to approach their training. Participant Eight also agreed that digital literacy is critical but added that the teacher does not necessarily have to be an advanced software developer but that it is beneficial if the teacher already knows their way around a computer. Participant Nine continued that the digital literacy of the teacher is imperative in the sense that they have to be confident in using the computing devices even if they do not have advanced skills. Participant Nine continues that they have often seen teachers intimidated or flustered when using computers and laptops, which also need careful addressing to build their confidence. Participant Ten agrees that a suitable teacher is one that at least has some background on how to use computers.

4.2.1.4 English literacy

English literacy is an attribute that many of the participants suggested, with various degrees of conviction. Participant One added that English literacy is important at this stage, where the primary source of information and guidance on Coding and Robotics training is found online. They feel that a teacher should understand basic English concepts to understand resources and Coding and Robotics terms that are often English-dominant. Even if the students are taught in a non-English language, the ICT and coding terminology cannot always be translated meaningfully, and English terms are often used. Participant Two also commented on the topic of English literacy by adding that most of the coding applications, online coding platforms, and resources are in English, making it very difficult for a teacher who understands no English at all to use these resources and communicate concepts with students. Participant Six conceded that the coding platforms and supporting devices are operated in English but remained hesitant to make English literacy a requirement to be able to teach the subject. They continued that the Coding and Robotics CAPS for the foundation phase will be translated into the SA official education languages, enabling any teacher to teach the basic concepts in any language once the subject is officially included in the curriculum. However, the supplementing resources and infrastructure a teacher would like to use to add to the complexity and sophistication of the student's experience would require English literacy. Participant Seven agreed it would be helpful for a teacher to be English literate but feels it is not a strict requirement. They elaborated that many basic concepts could be explained, and thinking skills could be developed through activities requiring no English literacy or complicated terms to be used. However, they continued that as the subject's content progresses to a level of complexity that "would justify the name Coding and Robotics", the teacher would have to start using resources and programs that will require basic English literacy. Participant Seven added that even when the CAPS is officially published and translated into non-English educational languages, the hope would be that teachers would aim above the minimum standards and find their own resources online to supplement the content, which would mostly be in English. Participant Eight feels that the teacher must be fluent in English. They admitted that their stance might be due to their robotics company currently only offering the material and training in English. However, they continued that this will probably be the case with most Coding and Robotics resources at the moment. They conceded that once the subject is officially included in national curricula, the CAPS document will be translated into other languages but insisted that teachers should aim to supplement the CAPS standards with resources that will probably be available in English. They continued that their company, as well as competing robotics providers that wish to stay relevant, will develop their offered material in other non-English languages, but this will take time. The introduction of the subject should not be delayed, if possible, which means an English literate teacher will have to take up the reins until more progress is made in the field and the development of course material. Participant Ten added that especially young students learn more effectively when taught in their home language; however, the teacher might need to do additional research for a subject such as Coding and Robotics, which will probably be in English. Participant Eleven agreed that none of our other languages in SA are as well supported in the Coding and Robotics communities as they are in English. They continued that English literacy should not be a strict disqualifier but agreed that for the teachers to have access to self-study resources related to Coding and Robotics fields online, they will need basic English literacy.

4.2.1.5 Self-confidence

Participant Seven offered that self-confidence is a vital attribute of a suitable Coding and Robotics teacher. They explained that while a teacher may not have the desired experience or digital skills, a teacher, confident in their learning ability, will overcome these challenges. They continued that confidence is essential regarding digital competence, for a teacher who is afraid or intimidated by the technology component of the subject will not be a suitable candidate. Participant Nine feels that the teacher's confidence directly affects the efficacy of their teaching methods but admitted that their fear or hesitation is usually due to misconceptions and can be addressed with proper training and demystifying conferences.

4.2.1.6 Passion for student's education

Participant Nine admitted that while the teacher does not necessarily need a passion for Coding and Robotics from the start; the adequate teacher could be identified as passionate and adamant about preparing their students with the best possible education. They continued that a passionate teacher should soon realise the value that Coding and Robotics will add to their students' lives and get on board with introducing the new subject. Participant Ten suggests that it comes down to whether the teacher believes in the importance of the subject.

4.2.1.7 Adaptability

Participant Ten offered that flexibility or adaptability is just as necessary as being willing to learn, for they feel that Coding and Robotics is an ever-changing and developing field and insist that the teacher should be willing to adapt their teaching methods and content.

4.2.1.8 Logical and mathematical thinking

Participant Two feels that the most important identifier of a suitable teacher is a logical thinker. Participant Two elaborates by adding that the teacher, for instance, has to understand concepts like circumference and angles and how far to turn by knowing how many rotations it would take to get to a certain point if the circumference is a specific value. They continue that it must be someone with a "logical, mathematical brain".

4.2.1.9 Inquisitiveness

Participant Eleven insisted that a teacher with an inquisitive nature could be considered for the position. They explain that due to the constant change and development in the field of Coding and Robotics, a suitable teacher will have to inquire continuously and investigate new technologies and concepts relating to the subject to ensure that students are constantly presented with the most optimal teaching opportunities.

4.2.1.10 Classroom management skills

Participant Seven offered that a teacher with poor classroom management skills should not be considered for the Coding and Robotics teacher position. They continued that the nature of Coding and Robotics lessons requires the teacher to often facilitate structured play activities, which could be ineffective if not managed properly. In addition, they found that inexperienced teachers often struggle with discipline and classroom management, which are vital skills to facilitate a subject such as Coding and Robotics. Participant Seven continued that classroom management is crucial to optimal Coding and Robotics learning. They explained that at the no-fee school where they worked, managing discipline in the class proved challenging and facilitating safe play with the robots to teach the students specific skills was near impossible. They suspect a similar situation would be even more challenging for inexperienced teachers. Participant Three feels that this subject requires the teacher to guide the students in learning through structured play. The teacher should act as a facilitator rather than "spoon-feeding" the students when they face particular challenges.

4.2.1.11 Mental capacity

Participant Seven mentioned that another attribute of a suitable teacher would be that they have capacity. They continued that they often found novice teachers who have just entered the profession and are mostly young and reasonably inexperienced are simply trying to find their feet with the daily realities and demands of teaching. Participant Seven feels that these teachers would probably not have the time or emotional capacity to take on the task of learning to teach Coding and Robotics right away. Especially since inexperienced teachers sometimes struggle with discipline and classroom management, which are vital skills to facilitate a subject such as Coding and Robotics.

4.2.1.12 Gaming experience

Participant Eleven offered that a possible identifier of a suitable Coding and Robotics teacher could be a teacher who is an avid gamer. They continued that a person familiar with the world of online gaming will most probably be familiar with many terms and infrastructure related to Coding and Robotics education. They continued that many of the concepts encountered through gaming can be related to Coding and Robotics education, which would immediately give the teacher a touchpoint with the language and jargon used in the subject. Finally, they admitted that this is not an attribute that disqualifies a teacher if not possessed but could instead be seen as a possible qualifier if they possess it.

4.2.1.13 Summary of teacher profile attributes

The twelve attributes discussed in this subsection describe a suitable Coding and Robotics teacher from the SMEs' perspectives. Motivation and enthusiasm, willingness to learn, digital literacy, English literacy, self-confidence, passion for student education, adaptability, logical and mathematical thinking, inquisitiveness, classroom management skills, mental capacity and gaming experience comprise the profile of a suitable teacher.

4.2.2 Teacher training

The participants all agreed on the importance of appropriate training to ensure that teachers are well-prepared to start teaching the new subject. The success of the rollout of the new subject will depend on the competence of the teachers. Unfortunately, most teachers currently in service will not have any experience or training in Coding and Robotics education. Therefore, if a school wants to start including Coding and Robotics in their curriculum, the teacher chosen for the subject will need to be well-equipped and prepared to teach it. Participant Six continued that educational institutions will probably train education students to present the Coding and Robotics subject to the level required by CAPS. Therefore, if a school has the means to supplement the curriculum to teach more sophisticated lessons, they will need to train and support their existing teachers in their own capacity. The participants were asked to comment on their experiences and give suggestions concerning Coding and Robotics teacher training.

4.2.2.1 Participants' experiences with Coding and Robotics teacher training

Participant One attended frequent information sessions hosted by the WCED on Demystifying Coding but felt that those sessions acted more toward raising awareness on the subject than offering practical guidance on teaching the subject. Participant One also attended information sessions hosted by the *Skoleondersteuningsentrum* to get teachers excited about new technological developments in the classroom. Participant One frequently attended information sessions hosted by various private Robotics Education providers, including Resolute Robotics, Schoolscapes and Optimi, introducing their respective products. Participant One offered that, in their experience, most of these sessions did not offer practical training on the content and pedagogy involved with teaching the subject. These sessions instead allowed teachers to be exposed to different educational technologies and Coding and Robotics concepts to empower the teacher with confidence in the subject's sphere. They continued that the most valuable practical information and guidance were found online in their individual capacity by reading articles, watching tutorial videos and visiting online platforms about educational robotics and coding. Participant One added that while the sessions they attended are important to help a teacher stay informed on the latest advancements in the subject and related available technology, the DBE will have to create a standardised in-service training program that teachers can attend once the Coding and Robotics subject is officially included in the curriculum.

Participant Two explained that all the Coding and Robotics teachers at their school received training from a coach at Kids Innovate Africa, a private robotics education solution provider. Their school paid the coach to teach Coding and Robotics to the students for a month, and the schoolteachers sat in on those lessons, made notes, and participated alongside the students. Participant Two emphasised the benefit of experiencing the interaction between the coach and the students. They explained that it was encouraging to see how the lessons were practically taught to students and how the students responded with enthusiasm.

Participant Three offered that they also attended information sessions about Coding and Robotics hosted by the WCED. They felt that these sessions focused on raising awareness and reducing stigmas around the topics but did not properly equip teachers with the skills and practical examples necessary to teach the subject.

Participant Five mentioned that they did not undergo any formal Coding and Robotics training before they started teaching the subject. However, their school is a Google School that uses the Google suite on Chromebooks in their classes. They continued that when integrating the Google suite into the school in 2015, they attended the Google Educator training. They continued that these training opportunities were very informative about some of the digital literacy skills necessary for Coding and Robotics teaching. These sessions also introduced Participant Five to other teachers in other schools interested in technical and digital innovation who provide valuable peer support in the Coding and Robotics teaching process. Participant Seven equipped themselves with the knowledge necessary to teach Coding and Robotics by doing online courses through edX and Udemy. They also completed the CS50 course, which they highly recommend as an introduction to the basics and understanding of Computer Science. They continued that of all the courses they completed, the CS50 was the best course to learn about programming. They also gathered information and ideas from online communities and from watching YouTube videos. Participant Seven continued that while watching videos and learning from other developers online was very insightful, translating that knowledge into lessons to teach younger learners was the main challenge. They continued that they found it quite helpful to attend conferences, such as the Cracking the Code Conference hosted by Wynberg Girls' Junior School, as well as conferences hosted by InnovateEDU. They continued that these conferences created space to converse with other teachers who also recognised the relevance of teaching Coding and Robotics. They could discuss and propose ways to apply the knowledge in the classroom to teach students successfully.

Participant Ten explained that they learned to teach Coding and Robotics by attending introductory conferences hosted by the WCED and further self-studying relevant courses through Udemy.

4.2.2.2 Pre-service training

Participant Five strongly advocates for all schools to start introducing Coding and Robotics lessons if they have the means, even before it is an official requirement. However, they realise teachers are not adequately trained for the subject in undergraduate education qualifications, for the subject has not yet been formally included in the national curriculum.

The participants agreed that pre-service training does not provide adequate digital literacy training at this stage. They continued that it would be much more attainable for more schools to start introducing the subject in their capacity if teachers were at least properly trained to use technological infrastructure in the classroom in pre-service training. Participant Five was adamant that their Bachelor's in Education did not equip them with the necessary digital skills to incorporate technology in the classroom, let alone the pedagogy skills required to teach Coding and Robotics. They continued that a heavier focus on technology in the classroom should be included in pre-service training, even if Coding and Robotics specific content is not yet included. If all teachers could be equipped with basic digital literacy in their educational training, keeping up with teaching the 21st-century skills that the students need to learn would be much easier. Participant Seven feels there is a desperate need for universities to train teachers from the undergraduate level to prepare them to face challenges in terms of technology integration and how to solve problems regarding teaching infrastructure.

The participants agreed that pre-service programmes should prepare teachers for digital integration in the classroom to pave the way for the eventual inclusion of Coding and Robotics concepts once CAPS is updated. Participant Nine agreed that digital literacy or computer skills should be taught nonetheless but highlighted that "it seems futile in the context where 16000 schools in SA do not have computer labs". They continued that training teachers for Coding and Robotics will have to equip them to teach the subject mainly using unplugged methods.

The participants agreed that pre-service training would have to start teaching Coding and Robotics once it becomes a formal part of the national curriculum. Participant Seven added that universities and colleges need to come on board and update their curricula to ensure that teachers entering the profession are well-prepared.

Participant Six offered that the specific design and inclusions of the training cannot be finalised before the national curriculum is released. The content in the final version of the Coding and Robotics CAPS will determine the skills and knowledge that the next generation of teachers will be taught in pre-service training. However, Participant One suggested that the training should preferably enable teachers to keep up with the development and future versions of the subject, for Coding and Robotics is an ever-changing field. Once the Coding and Robotics CAPS is updated, all foundation phase pre-service teachers should be trained to teach it in their respective education qualifications. From the intermediate phase, not all teachers would need to teach Coding and Robotics, for subject specialists usually teach their respective subjects to more than one class from grade four onward.

4.2.2.3 In-service training

Participant One admitted that, including themselves, most teachers currently in service in South African schools did not receive training on the subject of Coding and Robotics in pre-service training. This is because the subject is still very new to the South African context and has not yet been formally included in the national school curriculum. However, this inexperience suggests that in-service teachers must be trained to prepare them to start teaching the subject.

Participant Seven mentioned that the group of new teachers that enter the profession every year is too small to ensure that every school has a trained Coding and Robotics teacher, which means that in-service teachers will need to be trained in the subject. Participant Seven continued that the challenge they have witnessed with in-service training is that if it is self-driven, the uptake is often poor, and if it is made a requirement, there is often a lot of backlash and resistance.

Participant One suggested that continuous in-service teacher professional development is vital, especially in a subject such as Coding and Robotics. The field of Coding and Robotics is ever-changing as the 4IR progresses, and this will require the teachers of the subject to remain informed on the latest educational technologies and coding environments. Participant One is adamant that the success of the new Coding and Robotics subject as rolled out by the DBE will depend on the availability and competence of the teachers. Therefore, the DBE will have to provide guidance on selecting the appropriate teacher and create training opportunities for these in-service teachers to be prepared for the new subject. Participant Seven mentioned that standardised training for Coding and Robotics would need to be made available by the DBE to all teachers who wish to start teaching the subject once it is officially included in the national curriculum to ensure the successful rollout of the subject.

Participant Four feels that in-service teacher professional development will have to provide the context of the subject, as well as the content and pedagogical knowledge. In-service teachers often do not have any point of reference to the subject and will have to be oriented on what exactly Coding and Robotics entails. They must also be familiarised with how the subject fits into the bigger picture of the student's development. These teachers will have to grasp the value of the subject. They need to realise how the skills and learning outcomes that Coding and Robotics aims to achieve will improve the student's preparation as a future citizen and employee of a digitally driven workplace. Participant Four continued that if these teachers selected to start teaching Coding and Robotics do not buy into the idea of including the subject, the value of the student's education will be severely compromised.

4.2.2.4 Suggested attributes of training

The participants were asked to recommend considerations to ensure that Coding and Robotics training programmes successfully prepare teachers to teach the subject. Their suggestions yielded specific attributes of Coding and Robotics training that are discussed in this subsection.

4.2.2.4.1 Address misconceptions

Participant One commented on the value of attending demystifying conferences, where awareness is raised regarding the new subject of Coding and Robotics. Participant Three mentioned that many stigmas surrounding the topic of Coding and Robotics need to be addressed. Participant Eight agreed that an essential part of training a Coding and Robotics teacher would be addressing common misconceptions surrounding the subject. They continued, "Teachers are often scared of approaching the subject, for they do not know what it entails and are petrified that their jobs will be taken away from them. It is a very intimidating field for many of them." Teachers need to be educated on what the subject aims to achieve and what the teacher's role will be in facilitating the subject. Participant Eight continued that, especially with the younger grades, the teacher is the most important person in the room. They need to be empowered to feel confident in their knowledge and competence in the subject for it to be facilitated successfully. Participant Eight added that the training should first ensure that all teachers fully understand the reasoning behind the inclusion of the subject to get them motivated for the subject. While Coding and Robotics is quite a buzzword in the educational sphere, many teachers do not grasp the specific value it will add to the student's skill set. Participant Eight stated, "We all hear that Coding and Robotics is an essential skill, but not everyone is being told exactly why it is an essential skill." Participant Nine said they often saw a previously uninterested teacher turn into an enthusiastic Coding and Robotics teacher when exposed to the correct content at the training sessions. Participant Nine continued that if common misconceptions are addressed, and the teacher is enlightened on how certain aspects of Coding and Robotics are related to aspects that the teacher is already implementing in their classrooms, they are often much more excited to teach the subject.

4.2.2.4.2 Continuous

Participant Eight insisted that training should not be a once-off session. Instead, they explained that they would suggest one initial training session of multiple hours where the resources, robots or teaching tools are introduced. Afterwards, sustained support should be provided weekly to ensure continual guidance is provided to the teacher as they encounter challenges or need reinforcement of previous concepts covered. Participant Seven agreed that continuous long-term training would be ideal, where the teacher attends a session every week, for instance. Participant Seven explained that the topics covered in Coding and Robotics are often not concepts that the teacher would be familiar with, meaning they would need more time to grasp them.

Participant Seven offered that a challenge connected to teacher training is that the opportunities and conferences often happen during school time, and all schools do not have the capacity to send a teacher to training during school hours. They continued that these training sessions are often very time-consuming, for it is not effective to have a once-off session and expect the teacher to be fully capable of teaching the subject; training needs to be very comprehensive. They continued that a multiple-day conference or training program is the best solution to ensure concepts are transferred sustainably. This would mean the school must manage without the teacher for multiple days. Presenting the training during school holidays is not ideal, for Participant Seven continued that it will be met with controversial responses. They continued that even though teachers are often contractually obliged to be available for training during holidays, they also need to rest. Therefore, a Coding and Robotics training program should preferably be a long-term arrangement that does not take too much time every week while still providing continuous support to the teacher.

4.2.2.4.3 Scaffolded

Participant Nine offered that in the same way that the content taught to the students should be carefully scaffolded, the teacher training should also progress at a reasonable pace. The content should be structured to increase complexity to make productive use of training time while not moving too quickly for inexperienced teachers to keep up. They continued that, for instance, there cannot be an expectation on a previously inexperienced teacher to master Python programming through a few days of training; they offer that teaching block coding to the teachers first is preferable.

4.2.2.4.4 Low barrier to entry

Participant Nine offered that they have trained more than 2000 teachers from various communities to teach Coding and Robotics through their Tangible Africa programs. However, they insist that the most crucial consideration to keep in mind is the barrier to entry. If this subject is to be introduced in all communities in the country, the teacher training should start at a very low level and not assume that the teacher has any prior knowledge of the subject. It should not be assumed that all teachers have a certain level of fundamental knowledge; the basics of the subject should instead be the starting point of the training.

4.2.2.4.5 In-person

Participant Eight explained that they had been involved with the training of many teachers when they equipped them to teach the lesson plan provided by their private robotics company. They found that the training is more effective in person to physically demonstrate activities with the robot. However, they admitted that online sessions often help to "force" the teacher to get used to online meeting platforms, which could increase their general confidence around using computing devices.

Participant Five offered that one of the significant advantages of having the training conferences in person is that the teachers get to meet and network with other teachers who also teach Coding and Robotics. Participant Five continued that these connections are invaluable in providing peer support to the teacher when future challenges arise. Participant Seven agreed with this, adding that the in-person conferences allowed for valuable discussions among fellow trainee teachers about the practical implementation of the subject in the classroom.

4.2.2.4.6 Demo lessons

Participant One commented that while educating teachers on the proper definition and purpose of Coding and Robotics is vital, it is equally important that teachers be offered practical guidance on teaching the subject. Participant Two offered that it is extremely valuable for the trainee teacher to experience a demo lesson being taught, where the trainer teaches a Coding and Robotics lesson to students while the trainee teacher gets to observe the practicalities of teaching the subject. They continued that experiencing to what degree the facilitator assists the students with difficulty is especially helpful, particularly for an inexperienced teacher. Participant Seven also experienced that watching the demo lessons being taught to the students was very helpful, for they could see how the concepts were practically taught in class as well as the application of pedagogical methods. They added that it was motivating to see how engaged the students were in the activities and to see what the students were capable of. After the demo lesson was completed, the teachers had to analyse the lesson and identify the different skills taught through the activity to break down the application in the classroom.

Participant Eight agreed with the value of having students at the training sessions so that the teacher could see how the students interacted with the lessons. However, Participant Eight added that the teacher should not be expected to take the lead with the students in the training session. Instead, the trainer should facilitate the activities, for an unconfident teacher could feel intimidated to be expected to teach before they are properly equipped to do so. Participant Eight also offered that if it is not possible to have students present at the training conferences, the trainer could treat the trainee teachers as the students and have them participate in the activities themselves to demonstrate the process. Participant Nine added that having the teachers complete the activities and work in groups the same way the students would also demonstrate how learning would take place in the classroom and present the opportunity to analyse the pedagogical methods applied in the lessons.

4.2.2.4.7 Relatable

Participant Nine offered that the training content should be relatable to the trainee teachers. The course material should be designed to connect to specific topics or activities from the teacher's point of reference. This will help them understand the context of the new concepts while keeping them interested in the training.

4.2.2.4.8 More than content

The participants agree that it is important to ensure the teachers grasp the subject's content. However, they insist that only covering the topics in the Coding and Robotics curriculum in the teacher training will not equip the teachers to present these topics to students properly. It is equally important that teachers be equipped with the necessary pedagogical knowledge and knowledge of the latest available teaching tools and technologies.

Participant One agreed that many teachers may need to be more familiar with the concepts and content covered in Coding and Robotics and will need to be introduced to it at an appropriate pace. However, teaching them how to convey these concepts is equally important. The teacher should understand how learning takes place and what ways of thinking are applied. The training should inform of the higher-order thinking skills that the student is developing through Coding and Robotics education. This will allow the teacher to guide the student to develop these skills through participation in specific activities. Participant One adds that the lessons will not be taught effectively if the teacher is unaware of the skills and thinking methods that the student should be developing through Coding and Robotics. Participant One added, "The student simply going through the motions of playing with the robot for a whole period will not achieve any of the higher-order thinking skills that could be taught successfully in this subject if the teacher cannot provide meaningful guidance in developing those skills." Participant One continued that the development of a student's computational thinking, critical thinking, problem-solving and self-confidence often needs thoughtful mediation from the teacher, even when participating in open-ended play.

Participant Five offered that they have experienced training opportunities where teachers are informed of what Coding and Robotics is but not how it will be taught and how to approach it. Participant Five continued that it is important to equip the teacher with adequate knowledge of the higher-order skills that the subject aims to teach and to empower them with the pedagogical tools to design their own lessons and activities to teach these skills. Participant Five continued that at a well-resourced school with advanced infrastructures, such as theirs, it is easier to put the curriculum together by acquiring expensive kits, such as LEGO, with many online resources and support available. However, if the school were heavily under-resourced, it would be much more challenging to know where to start or how to put the lesson plan together, especially if the teacher is inexperienced. In that case, a structured training course that guides the process of designing activities would be particularly valuable to ensure that teachers are confident to create their own lessons to teach specific topics.

Participant Three feels that pedagogical concepts are universal no matter the subject but added that the teacher should be advised on how to apply specific pedagogical knowledge. The teacher should be guided on how certain universal teaching methods they should have learnt in their respective teaching qualifications can be used in the context of Coding and Robotics.

Participant Four (teaching expert) elaborated that research in the last century has proven that teachers cannot only be content experts but also need to understand pedagogy. Participant Four stated that a teacher must be trained on how thinking takes place and how learning takes place to guide students in the process successfully. They continued that though many models exist to illustrate how learning takes place in a young student, the chosen model for educating Coding and Robotic teachers should be simple enough that many teachers can understand it and be practical to implement in their lessons with the students. The Semantic Wave Theory is one pedagogical model that has successfully been included in teacher education to improve students' cumulative learning. It follows the approach of connecting an abstract concept and a concrete context to introduce a new concept by linking it to a real-world context. For example, instead of simply introducing a new abstract concept such as velocity by expanding the equation in a theoretical manner, the real-world context should be included by demonstrating how a small car covers different distances in the same amount of time to see practically how velocity is a function of displacement and time. This method encourages "waving" between the two ways of thinking continually, from abstract to concrete and back to abstract, to present the student with more than one perspective on a concept. Participant Four was adamant that Coding and Robotics education must continue to draw connections between what skills or knowledge the student should be learning through playing with the robot and context from their frames of reference to allow successful learning. Participant Four added that often with young children, it is valuable to start the wave approach with the concrete context and then explain it further with theory. For instance, the teacher should have the student make a robot move from one point to the next first and then explain concepts such as speed and direction from a theoretical perspective only once the student has already observed it physically. Therefore, having the students play with the robots while explaining the scientific principles behind the activity is very effective in learning.

Participant Eight agreed that teachers need to be equipped with different strategies and tools to teach various Coding and Robotics topics. The same topic can be approached from different angles, and the teachers need to be able to switch between approaches fluidly. For instance, the concept of acceleration can be explained theoretically by solving the equations or demonstrated practically with a robot.

Participant Seven said it is essential to communicate the higher-order thinking skills developed in the subject to ensure the teachers grasp the value the subject would add to a student's life. Participant Seven continued that explaining to them that skills such as problem-solving and collaboration would be developed would often enthuse a previously disinterested teacher about the introduction of the subject. Participant Seven offered that it would be helpful to connect the subject of Coding and Robotics to concepts such as creative thinking that a teacher might already unwittingly be teaching to make it more relatable to them. Participant Seven continued that teachers will only successfully facilitate the learning of the required skills if they understand the value and applicability of those skills in real life. They continued that it is vital to understand the thought processes and how knowledge is structured to ensure that teachers effectively facilitate learning.

4.2.3 Conclusion

In this section, the teacher factor is presented. The gathered data from the SMEs' perspectives produced twelve attributes that comprise a suitable Coding and Robotics teacher profile. The teacher training is also expanded into attributes of training to ensure that teachers are adequately prepared to teach the subject.

4.3 Infrastructure

From their perspectives, the participants were asked to comment on appropriate infrastructure to support the teaching of Coding and Robotics. They were also asked to suggest elements of infrastructure that should be considered to ensure an optimal teaching environment for Coding and Robotics.

4.3.1 Teaching space

The participants all agreed that an appropriate teaching space is the most important infrastructure element supporting Coding and Robotics education. Participant One continued that the setup of the teaching space or Robotics lab will depend on the school's specific needs. The participants all agreed that the primary necessity of the classroom is ample space. Participant Two suggested that if the school already has a computer lab, it be used for Coding and Robotics. However, the participants agreed that a designated Robotics lab is optional; any classroom could be used, provided it is spacious enough. Participant Three explained the significance of the classroom being big enough by highlighting that the subject often involves structured play activities that require free movement in the class.

Participant One suggested arranging the classroom in a multi-purpose way to create different activity stations if resources are limited. They continued that in their class, they have a computer station with 15 computers, a robotics table where a group of students can complete specific missions with a robot and tablet, as well as a station where students work with the robotics kits on the floor.

Participant Three highlighted the importance of the tables being flat-surfaced. They explained that the robots should not be operated on sloping desks, for the robots would not be steered safely without falling and causing damage. Participant One also suggested that the tables be mounted on wheels to be moved easily and allow a versatile teaching space. Participant Three offered that if flat-surfaced tables are not available, the furniture should be moved to the side, and robotics activities should be performed on the floor.

Participant Nine mentioned that many schools in SA have overfull classrooms, which would not allow adequate space for working and playing with robots, and suggests that the assembly hall could be used in those cases. Participant One continued that ideally, the classroom would have enough space for storing the robots in their assembled state between lessons without having to take them apart to be stored in a smaller space.

4.3.2 Safety and security

All the participants emphasised security measures as one of the most critical elements of the infrastructure. They agreed that no matter the sophistication of the resources, safekeeping should be the highest priority.

Participant One offered that their robotics lab serves as a storeroom for the devices and robots and that certain measures were implemented to secure it. The classroom has an alarm surveillance system, safety gate, burglar bars and locked cupboards where the robots and tablets are stored. Participant One adds that the WCED often has certain requirements for the safekeeping of resources that they provide to schools. For instance, the computers granted to Participant One's school by the WCED have to be located in a classroom with burglar bars, an iron gate and an alarm system.

Participant Two added that the insurance of the resources is also something to consider to counteract the possible financial impact of theft or damages.

Participant Three added that ideally, the classroom where the Coding and Robotics teaching takes place would be the same space where the resources are stored securely to prevent the teacher from moving all the resources back to the safe or storeroom after every use. Participant Eleven offered an interesting outlook on security measures. They explained that having a secure safe or storeroom to store the resources is important. However, they added that the storage space should preferably be as close to the teaching space as possible, and the teacher should have direct access to the resources without involving a third party every time the artefacts are used. This would make it easier for the teacher to reach the equipment. If, for instance, the robots were stored in the school safe, the staff member responsible for access to the safe would have to assist the Robotics teacher every time the robots needed to be fetched for class, which would waste precious teaching time. They added, "The harder you make it for the teacher to access the resources, the less they will use it." They continued that the storage location should be big enough for the robots to be stored in their assembled forms so that the robot can be kept in their form as used for a specific activity to be continued in the next session without having to rebuild the robot.

Participant Nine agreed on the importance of practical security measures by elaborating that the resources not only need to be stored securely when not in use, but the teaching space where they will be used also has to be secured. Participant Nine continued that once it becomes general knowledge that the school has acquired valuable resources, the prevention of unrestricted entry to the premises should also be prioritised to avoid robberies. They continued that measures such as fences, security cameras and burglar bars in the rest of the school will also have to be considered.

Participant Five mentioned that mismanagement of resources often leads to compromised security measures. They emphasised the importance of having someone accountable for the safekeeping and management of the devices.

4.3.3 Electricity

The electricity requirement will depend on the devices used for Coding and Robotics education. The availability of electricity in the teaching space will determine whether desktop computers can be used. If there are no electricity points in the Coding and Robotics classroom specifically, but there are elsewhere in the school, mobile computing devices and robotics kits could still be used after being charged elsewhere.

Participant One offered that the subject of Coding and Robotics can be introduced through unplugged activities without sophisticated computing devices and robotics kits at first, ensuring flexible electricity needs in the classroom. However, Participant Two feels that the availability of electricity is non-negotiable if the technological sophistication of the subject is to be kept at an advanced level. Once the devices and robots are acquired, the requirements should be revisited to ensure the necessary electricity supply is available. They explained that the availability of computing devices is vital to ensure that the students have adequate exposure to advanced coding activities. If desktop computers are used, the classroom must be equipped with electricity points. However, the electricity supply can be outside the space where the teaching happens if mobile devices such as laptops or tablets are used. In that case, it would mean extra effort for the teacher. These devices could be charged at another location with electricity, preferably on the school property, before being used for a lesson in the Coding and Robotics classroom. Participant Three offered that it is favourable that the classroom has charging points where the robots and laptops or tablets can be charged between uses to prevent the teacher from having to move around to another location to charge the devices.

Participant Five also advocated for the inclusion of teaching tools and robots that make use of electricity to ensure adequate complexity of the subject; however, they mentioned that loadshedding might be something to consider. Participant Six agreed that the computing devices should preferably be battery-powered to allow operation when there are power outages. Participant Six adds that solar power systems are becoming more of a necessity in schools to keep vital functions, for instance, the school internet and admin department running. However, it would usually not be achievable to have all the computers in the Robotics lab running from the inverter system during loadshedding, which suggests that battery-powered computing devices such as laptops or tablets should be favoured. Participant Nine offered that many schools in the SA context will not be able to afford a sophisticated solution to compensate for loadshedding, which suggests an unplugged teaching alternative needs to be found.

4.3.4 Wi-Fi

The participants agreed that electricity and Wi-Fi access are not negotiable to teach this subject on a technologically sophisticated level. Participant Eight agreed that Wi-Fi is crucial to allow online simulations and platforms to be accessed. Participant Eleven continued that another advantage of a strong Wi-Fi connection is that the students can be allowed to do their own research and practice their problem-solving skills by having guided access to online resources.

Participant Ten continued that the web-based coding platform they use to program their LEGO kits requires a stable Wi-Fi connection. Participant One tries to maintain a paperless approach, requiring the students to access their worksheets and resources online. They also have the students play online games, which require strong internet access. Another motivation for prioritising Wi-Fi infrastructure is that some computing devices can only be operated when connected to the internet. Participant Three continued that their school already had a certain amount of Chromebooks, which they then also used for the subject of Coding and Robotics. However, Chromebooks running on Chrome OS instead of an offline operating system, such as Microsoft Windows, must be connected to the internet at all times. This means that their Coding and Robotics lessons subsequently rely on the availability of Wi-Fi infrastructure that can connect all the devices to the internet without lagging. Participant Seven offered that at their school, school-wide Wi-Fi infrastructure was set up to support digital integration in the school. Participant Seven continued that if school-wide Wi-Fi installation is not possible, a mobile router or mobile hotspot should be set up for the specific Coding and Robotics period to enable internet access for the subject.

Participant One suggested that if no internet connection is available in the Robotics classroom or the signal strength of the Wi-Fi does not allow all the students to have access at a productive pace, unplugged methods could be used to start the teaching of basic concepts. They continued, however, that as the students progress, more sophisticated teaching tools and devices should be acquired as soon as possible, requiring the connectivity matter to be revisited. They continued that Wi-Fi is not crucial, for many of the robots can be coded with offline applications. Participant Five also feels that Wi-Fi in the particular classroom is a relaxed necessity. As long as the coding software and necessary resources can be downloaded onto the computing devices at another location with an internet connection, they can be used offline to code the robots in the class, presuming the computing device can connect to the robot through Bluetooth.

An essential element of the Wi-Fi infrastructure is access restriction. A carefully managed firewall should be considered when allowing the students to access the internet to ensure safe use but still allow necessary resources to be accessed. Participant Ten mentioned that the government has initiatives in place to equip government schools with Wi-Fi infrastructure. They continued that their school was one of the receivers of such a government line but admitted that they hardly ever use the government Wi-Fi for it has very restrictive safety measures in place. They explained that they, for instance, had to get special permission from IT support to lift the firewall to access the LEGO coding environment online.

Participant Ten continued that they understand that the government tries to make sure that the Wi-Fi is used responsibly, but they feel that it is too much admin for them to request permission for all the online resources they wish their students access. Participant Eleven agreed that a carefully restricted firewall should be considered when all students are provided with internet access to ensure safety while allowing access to important online resources. They explained that at their school, they are fortunate enough to have Wi-Fi that supports all the students with connectivity to work on individual iPads at all times. However, they admitted that the firewall on their Wi-Fi sometimes creates unnecessary restrictions. They continued that while they understand that their school IT department wishes to prevent students from accessing sites such as YouTube unsupervised, their students are well-disciplined and could benefit from being allowed to access tutorials on YouTube.

4.3.5 Computing devices

All the participants agreed that the availability of computing devices is vital to ensure that the subject of Coding and Robotics is presented on an advanced level. They admitted that unplugged methods could successfully be used to teach the fundamental principles and thinking skills that the subject aims to teach. However, the complexity of coding and computational thinking that can be taught will be limited. The participants suggested desktop computers, laptops, tablets, iPads and smartphones when asked to comment on computing devices appropriate for Coding and Robotics education.

Many schools are already equipped with desktop computers, which can be used for Coding and Robotics instruction. Participant Eight added that they prefer computers or laptops over tablets because they feel that computers and laptops are more compatible with most available robots. Another advantage of computers or laptops is that other computer literacy skills can also be taught, which gives it a dual purpose. Participant Eight offered that the computing devices provided by the DBE are often desktop computers.

Participants Three, Five and Seven offered that their school already had a certain amount of Chromebooks, which they also implemented for Coding and Robotics. Chromebooks are considered a more affordable option than other mobile computing devices but require an internet connection. Chromebooks run on Chrome OS, as opposed to an offline operating system such as Microsoft Windows, which means it needs to be connected to the internet at all times. This means that their Coding and Robotics lessons subsequently rely on the availability of a Wi-Fi connection. This also means that the Wi-Fi signal strength will have to be able to support all the students working on Chromebooks at the same time. Participant Seven continued that while they saved on the cost of the devices by choosing the Chromebooks, the cost of internet infrastructure was much higher.

Participant Seven offered that tablets are cheaper than laptops while still providing a mobile solution but offering less functionality. Tablets work well with most block-based coding applications or interfaces where the connected robot is instructed through drag-and-drop instructions. However, once the students progress to more advanced activities, such as line-based coding, where more complex software is developed, a laptop or desktop computer would be preferable. Participant Five feels that iPads work well to provide students with the opportunity to "program something to make it follow code" while being less expensive than other mobile computing devices like laptops.

Some participants mentioned that if the school cannot provide computing devices, a combination of devices could be used if the students were allowed to bring their own devices to school. However, classroom management will be more challenging, for the design of the activities will need to be adapted to the particular devices available. The teacher will need to set time aside to ensure the necessary software setup on the different devices is possible. The school will also need to provide a fast internet connection so that the students can access the necessary platforms or resources on their own devices. Participant Nine mentioned that if computing devices are not available, the students could also be introduced to coding concepts through smartphone apps. If the students had phones and were allowed to use their phones for the Coding and Robotics lessons, they could work in groups where necessary and be exposed to the real-time feedback of the code they design. Participant Two, however, offered that a "bring your own device to school" policy would not solve the problem of computing device availability at a school such as theirs where there are students from highly privileged households as well as less fortunate households in the same class. To maintain an equal-opportunity learning environment, the school must provide the devices.

Participant Two also mentioned that another consideration in the choice of device is whether the school wishes to enter their students into robotics competitions. If the students travel to competitions, they cannot only have desktop computers but need a mobile solution such as laptops to take with them to compete.

4.3.6 Air-conditioning

Participant Six added another aspect to consider, namely air-conditioning. Temperature regulation will be necessary if a room full of desktop computers is used for Coding and Robotics. However, they continued that when laptops or Chromebooks are used, the cooling is not an issue, which might be something to consider when choosing computing devices.

4.3.7 Projector

Participant Eight mentioned that one additional piece of equipment that they would suggest for the robotics class is a projector or a smart board. They explained that if the funds are limited, having a projector will allow the teacher to demonstrate simulations or show robotics videos to the whole class without each student needing access to their own computing device. They admitted that while the projector is an older technology than the smart board, it is often preferable for being much more affordable and can be used against a wall or whiteboard.

4.4 Artefacts

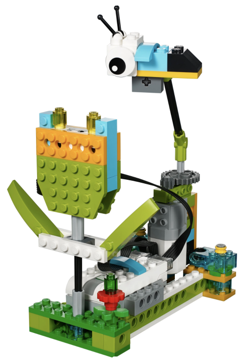
Artefacts refer to the educational tools used by the teacher to aid the learning of certain concepts. Of course, many concepts can be learnt in an unplugged fashion without equipment. However, as the students progress, incorporating electronic devices and robotics kits will expand the range of skills that can be taught.

4.4.1 Participants' individual perspectives on teaching artefacts

The participants were asked to comment on their experiences with Coding and Robotics teaching artefacts. They gave examples of the robotics kits that they have worked with and made comments about the complexity of the different kits. A few of the examples that the participants mentioned are displayed in Figure 4.1 for reference.

Participant One has experimented with many different robotics kits to find a fit that works best for their school's specific needs. They have used Cubroid Coding Blocks. They explained that these worked well as an introduction to the subject, and they used these kits for all the grades that started with no background knowledge of the subject. They suggest that these kits are best suited for foundation phase students, for the complexity of the design and manoeuvres that can be achieved with this specific robotics kit is not very advanced. The parts are also quite large, which makes it well-suited for younger students who can handle it easily without the safety risk of small hazardous parts. Participant One also has different LEGO kits in use, namely the WeDo models, Spike models and Mindstorms EV3 models. They offered that the LEGO WeDo is well-suited for young (grades R to

(a) *Cubroid (Cubroid, 2023)*



(b) *LEGO WeDo (LEGO, 2023b)*

(c) *LEGO Spike Essential (LEGO, 2023a)*

(d) *Thymio (Thymio, 2023)*

(e) *Code & Go Robot Mouse (Learning Resources Ltd, 2023)*

(f) *Edison robot (Learning Resources Ltd, 2023)*

FIGURE 4.1: *Examples of robotics kits mentioned by the participants.*

three) students but can also be scaffolded to more advanced activities. Participant One continued that the LEGO Spike kits are more advanced and versatile than the WeDo kits but are much more expensive. The Mindstorms EV3 models are well-suited to intermediate-phase students but are not available to purchase anymore. They continued that a great advantage of the LEGO kits is their popularity, for there is a tremendous amount of resources available online regarding activities and lessons that can be taught using them. Participant One added that another motivation for the LEGO kits is that students can participate in the First LEGO League, which, as suggested by the name, requires the students to compete using LEGO robotics kits.

Participant Two also uses LEGO EV3 Mindstorms and LEGO Spike Prime robots at their school because they are a requirement for competing in the World Robotics Olympiads (WRO) and the First LEGO League, in which their students compete. They agreed that these robots are expensive but suggested that they should be acquired over a couple of years to lessen the immediate expenses. Participant Two prefers the EV3 Mindstorms, for they have a small screen on the robot that provides real-time feedback where the code being executed can be seen. In addition, they recommended having a maximum of two students per robot, for they found that in bigger groups, one student would sometimes drift off and lose interest.

Participant Three uses the LEGO Spike Essential and Spike Prime robots in their lessons. The Spike Essential is aimed at students aged six and up, while the Prime is aimed at students aged ten and up. These robots were again selected due to their requirement to enter the WRO. The trustworthiness of the brand was also a motivator. Participant Three continued that the LEGO robots appealed to them specifically due to the number of supporting resources available and the large online community of people using the LEGO kits that could provide inspiration and help with designing and teaching lessons. Participant Three said they would recommend that an inexperienced robotics teacher, such as themselves, opt for a popular robotics kit like LEGO to ensure a lot of support and examples can easily be found. They continued that they started all the students (grades three to six) off on the LEGO Spike Essential robots, even though they are actually aimed at younger students, to introduce them to the basic concepts. Then, they started incorporating the LEGO Spike Prime robots in lessons for the grade five and six students in the second year. They continued that more than three students working with one robot often resulted in some students losing interest and not participating.

Participant Four agreed that many fundamental concepts could be taught without resources but emphasised the value of a tactile teaching tool in early childhood education. They continued that young students often learn new concepts more easily through practical experience and observation instead of theoretical explanations. They continued that the presence of a robot that allows real-time visual feedback in the coding process improves the child's learning experience. Participant Four has experience with Coding and Robotics programs launched in less fortunate communities and argues that the cost of the robots, such as LEGO, is the primary constraint in these communities. They mentioned that they have successfully worked with teaching young students with a cheaper robot, the Thymio robot, which a nonprofit association designed to offer STEAM journeys to learners of all ages. However, they admit that the robot is very basic and not very customisable, which limits the implementation possibilities. The robot's shape cannot be altered, which removes the mechanical design aspect of the Coding and Robotics subject. However, it can still complete many functions and teach the students basic coding logic and commands. Participant Four is adamant that this is a very affordable solution to give students in poorer communities access to a tactile, visible feedback resource that will enable successful learning, even though the students will not be able to compete in Olympiads and competitions.

Participant Five agreed that coding concepts and computational thinking skills could be taught with unplugged artefacts, for instance, using arrows and instructions and numbers on cards for one student to "code" or instruct another student to perform specific movements. However, they feel that these solutions limit the subject's sophistication and will not succeed in preparing students for the digitally-driven workplace as intended. They conceded that unplugged lessons could be taught in the foundation phase but suggested that some programmable devices be introduced in the intermediate phase to ensure a scaffolded curriculum. Participant Five explained that their preschool students have used the Code & Go Robot Mouse Activity Set to teach the basic principles of Coding and Robotics. The Robot Mouse is a device with buttons that command specific actions and movements without needing an external computing device to control it. They admit that the artefact is not very versatile, for it cannot be customised into many shapes like its more sophisticated counterparts, for instance, the LEGO kits. However, it is often preferable for being much more affordable than some of the other options, mainly since it does not rely on the availability of a laptop or tablet while still providing the student with tactile feedback on their coding decisions. They added that another similar option for a more affordable robot to introduce students to coding concepts is the Bee-Bot. Both options are useful for younger (grades R to three) students because they are robust and do not contain small hazardous parts. For the foundation phase students, Participant Five uses the Sphero robots connected to their iPads to introduce the students to control the robot through block-based coding. In the intermediate phase, they use the LEGO WeDo robots and the LEGO EV3 Mindstorms for the grade eight and nine students, both of which are also controlled by coding solutions created on their iPads.

Participant Six (robotics provider) is not a strong advocate for expensive robotics kits being a requirement, for they feel it would exclude too many students from access to the subject. Instead, they prefer the Edison robot, for they feel it provides a robust, enjoyable opportunity for the students to see the feedback of their code in a tactile manner without being very expensive.

Participant Seven advocated for using robotics kits by explaining that younger kids are often more motivated to continue debugging a problem if they have an incentive in the form of the physical robot providing feedback. They continued that visually seeing the result of their code is much more captivating than cryptically analysing code. The challenge of completing the task with a robot also makes it fun and engaging. Participant Seven worked with the Micro:Bit Robot but mentioned that the durability was not up to standard, and they spent too much time fixing problems. They continued that this unreliability hindered the student's experience, for they often were unsure whether the student was doing something wrong or whether the robot was faulty. Participant Seven also used the Edison robot because it was one of the few robots compatible with the Chromebooks they had available at their school at the time.

Participant Eight agreed on the importance of the ratio of students to kits. They continued that a whole classroom cannot be taught properly with only one kit, which should be kept in mind when considering donations or grants that only provide limited resources. Participant Eight agreed on the value of having a tactile resource, such as a robot, to teach the subject. They feel that unplugged activities cannot be the only methods much past grade one or two, for they feel that if the subject aims to stay true to its name, the students should have exposure to robots. However, they added that unplugged lessons are one of the solutions to mitigate the teaching barrier of loadshedding.

Participant Nine advocated for using smartphones when computing devices and robots are unavailable. They continued that even in less fortunate communities, students often have access to smartphones. They suggested that even if only one student per group has access to a smartphone, it can still be utilised to teach basic Coding and Robotics concepts by simulating the feedback of the coding design. Participant Nine continued that another advantage of a smartphone is that it does not require electricity access. They continued that with the various applications developed by Tangible Africa for the various age groups, students can use cardboard coding cards that each contain an instruction to design a sequence of commands to perform a specific task. The coding cards are then scanned with the app on the phone to simulate the sequence of instructions that the virtual agent in the game then performs. Participant Nine continued that these teaching artefacts do not require electricity or Wi-Fi availability, for the application could be downloaded for offline use. Participant Nine added that this virtual simulation of the robot is an effective alternative to provide coding feedback if a real robot cannot be afforded.

Participant Ten explained that they decided on the LEGO kits due to their versatility. They continued that these kits could be used for various age groups and with different coding platforms. They continued that a significant advantage of the LEGO kits is that they can be coded with block-based coding but also allow scaffolded complexity by being compatible with line-based Python coding for older students. They admitted that the LEGO kits are generally quite expensive but mentioned the added incentive of being able to compete in the olympiads with the LEGO robots. Participant Ten agreed that the basic thinking skills and background knowledge of Coding and Robotics could be taught through unplugged methods but feels that from grade four onwards, the students should be exposed to some robots to provide real-time feedback on their software if possible. Participant Ten continued that the robots help keep the students interested and keep them excited about the activities to see the output of their code physically.

Participant Eleven uses the LEGO WeDo 2 kits with their foundation phase students and the LEGO EV3 Mindstorms, as well as the LEGO Spike Prime for the intermediate phase students. They also use the Blue-Bots with the foundation phase students, which are similar to the Bee-Bots in that they can be programmed with the buttons on the robot but provide more scaffolding. The Blue-Bots can also be programmed through the tactile reader, where students place cards into frames to create a linear coding sequence of instructions for the robot to perform. The third application is where the Blue-Bot is connected to an iPad or computer through Bluetooth, and instructions are given from coded commands arranged in the accompanying application. Participant Eleven agreed that unplugged methods are effective in teaching basic concepts. They added that, especially with the younger students, playing games with them where they "are the robots" and have to follow certain instructions and perform the actions allows movement, which increases their focus and bodily awareness.

Participant Eleven mentioned a unique artefact that they use at their school. They have a 3D printer, allowing the more advanced students to design and print parts compatible with their LEGO kits to perform certain tasks. For instance, one student designed and printed a clasp that can be attached to the robot to enable it to hold a pencil. The robot will then be coded to draw mandalas for a collaborative project with the Arts subject.

Participant Eleven commented on the use of drones instead of robotics kits. They strongly feel that it is a less effective solution than the robotics kits, for it is less versatile and requires more careful classroom management. Participant Eleven offered that a specific issue they have with the drones is the noise they make, causing restlessness in the classroom. In addition, they offer that drones generally have a short battery life, which means they cannot be used for multiple classes consecutively.

4.4.2 Choosing the robotics kit

The selection of an appropriate robotics kit is essential to ensure effective teaching of Coding and Robotics. The decision should be carefully considered, for purchasing resources could be quite expensive. The participants were asked to contribute attributes of a robotics kit that should be considered when choosing a kit.

4.4.2.1 Expense

The participants agreed that the most consequential consideration is the cost of the robot, for most schools have carefully managed budgets. As a result, many schools will not have the funds available to purchase many sophisticated kits at once. Participant Five offered that the simpler the robot is, the cheaper and easier it will be to maintain and operate. For example, the LEGO EV3 Mindstorms robots that are very versatile and scaffolded are costly and have many different parts in a kit that must be managed and sorted to avoid getting lost among other kits. Participant Seven agreed that while a school should aim to expose students to advanced technology to ensure they are prepared with 21st-century skills, a realistic approach should be taken. They continued that each school will have to evaluate their own needs and capabilities to determine whether they have the funds and infrastructure to support a complex solution.

4.4.2.2 Popularity

Participant Three said they found the robot's popularity to be an influential attribute in choosing the kit. They continued that for a relatively inexperienced robotics teacher, they would recommend using one of the more well-known robotics kits to ensure that there are a lot of resources and communities available online that also use the same kits and can provide guidance and inspiration in lesson planning. However, they continue that if one of the lesser-known kits is chosen, the teacher will have fewer resources and examples available and have to be more creative in designing their content.

4.4.2.3 Customisable

Participant Three highlights that mechanical versatility is also something to consider when choosing robotics kits. They continued that some of the kits available on the market are robots that are mostly a fixed shape while having some customisable parts. For instance, the robot would be in the shape of a dog or a car, with only the wheels being changeable. While these kits teach students valuable concepts such as angles and speed when coding the robot to move to a specific location, mechanical design concepts are often neglected. Instead, Participant Three recommended choosing a robotics kit with diverse parts so many different shapes can be built to achieve different goals. This would ensure that the student's creative thinking skills are developed more extensively for their robot design would also be part of their solution to a challenge.

4.4.2.4 Versatile

Participant One commented that the chosen kit has to be scaffolded. This means that a kit should be useful to different levels of competence to ensure that the same kit can be used to teach different grades. If a new, more advanced kit has to be bought for every year group, it can become quite expensive. Participant Two agreed that scaffolding is one of the robotics kit's most important attributes. Even though LEGO is very versatile in that regard, other cheaper options can also be used for multiple age groups. Participant Seven agreed that scaffolded complexity coincides with a versatile design to some extent. If the robotics kit allows many different shapes to be built, the number of possible lessons to be taught with the same kit increases.

Participant One also mentioned that another attribute of the robotics kit's versatility is whether it can be coded with more than one coding platform. They continued that it is useful if the kit can be coded with block-based and line-based coding software to allow scaffolded complexity. Participants Three and Seven agreed with this statement, adding that the LEGO Spike sets, for instance, allow for versatile complexity. Those robots can be programmed with simple drag-and-drop block-based coding in Scratch and the LEGO App and also allow more complex code to be created with the Raspberry Pi Build HAT extension to enable collaboration between LEGO Education and Raspberry Pi. Participant Eleven agreed that a great advantage of LEGO kits is that they can be coded with the block-based LEGO app and line-based Python platforms.

4.4.2.5 Compatible with computing device

Participant One added that the kits would also have to be compatible with the specific computing device that might already be available at the school. Participant Seven also mentioned that the robot should be compatible with the available computing devices; in their case, only some robots were compatible with the Chromebooks used at their school. Participant Five explained that if the robots connect to the computing device through Bluetooth, it could only be considered if the available computing device has Bluetooth capabilities.

4.4.2.6 Robust

Participant Seven offered that the robot must be durable and not break easily, for too much time is lost on fixing faulty robots, taking away from the student's time with the robot. Participants Nine and Eleven agreed that, especially with young, foundation phase students, the robustness of the robot is non-negotiable. Participant Ten agreed, saying that in the foundation phase, students should work with robots that do not easily break when handled roughly.

4.4.2.7 Not hazardous

Participant Five mentioned that an important consideration for young (grades R to three) students is that the kit should not contain small parts to ensure safe use. Participant Ten agreed that in the foundation phase, students should work with robots that do not contain small parts that could be hazardous to small children.

4.4.2.8 Battery life

Another attribute of the robot that should be considered is its battery life. If there are not enough electricity points or a suitable charging spot in the robotics classroom, the kits will have to be charged elsewhere, and then their use in the class will be limited to the number of hours of battery life. Participant Eleven mentioned that the reality of loadshedding suggests that the robot should preferably have a long battery life to minimise the complexity of planning and managing the charging of the various devices.

4.4.2.9 Number of students

Participant Five offered that the number of students to be taught in the Coding and Robotics class at once will need to be considered when choosing a kit. They feel that, ideally, they would want two learners to work on one kit, which would be expensive to afford that many kits for a big class. Participant Five found that if four or more students work in a group, some learners lose interest and do not participate. Participant Seven agreed that sharing the robot to mitigate the financial impact is challenging, for more than three students per kit is ineffective.

4.4.2.10 Connectivity requirements

Another attribute that should be considered is whether the specific robotics kit can be coded with offline applications. Participant One added that if there is no suitable Wi-Fi available in the classroom to support online coding, the coding application can be downloaded beforehand and used offline with the robot, presuming the robot supports these applications.

4.4.3 Robotics table as artefact

Participant One also mentioned that another resource they often use in the class is the robotics table with the missions map for the First LEGO League challenges. This consists of the LEGO mat laid out on the flat table to allow the students to complete the specific missions with the LEGO robot on the map and practice for the First LEGO League competitions. An example of a First LEGO League robotics table is displayed in Figure 4.2

FIGURE 4.2: *First LEGO League robotics table (First SA, n.d.).*

Participant Two also commented on the usefulness of the robotics table, which allows students to practice for the specific activities encountered at the First LEGO League. Participant Two emphasised that the most critical attribute of the robotics table is that it has a small lip around the edge, which is vital to keep the robots safe. They continued that the students sometimes make mistakes with the coding of the robots, which could steer them off the table's edge. If there is no obstruction on the edge, the robots can fall to the ground and break easily, which could be very costly.

Participant Eleven emphasised the value of having a robotics table. They continued that severe breakages are prevented by only allowing students to build and run the wheeled robots that can move around on the robotics tables. They insisted that even if the LEGO tables with the activity mat are not used, any table with raised walls on the side can be used. They continued that if a table with a raised edge is not available, they would recommend rather working on the floor than risking the robots falling off a regular table. However, managing all the parts in the kit could be challenging when building on the floor because some kits have many small parts that can easily get lost.

Participants Three and Five also agreed on the practical usefulness of the robotics table's raised edge in ensuring all the small parts in the robotics kit stay together without falling off the table's edge. The use of the table helps manage parts, which could be challenging if the kit has many complex parts.

Participant Nine offered that another mat or surface effectively used in Coding and Robotics education, besides the LEGO mat with the mapped challenges, is a grid mat. It is a large grid, similar to a chess board, that can be used to orient specific movements. The students can play games where they instruct or "code" each other to perform certain movements. For instance, they can design a sequence of movements to guide the student from one tile location on the map to another tile location while avoiding certain obstacles placed on the mat. Participant Nine continued that these exercises effectively teach spatial awareness, sequencing of instructions, collaboration and communication skills without relying on sophisticated infrastructure. Participant Eleven suggested that drawing grids on the floor with masking tape or chalk can also work to create a reference for certain actions to be performed.

4.4.4 Limited availability of robotics kits

Participant One offered that multiple online educational games can be used to teach Coding and Robotics concepts and lessons without the need for a robotics kit. They mentioned that they used the Bee-Bot online emulator, Scratch, and the TANKS Coding App to introduce the students to relevant concepts before acquiring the robotics kits. However, they insisted that it is vital to eventually give the students access to robots and argued the impact of tangible Coding and Robotics teaching tools. They added that they had seen students more engaged when they could practically interact with their code's feedback. Participant Two agreed with this comment, offering that they teach their students general computer skills and coding concepts before introducing them to the robotics side of the subject. Participant Three agreed that the Coding and Robotics concepts could be introduced through online simulators and unplugged games before the students get to work with the robotics kits. Participant Nine agreed with this statement, advocating for their Tangible Africa application solutions that do not need the availability of a robotics kit. Participant Ten offered that before they could afford to buy the tangible robotics kits, they used the Micro:bit online simulator. They admitted that it was more challenging to keep the students engaged with the content than when they could have the physical robot performing the actions, but suggested it as a cost-effective alternative. They continued that these online simulators are a good solution as long as there is stable Wi-Fi available, for the students should preferably not work in groups larger than two. This means that many computing devices that all need an internet connection to run the simulations will be in use at once.

There are various coding environments available that could be used to teach the coding concepts in the subject. Participant One mentioned that they use block coding methods to teach the kids the basic coding concepts without having to learn the specific syntax of a particular line-based coding language. Their students use Scratch to code the robots and use the Blockly coding environment. Participant Two mentioned that they also use online coding environments to introduce the students to coding concepts. They guide the students through Minecraft coding tutorials before introducing them to Scratch block-based coding. Participant Five also uses the Minecraft Education Edition to teach the grade four to nine students coding concepts by having them complete challenges with the agent. The agent is the simulated "robot" that performs certain programmable tasks in Minecraft. This activity, however, requires all the students to have devices with a stable internet connection to log in. Participant Eleven also offered that their students used the Apple Swift Playground to complete coding challenges and tutorials to introduce them to coding concepts.

4.5 Curriculum

The participants were asked to present their perspectives on the lesson plan they followed for the subject of Coding and Robotics. Their experiences and recommendations for the curriculum are presented here.

4.5.1 Participants' experiences on the lesson plan they followed

The participants agreed that teachers who wish to start teaching the subject are allowed the freedom of choosing their own content due to the subject not yet being a formal requirement of the national curricula. They offered that the aim of the subject should be to equip students with skills they would need in their future workplaces but that there are various sources of lesson plans.

A Coding and Robotics lesson plan could be bought from an external robotics education provider that develops programs for a school to implement. The teacher could also design their own lesson plan by accessing online resources and following examples from online communities that share an interest in the subject. Some robotics kits also provide supporting resources and tutorials that could be used as a lesson plan. Finally, the Coding and Robotics CAPS draft could be used as inspiration for activity design, while the final CAPS has yet to be finalised.

Participant One offered that they intentionally started teaching Coding and Robotics at their school before the subject was officially included in the national curriculum to allow themselves and their students a chance to get familiar with the subject. Participant One also added that they wanted to take advantage of the fact that they were not yet expected to follow the CAPS curriculum for the subject and could choose what they presented to the students. Participant One said that they wanted the exposure they gave their students to be more technologically sophisticated than the content suggested in the CAPS draft. Participant One introduced the subject by teaching the grade four to seven students the same simple lessons at first, for those students had no previous experience with the subject. However, after the first year, the older students who had exposure to the subject were taught a scaffolded lesson plan while the new grade four group started with the simple lesson plan again. The Cubroid robots and LEGO robots had accompanying lessons that Participant One used as inspiration at first to start designing activities for the students. Participant One teaches the younger students using only block-based coding environments to allow them to master the concepts without spending much time on debugging. The grade seven students are introduced to basic line-based coding, but the focus is still more on the developed higher-order thinking skills.

Participant Two discussed the content themes that they covered with their students. They integrated Coding and Robotics with a subject they previously called Digital Literacy. Therefore, they still included some digital literacy skills in the Coding and Robotics lesson plan. They argued that students nowadays are very savvy with smartphones and tablets but lack basic computer skills that will still be needed in the workplace. In the first term, they cover general computer skills; in the second term, they teach cybersafety and cyberbullying. The third term introduces coding concepts and block-coding exercises; in the fourth term, they use the LEGO EV3 Mindstorms and the LEGO Spike Primes to teach robotics. With the robotics content covered in the fourth term, they try to teach the mechanical part of building and assembling the robot for a specific task by incorporating geometry skills and tying the activity to concepts such as angles, distance, speed, the circumference of the wheels and so forth.

Participant Three offered that they currently follow the lesson examples provided with the LEGO kits but also supplement the activities with challenges of their own design to make it more complex.

Participant Five explained that they designed their curriculum based on the United Nations Sustainable Development Goals to ensure that the 21st-century skills taught to the students are relevant. They follow a project-based learning approach to allow creative problem-solving opportunities rather than having all students memorise the same pieces of information often found in traditional education designs.

Participant Nine offered that through the design of their Coding and Robotics lessons at Tangible Africa, they aimed to focus on digital design, problem-solving, communication and computational thinking skills. They explained that these 21st-century skills are vital to prepare students for their future workplaces.

Participant Ten said they are currently using the tutorials available with the LEGO kits. However, they agreed that careful scaffolding would be vital once they become more experienced and the students outgrow the current lesson plan.

4.5.2 Curriculum considerations

The participants were asked to make suggestions of attributes of the curriculum that should be considered for the subject of Coding and Robotics.

4.5.2.1 Scaffolded

The participants agreed that the most important consideration of the curriculum is that it should be carefully scaffolded. Participant Five suggested that the curriculum will have to be cleverly designed to ensure that the student and the teacher, especially an inexperienced teacher, can keep up with the pace of increasing complexity. Participant Seven feels that careful scaffolding is crucial to ensure that the student's attention is maintained by keeping them engaged with new challenges without losing their interest by advancing too quickly. For instance, starting with computational thinking skills, progressing to block coding and finally attempting line coding is much more effective than immediately expecting students to be engaged by debugging lines of code and correcting syntax.

Participant Eight mentioned that careful scaffolding of their lesson plan is attained by starting with computational thinking skills in grade R, where a small robot is used to program it to move around and achieve specific goals. This robot of theirs does not need to be assembled but only coded through block-based coding platforms. Then, in grade four, the students get introduced to the Micro:bit and in grade five, to the Micro:Bit Car to ensure that the assembly skills are introduced and the coding complexity progresses steadily. However, introducing the subject at first does not mean that everyone has to start at grade one; grade seven students with no prior experience could also be introduced to the beginner robot and block-based coding.

Participant Nine also offered that scaffolding the subject's curriculum poses a challenge. It is crucial to find a balance between the goal of preparing students to pursue advanced technical tertiary education and preparing all students to be digital citizens of the future. They continued that while one wants to ensure students are equipped with as advanced a skill level as possible to stimulate their interest in careers such as Computer Science, it is noteworthy that this remains a mainstream subject that should benefit all students in the country. This suggests that basic skills for their future workplaces should take priority. Participant Nine offered that each school might take the liberty of making minor adjustments to the curriculum to serve the interests of their specific students better. They continued that if students have a particular interest in the topic, a school should consider presenting an advanced extramural robotics club where the curriculum from class can be supplemented.

Participant Eleven offered that they teach Coding and Robotics as a school subject and an extracurricular robotics club to allow the students interested in the subject to train for the First LEGO League and the World Robotics Olympiad. They continued that this double stream method was implemented to make sure that the standard pursued in class is still manageable for all the students, even the ones with little interest in the subject, while creating a space for the interested students to proceed at an advanced pace.

4.5.2.2 Low barrier to entry

Participant Seven mentioned that the course material should consider all students' realistic capabilities. Many students in the country do not have the same basic literacy or digital literacy skills due to unequal education in different communities. This implies CAPS cannot be written for an ideal world case where all the students were equally equipped to be introduced to such new concepts. The curriculum in grades R and one should not start at a level that requires significant background knowledge, for in many cases, those students cannot even count or write their own names yet. Participant Seven suggested that the national curricula should instead state the minimum requirements and allow a school with resource capabilities to supplement the lessons if their students already possess the necessary background skills. Every school will have to apply their own discretion with their capabilities in mind.

4.5.2.3 Sophisticated technology exposure

The participants agreed that the subject should ideally expose students to an advanced level of technology. Participant One understands that a curriculum to be implemented in all public schools in SA cannot rely heavily on the availability of computing devices and robotics kits, for that would exclude many students from having access to Coding and Robotics education. However, they strongly feel that the subject should include a level of practical coding practice and exposure to robots to demonstrate the effects of code in a tactile manner. Participant One added that the fundamental background knowledge and skills involved in Coding and Robotics could be taught using unplugged methods. However, the complexity of the experience that can be achieved will be capped. They continued that they feel the subject will only adequately prepare students for the skills needed in the digitally-driven workplace if they get first-hand experience with computing devices and robotics kits. Participant Three agreed that certain important concepts, such as sequencing, can be taught without sophisticated technology. However, they also insisted that the educational integrity of the complexity of the subject can only be maintained if the students eventually get exposure to electronics and robotics that can allow them to see the feedback of their developed software in real-time. Participant Seven agreed that each school would need to strive toward teaching this subject at an advanced level, for if one wants to stay true to one's word, a subject called Coding and Robotics should actually teach both coding and robotics. They claimed, "If we want to say our kids are learning coding and robotics, there are advanced skills and technology exposure that goes along with it, which need to be the ultimate goal."

4.5.2.4 Unplugged elements

The curriculum should include specific unplugged activities to introduce certain concepts. Participant One offered that the fundamental skills of Coding and Robotics can be taught using unplugged methods. Participant Three mentioned that certain basic coding concepts, such as sequencing and loops, can be taught with unplugged activities.

Participant Five offered some unplugged examples of activities that can be included in the curriculum to make it less technology-reliant. They continued that the 21st-century skills that the subject is trying to teach, such as communication, collaboration, computational thinking and creativity, can all be developed on a fundamental level through specific unplugged activities. This can be done in presentation form, asking students to create a poster or build a prototype product or robot in groups from recycled materials. It would require them to work together, think creatively and communicate with each other and the class. However, they insisted that these unplugged activities will not allow students the authentic experience of the potential the subject has to offer.

Participant Eight agreed that basic concepts could be taught unplugged, for instance, by having the students design and build a board game in groups to develop creative thinking, problem-solving and collaboration skills, among others.

Participant Nine added that many of the concepts that Coding and Robotics aims to teach could be linked to games they are already playing; for instance, Simon Says or Hopscotch or Twister could be used to explain conditional statements and sequencing.

4.5.2.5 Mechanical building aspect

Participant Two suggested that the subject of Coding and Robotics curriculum should not only focus on coding skills but that the mechanical aspect of Robotics should be included. Design thinking and creative thinking skills could be successfully developed if the students are presented with the opportunity to assemble their robotics kits into unique structures as part of their solution to solve specific challenges.

4.5.2.6 Carefully curated scope

The range of topics to include in the curriculum should be carefully considered. Participant Six commented on the current draft version of the CAPS Coding and Robotics by suggesting that they think it is not covering the topics in depth, for the scope of the topics is too wide. However, they conceded that this first version of the curriculum was probably designed to cover all the bases and test what is achievable. The final version should include a smaller, more refined range of topics to allow more time to spend on one concept.

Participant Seven also commented on the draft CAPS for Coding and Robotics by stating that the curriculum was too crowded to be realistically implementable. They continued that the number of topics the curriculum aims to cover is not possible if one still wants to ensure enough time is spent for the students to grasp the full extent of the topics. They continued that it may have been possible in an ideal world situation where no time was lost on admin or setup of activities and management of resources, but feels that the DBE will have to prioritise specific topics and exclude others. Participant Seven stated that "digital literacy, digital citizenship, spreadsheet skills, design and technology elements and coding skills are all valuable for a student to learn, but it is not attainable in one subject". Participant Seven feels that the curriculum needs to be realistic in considering the student's capacity.

Participant Eight insisted that the curriculum of Coding and Robotics should not try to cover too broad a spectrum of topics, for then the integrity of the standard will be compromised. They continued that, in their opinion, Coding and Robotics skills should be distinct from ICT or spreadsheet and text editing skills. While all those skills are essential, there is not enough time in the periods that will be allocated to Coding and Robotics to cover all of these topics thoroughly. Participant Eight feels that the subject should aim to expose the students to coding and robotics concepts at an advanced level rather than include other topics that are more relevant to computer literacy, circuit boards, or technology.

Participant Nine agreed that the curriculum should be carefully curated to ensure that it is manageable and that there is enough time spent on specific topics to enable proper mastering of the skills. They continued that students learn at different paces and insisted that there should be ample time for the meaningful grasping of various topics. Participant Nine agreed that the definition of the subject should be carefully determined to ensure the content rings true to the name. They feel that application skills, such as Word and Excel editing, and digital literacy should not be the main focus, "otherwise, the subject should have been called Computer Skills". They feel that only topics and higher-order thinking skills related to coding and robotics activities should be included in this specific subject's curriculum.

4.5.2.7 Continuously updated

The 4IR ensures continuous development in the world of technology and innovation. The subject of Coding and Robotics aims to prepare students for an ever-changing digital workplace of the future, which implies that the content taught in the subject should also be adjusted regularly to stay relevant. Participant Five feels that the basic concepts and thinking skills developed could be constant but emphasises that the content of this curriculum will have to be continuously evaluated and updated to ensure that it still serves its purpose of preparing students for an innovative workplace.

4.5.2.8 21st-Century skills

The participants agreed that the subject's focus should be on developing higher-order thinking skills. Participant One mentioned that computational thinking, problem-solving and critical thinking skills should be prioritised through the challenges completed with the robots. The student's self-confidence should also be developed by allowing them to take the initiative in completing challenges.

Participant Three offered that the main focus of the subject should not be memorising specific facts as in other, more traditional subjects but instead developing problem-solving and computational thinking skills through completing challenges with the robots.

Participant One continued that the aim of the subject should not be to make professional software developers of all the students but rather to lay the foundations to be successful in the digitally-driven workplace by equipping students with the appropriate thinking skills.

Participant Four highlighted that research strongly suggests that a curriculum for young students should not follow the silo approach, where it only focuses on knowledge. They continued that a "well-designed curriculum should include content, skills and being". This means that the knowledge that will be learnt, the skills and practices that will be mastered, as well as the "being" and emotional development of the student should be included in the curriculum. This means that the curriculum cannot only include specific facts and information that need to be recited, activities that need to be completed or thinking skills that need to be developed; it must have all three.

Participant Five mentioned that some of the 21st-century skills that the subject should champion are communication, collaboration, computational thinking and creativity.

Participant Seven suggested that for the foundation phase students, the aim should not necessarily be to teach them computer programming skills but rather lay the foundation for 21st-century skills by teaching higher-order thinking skills such as computational thinking. Participant Seven was adamant that exposure to these topics is much more important at the foundation phase than teaching complex coding skills. Participant Eight agreed that the ways of thinking developed through Coding and Robotics are much more important than the specific coding syntax. These skills, like computational thinking, problem-solving, and pattern recognition, are valuable beyond professions such as Engineering or Software development but are needed in many sectors of the economy. Participant Eight was adamant that, for instance, analytical skills should not be considered an aptitude that a student either does or does not have but that these skills can be developed and mastered through careful curriculum design.

Participant Nine offered that the subject should focus on digital design, problem-solving, communication and computational thinking skills. Participant Nine agreed that in primary school, especially in the foundation phase, the activities of Coding and Robotics should not be angled towards mastering specific programming languages but instead, be seen as opportunities to develop relevant higher-order thinking skills. Participant Nine offered that from their experience lecturing first-year university Computer Science modules, they found that it is not necessarily helpful that the student should already know the specific programming language's rules and syntax when they enter university. It is more important that they possess adequate problem-solving and communication skills. They continued that from this observation, it is imperative that school children be equipped with these skills to pursue tertiary education in technical fields such as Engineering and Computer Science.

4.5.2.9 General coding principles

Participant Eight suggested that the curriculum for Coding and Robotics should not focus on mastering one specific programming language but should instead teach fundamental concepts that could be applied in any language to enable the students to adapt to different coding environments. For instance, concepts such as loops and if-statements will serve the same function in many languages, which makes understanding the concept more important than memorising the syntax in a specific language. They continued that the activities should focus on problems that need to be solved using certain skills. Participant Eight offered that the most important coding concepts that should be taught are decomposition, abstraction and sequencing.

Participant Eleven agreed that the specific programming language taught is less important than ensuring the coding fundamentals and concepts are mastered. If students are equipped to solve any problem by describing the plan with pseudo-code, they can always teach themselves whichever programming language they may need to use in the future. Participant One agreed that the exact coding syntax should not be a point of focus and that basic thinking skills and general coding principles should be pursued in primary school.

4.5.2.10 Pedagogy

Participant Eight suggested that the curriculum should provide pedagogical guidance to the teacher and clearly define the topics that need to be covered. The lesson plan should contain multiple approaches to teach the same content to ensure that different ways of thinking are employed in the activities. Participant Eight continued that the lesson plan should cater to different learning styles and highlight the connection between the developed higher-order thinking skills and the activity performed.

4.5.2.11 Teamwork prioritised

Participant One mentioned that teamwork is an essential skill that Coding and Robotics can address. The subject leans towards group activities and challenges, which creates ideal opportunities for developing communication and teamwork skills.

Participant Four also commented on the importance of peer learning skills. They offered that peer learning is not necessarily a skill that a teacher can teach but rather a subliminal observation and reaction dynamic developed when working with another person. They emphasised how crucial it is to develop these skills by working with other students in a team during the robotics lessons. They continued that teamwork is a fundamental graduate attribute in engineering and technical tertiary qualifications because, in industry, employees will have to work in groups. Therefore, coding and Robotics as a subject can help prepare students for their future studies and workplaces by developing these vital skills in classroom activities.

4.5.2.12 Structured play

Participant One suggested that structured play activities should be used to allow students to solve problems at their own pace and practice creative thinking. Participant One suggested that this subject presents the opportunity to help students think for themselves and be confident in their critical thinking if they are allowed to "figure things out themselves" with minimal interference from the teacher. They continued that the development of higher-order thinking skills should be enabled by facilitating structured play with the students. They insisted that students should be encouraged to think creatively when facing challenges and debugging a particular piece of code rather than the teacher providing all the answers. Participant Three feels that if there is too much prompting or tips in the structure of an activity, the student's creativity could be lost. They continued that it could lead to "cookie-cutter code" where all the students end up with the same code as a solution to a problem, which defeats the purpose of encouraging initiative. Participant Nine offered that, especially with the foundation phase students, the lessons must be designed to enable structured play to ensure that students stay interested and that it remains fun.

Participant Eleven offered that an important aspect of the lesson plan is that it should allow students to learn at different paces. They recommended that the curriculum include frequent structured play instead of traditional teaching methods where the teacher takes the lead by talking through content. Participant Eleven continued that they used the Swift Playground tool to introduce students to coding concepts where they had to complete tutorials. They continued that the self-paced nature of the lessons allowed the teacher to facilitate when the student faced challenges while allowing them the freedom to exceed the average pace if a student had a particular knack for it. They admitted that this self-paced, structured play method might introduce challenges in assessing the students fairly.

4.5.2.13 Relatable

Participant Five commented that the curriculum should be designed to introduce theoretical concepts by connecting them to a real-world context or experience to which the student can relate. Especially for younger students, the lessons should be designed to create an experience or opportunity for the student to observe a phenomenon by performing certain actions with the robots and then connecting that observation to the theoretical explanation for the concept. The curriculum must include the real-world application of a concept and elaborate on the relevance of completing specific projects.

4.5.2.14 Prepare for high school

Participant One offered that Coding and Robotics at the primary school level should equip students with general skills that would be useful in their future workplaces, even if they do not pursue further education in the field. However, the subject should also allow students to make well-informed decisions about pursuing Computer Science-related subjects in high school. It should ultimately prepare them with the basic skills required to pursue tertiary education in technical fields such as Engineering.

4.5.2.15 Avoid discrimination

Participant Six added that the curriculum published by the DBE would only state the minimum requirements for Coding and Robotics but predicts that, as with other subjects, the complexity and sophistication of the subject will be much higher in privileged schools with ample resources and infrastructure. Participant Six continued that while this subject should aim to prepare students for the digital future as best as possible, the benchmark standards required by CAPS cannot be designed in a way that would be discriminating. The reality in SA is that many public schools do not have sophisticated infrastructure or availability of resources, and if the requirements of the subject relied on these technologies, many students would be excluded from the opportunity to be exposed to these concepts. Therefore, Participant Six advocated for a mainly unplugged curriculum that should be supplemented with available resources as much as possible but admits that from the intermediate phase, the subject should introduce exposure to digital devices to meet the learning outcomes.

4.5.2.16 Assessment requirements

Participant One also commented on the assessment of Coding and Robotics. They mentioned that they personally enjoyed the unstructured way they presented the activities to allow the students to learn and explore in a creative, stress-free environment. Participant One continued that they are sceptical about the effects that assessment in the subject will have on the student's performance. They admitted that it is essential to ascertain whether a student has mastered a specific skill, but feel that assessment should be approached creatively in a subject such as Coding and Robotics so as not to ruin the element of fun that often keeps the student's interest. Participant One is adamant that the goal of the subject should be to develop computational thinking, problem-solving and critical thinking skills in the student rather than incentivising students to follow specific instructions with the robot. They continued that group-work skills and self-confidence should be cultivated. Participant One found that the students are afraid of taking risks and making mistakes and often give up quickly, especially since they struggle to work together after being isolated during the COVID lockdown. This is why Participant One wishes to avoid traditional assessment methods to prevent extra pressure on the students.

Participant Six agreed that one of the biggest challenges with a subject such as Coding and Robotics is developing assessment standards to determine the student's ability. As much as each school will have to adjust and improvise their own approach to introducing the subject, as soon as it is officially included in the national curriculum, there will have to be certain universal learning outcomes and standards to measure whether a student has mastered the adequate skills to progress to the next academic grade. These assessment methods will be the benchmark of knowledge that a student must have at a certain grade level but do not limit the school from teaching skills beyond the benchmark complexity. Participant Six suggested that project-based assessment be included to allow creativity and play but still have measurable skills that should be displayed to complete the project.

Participant Eleven also commented on the challenge of assessing the subject meaningfully. They continued that the aim of developing a piece of software is for a specific function to be executed successfully, which suggests a simple pass-or-fail assessment method; however, that is not how school works. They continued that what they are currently doing is having the students complete a certain project and then marking on a rubric the concepts they mastered through that project. They would, for instance, look for specific actions that the student should have made the robot perform and give a mark if each of those actions was performed, regardless of the specific code they used. They wish to encourage students to find unique ways of completing challenges rather than copying their classmate's code and submitting that. They also have an assessment section for self-reflection where the student should comment on what they learned through the activity. They are required to comment on aspects like what obstacles they faced, what they would do differently in future projects and what the real-world application of the particular challenge could be outside of the classroom. Assessing specific actions performed with the robot is more straightforward than establishing whether the student developed specific higher-order thinking skills. Participant Eleven commented on the method of observation as assessment, where the students proceed with a certain challenge while the teacher moves between the students, observing whether they are exhibiting specific skills or ways of thinking through the completion of their activities. Participant Eleven feels that while there is space to explore this method, the time frame does not allow it at the moment. They would not manage to observe all 35 students in every class fairly while managing the classroom and assisting with challenges if each class only has the subject for one hour per week.

4.5.3 Integration with other subjects

Specific higher-order thinking skills that Coding and Robotics aims to develop could be taught in other subjects as well. This implies that there could be a collaboration between the subjects to reach a common goal of teaching relevant skills. The suggestion to introduce Coding and Robotics into other school subjects is explored.

Participant One agreed that there is value in moving away from the silo educational approach and having more interaction between the subjects. They continued that Coding and Robotics is a subject that can be interconnected with other subjects and integrated into other lessons. However, Participant One argued that the reality of training and educating one teacher in their school was challenging enough; having to train all the other disciplines' teachers to the extent where they could incorporate Coding and Robotics lessons into their course material would be a timely process. They continued that this would definitely not be attainable in the initial introduction of Coding and Robotics to a school. They admitted that after the subject has been included in the curriculum for a few years and pre-service teachers start being trained in the subject as well, it would be much easier for all teachers to include Coding and Robotics lessons and concepts in their respective subjects. All the teachers will need to be trained and competent to ensure that the subject's concepts are taught effectively.

Participant Two added that they were lucky to already have a timeslot in their school's timetable allocated to Digital Literacy, which made it much easier to integrate the introduction of Coding and Robotics with that subject. Integrating Coding and Robotics with Digital Literacy also avoided the problem of having to train non-digitally literate teachers to present the subject, for the Digital Literacy teachers were already comfortable with using computing devices.

Participant Three feels that the possibility of integrating Coding and Robotics content into other subjects would depend on the topics included in the curriculum. They admitted that the feasibility of such an endeavour would very much rely on the content and learning outcomes that are ultimately defined for Coding and Robotics. They agreed that the subject should incorporate a high level of technological sophistication, keeping in line with the aim of preparing students for future workplaces that would often also require high digital competence. With this goal in mind, learning outcomes like computer literacy and coding skills would be the focus, which is reliant on the availability of computing devices. For example, the concept of spreadsheet design, as suggested by the draft CAPS, could easily be incorporated into Mathematics lessons. However, it would require the students to access computing devices in the Mathematics classroom. They speculated that if the aim of Coding and Robotics is watered down to simply communicating basic concepts and thinking skills with the students without advanced technology, it would be possible to integrate into other subjects. For instance, the topic of sequencing could be incorporated into a subject such as English. This could be done by having students do an oral presentation describing a food recipe in the steps that follow one another in the same way that a developed program is structured in an intentional sequence of commands to achieve a goal successfully. Participant Three conceded that the basic introductory concepts of Coding and Robotics could be introduced in other subjects but remains convinced that the desired sophisticated technological exposure to robots and software development will only be possible in its own timeslot.

4.6 Support network

The support network refers to the people, other than the teacher, directly influencing the success of Coding and Robotics implementation in a school. The participants were asked to comment on the members of the support network and the extent of their influence.

4.6.1 School management

Participant One insisted that the support of the school management is crucial. They continued that the principal and School Governing Body had to be on board for this subject to be launched. They admitted that the school budget is controlled mainly by the school management, making it challenging for a teacher to attempt to introduce the subject without the funding allocated by the school management. Participant Three offered that the School Governing Body, consisting of representatives chosen by the parents, usually has considerable sway over how the funds are allocated in a quintile five school. This allows them to influence the opportunity for Coding and Robotics to be introduced in the school. Participant Ten agrees on the importance of having the principal and school governing body support the inclusion of the subject. They offered that these management agents control the funds, which greatly influences the manner in and approach with which the subject will be presented. Participant Three continued that the school management team, including the principal, allows and enables the teacher to attend training courses for the Coding and Robotics subject, which would not be possible without their permission and funding. Participant Five agreed that if the school management does not actively support a teacher's enthusiasm to introduce the subject, the teacher can still include the concepts and basic skills in their classes. However, it will not be sustainably scaffolded learning, for the initiative will stay in that one class. On the other hand, if the school management supports school-wide inclusion of the subject or concepts, it will allow the students to learn the aimed skills progressively. Participant Seven agreed that the school management's support would determine whether the subject is prioritised and whether it successfully becomes part of the school-wide policy to present quality Coding and Robotics education.

Participant Eight offered that school management is crucial in facilitating the change management involved with sustainably introducing the subject. They continued that if one has a change leader at the school who is negative about the subject, it will not be implemented optimally, if at all. Therefore, it is crucial that the school management is on board; for it to be a positive introduction, one needs positive change agents. Participant Eight offered that often the teacher is the change agent that tries to instigate the introduction of the subject, but continues that without the school management's support it will not be sustainable change. Participant Nine offered that they had often experienced that the principal's personal priorities have a significant effect on what initiatives are sustained in a school. For example, if the principal does not support the inclusion of the subject, an enthusiastic teacher will probably not achieve much.

Participant Six also mentioned that the school secretary could be considered a gatekeeper or enabler of the process of Coding and Robotics implementation, for many stakeholders contacting the school to suggest possible collaborations would make contact with the secretary first before presenting their case to the principal and School Governing Body. This means that the secretary could also be considered a player who needs to be informed and on board with the school management's decisions regarding Coding and Robotics introduction.

4.6.2 IT support

The participants agreed that IT support at a school is vital to ensure that the subject is presented properly.

Participant One offered that their school has an IT staff member responsible for maintaining the school's hardware and software infrastructure. Participant One admitted that it takes considerable pressure off the teacher to have a separate staff member responsible for fixing certain technical difficulties and updating software and hardware infrastructure. This allows the teacher to focus on the preparation of lessons and instruction of the students. However, they continued that they feel the staff member has to be on-site to ensure that problems can be fixed immediately without wasting valuable teaching time due to unforeseen technical difficulties.

Participant Four emphasised that resource management and sustainability are crucial for implementing the Coding and Robotics subject. The Coding and Robotics teacher and the IT support staff will have to take responsibility for the maintenance and safekeeping of the resources.

Participant Five agreed that IT support is crucial for assisting the teacher with technical issues, resource management, and maintenance.

Participant Six agreed that IT support would be very important in the maintenance and management of the resources. However, the teachers should be equipped to solve most of the technical difficulties to not rely too heavily on a staff member that many schools will not be able to afford on-site. Participant Six continued that most no-fee schools will not be able to afford an on-site IT staff member, for all their staff salaries are paid by the government. In that case, the teacher will have to solve most problems and only consult external IT support for specific issues. Participant Seven agreed that IT support is crucial for the subject to be implemented well, but suggests that there could possibly be an appointed IT department in an area that serves all the schools in the area if every school cannot afford their own IT staff member.

Participant Nine also commented on the futility of donating a robotics or computer lab to a school without including a retainer to provide technical support. They continued that they have seen too many labs locked and unused or dysfunctional due to the lack of IT staff to maintain them. Participant Nine also suggested that the schools could be provided with rotating IT staff that service a few schools in the same community. Participant Ten agreed that the IT support does not necessarily have to be a school staff member; a Public-Private support agreement can be arranged where an external company provides the maintenance support to the school. However, Participant Ten offered that the service should not have a long lead time. IT maintenance issues, for instance, faulty Wi-Fi, are a significant hindrance in teaching and should be handled as soon as possible. They continued that their concern is that if the government is providing IT support in the form of one person servicing a group of schools, the waiting period for something to be fixed after it is reported would be too long. Participant Eleven emphasised the importance of the IT support being nimble and responsive to avoid losing a lot of teaching time due to IT support delays. For instance, switching on the generators and UPS systems when loadshedding starts is a vital part of sustaining the flow of teaching, which supports the argument for having support staff on site.

4.6.3 Parents

Participant One offered that the parents are also essential players in successfully implementing the subject. If the introduction of the subject relies on the students being able to bring their own devices to school, the parents will have to be on board.

Participant Three offered that at their school, where Coding and Robotics is introduced as an extracurricular Robotics club, the buy-in from the parents directly affects their children's opportunity to be exposed to the subject and, ultimately, the success of the introduction.

Participant Five added that a lot of the funding for initiatives such as Coding and Robotics comes from supportive parents and alums, emphasising the necessity of having the parents on board to contribute to the cause. Participant Ten continued that the launching of new initiatives in the school is often funded by sponsorships from a subset of parents, which emphasises their importance. Participant

Eleven agreed that they are fortunate enough to have parents who are willing to donate their time as well as their resources to assist the process of including the subject and insists that it is vital to keep the parents in the loop with developments to encourage their involvement. Participant Six added that the parents need to support the inclusion of the subject, for they need to approve the proposed school budget, which might need to include an allocation to the new subject.

Participant Seven offered that at the quintile five school where they worked, they experienced pressure from parents to start teaching Coding and Robotics. They continued that because many of the parents were in professions where Coding and Robotics skills were very present, there was an expectation for their children also to be learning those skills. Participant Seven elaborated that the parents often felt that the teachers were not doing enough. For instance, one parent of a grade three learner asked why his son was not learning Python yet, and the teachers had to explain the steady progression and background skills needed before certain milestones could be reached. Participant Eight agreed that a school ultimately feels pressure to please the parents, making them influencers in the process.

Participant Nine continued that, while there might be a diverse set of parents at any school, they need to buy into the school's teaching philosophy to ensure that they continue to enrol their child in that school. This suggests that the parents need to be on board with the school's implementation strategy for Coding and Robotics. Participant Ten agreed that the parents are vital agents of change, for if they are not on board with what the school is teaching their children, they could move their child to another school.

4.6.4 Teacher peer support

Participant Three offered that an essential inclusion in the support network is the network of Coding and Robotics teachers that provide help and advice to one another. They continued that because the subject is relatively new in the South African context, there is a notable advantage in teachers from different schools supporting each other and offering advice from their respective experiences. Participant Three continued that the platforms where they found the best advice from the Robotics teacher community are WhatsApp and Twitter groups. They highlighted that some of their most valuable news sources on relevant Coding and Robotics related infrastructure are in Twitter "EdTech" conversations. They added that this is especially helpful to a new teacher who is still unfamiliar with the world of Coding and Robotics.

Participant Five agreed on the importance of a peer support network. They offered that when they started teaching Coding and Robotics, they taught themselves most of the basic knowledge by speaking to Robotics teachers from other schools and gathering information from STEM teachers they follow on Twitter. Participant Five emphasised the value of the professional learning network of teachers and stakeholders. They also strongly suggest following relevant Twitter, Facebook and LinkedIn contributors and joining WhatsApp groups of teachers from other schools to share resources and ideas on the subject. Participant Six offered that the competitive mindset between rival or neighbouring schools will have to be set aside for a subject such as Coding and Robotics, where teachers from the same community could benefit from learning from each other.

Participant Seven mentioned that they met other teachers committed to introducing Coding and Robotics to their students at conferences organised by the WCED. They continued that those teachers became an invaluable resource to them by creating a space where ideas and challenges could be shared and discussed. They highly recommend the value of a professional learning community of Coding and Robotics teachers. They continued that it is beneficial for teachers who use the same learning resources to collaborate and offer support.

Participant Nine agreed that it is valuable for teachers to support each other when facing challenges regarding the subject, but it also suggests the value of having a mentor assigned to a group of teachers. They continued that when the teachers are trained, it is valuable to remain in contact with the trainer to ensure they can turn to the trainer for continued assistance. Although these mentors could provide virtual assistance, they can be in different areas; it is more important that they work with the same resources.

Participant Ten agreed that they had firsthand experienced the value of teacher peer support. They continued that their neighbouring primary school has been teaching Coding and Robotics longer than themselves and commented on the value of visiting their classes and learning from their approach. They continued that more affluent schools could provide advice and support to schools that do not have the necessary resources.

Participant Eleven started a cluster teacher support network for all the Coding and Robotics teachers in the area to allow them to discuss mutual challenges and learn from each other. This allows them to share lesson plans and offer solutions to mutual challenges.

4.7 Budget

The participants' different perspectives relating to the budget factor are presented in this section.

Participant One admitted that the technical sophistication they envision for the subject of Coding and Robotics would depend on the availability of funds. The devices and infrastructure required to support this definition of the subject are pretty expensive. Participant One added that they were fortunate enough to have computers, tablets, and installed Wi-Fi already, which is a significant expense. Therefore, they only had to fund the acquisition of the robotics kits. They funded it from the school budget by buying single robots at a time to get started and spreading the expense out over multiple years.

Participant Two offered that the budget would be the most significant constraint due to the expenses related to some factors.

Participant Three admitted that their school budget was a constraint, so they introduced Coding and Robotics as an extracurricular club to minimise the number of robots that had to be acquired initially. They continued that the club members have to pay a quarterly fee, which allows for the acquisition of resources. They admitted that this might exclude some students who cannot afford the fees but continued that this approach was simply taken as a starting point to launch the subject. In the following years, they will start teaching the subject during school hours with the resources collected from the club to allow all students access to the Coding and Robotics subject. They will continue to run the club even after the subject is introduced during school hours to allow the students that are very enthusiastic about these topics to be exposed to more sophisticated challenges than what will be covered in the classroom.

Participant Five explained that they funded the inclusion of their Coding and Robotics initiative through fundraising and financial contributions from supportive community stakeholders and parents. Participant Five mentioned that their Wi-Fi infrastructure was already in place; however, they transformed one of their vocational classes into a robotics lab. They also built two robotics tables and purchased iPads to program the robots. They admitted that one of the most significant expenses was the robotics kits.

Participant Nine offered that the school will have to consider their budget critically to determine what level of technical sophistication they will aim to implement. Participant Nine continued that the CAPS curriculum will probably not require expensive resources because that would exclude too many schools in the country. However, if the school wishes to supplement the CAPS standards, the availability of funds will have a colossal effect on the choice of service provider and resources.

Participant Ten offered that they bought their existing robotics kits from the school budget to start introducing the subject but offered that it would be a slow process to gradually build up resources by buying a few kits and devices every year. They recommended starting small, buying only a few kits in the first year to gradually expand the infrastructure and support necessary to teach the subject, instead of spending a massive amount at once on resources that might not be the best fit for the school.

4.7.1 Elements of Coding and Robotics budget

The participants explained the elements included in the Coding and Robotics budget.

Participant Two continued that infrastructure and artefacts would be the biggest influences in the success of the subject's implementation, and these can be pretty expensive to get in place.

Participant One offered that Wi-Fi, computers, tablets, and robotics kits are the elements incorporated into their Coding and Robotics budget.

Participant Three offered that their budget is mainly spent on acquiring robotics kits. Other expenses include security measures and the robotics tables. They admitted that the budget management is significantly simplified by the fact that the Wi-Fi infrastructure at the school was already in place and did not have to be installed specifically for Coding and Robotics education. They continued that if the Wi-Fi connection still had to be established, the required funds would be much higher. Participant Three continued that they are fortunate enough to also already have computing devices at the school that can be used for Coding and Robotics education.

Participant Five offered that in addition to the Wi-Fi infrastructure and classroom transformation, robotics tables and iPads also had to be bought. However, they agreed that the robotics kits were the most significant expense relating exclusively to Coding and Robotics.

Participant Six continued that most no-fee schools do not have an advanced infrastructure. To equip a school with no electricity, Wi-Fi or computing devices with the necessary infrastructure to teach the subject will be much more expensive than preparing a more fortunate school with a basic infrastructure to teach the subject. This phenomenon might continue to increase disparities between students' educational experiences in SA if not managed carefully.

Participant Seven mentioned that the bulk of their budget went into the installation of Wi-Fi infrastructure, for their Wi-Fi was installed in the entire school. Another considerable expense was purchasing computing devices, the Chromebooks, and robotics kits. They continued that their school tries to mitigate the effect of loadshedding by spending a significant amount of money on an inverter system to keep the Wi-Fi and computer lab running. These costs are not all directly related to Coding and Robotics exclusively but impact the implementation of Coding and Robotics. Participant Seven continued that the training conferences were also a big expense but offered that once the subject is formally included in the national curriculum, the DBE will probably present free training opportunities. The private conferences that a teacher would like to attend if they wish to supplement the complexity beyond the CAPS minimum requirements will require funds. Finally, Participant Seven mentioned that the maintenance of infrastructure and resources is an essential continuous expense. They continued that even if the resources and infrastructure are donated to the school, without the proper funds to maintain or fix broken components, the resources will become redundant and unusable very quickly.

4.7.2 Sources of funding

The participants offered various sources of funding that could support the introduction of the subject of Coding and Robotics.

4.7.2.1 School budget

Participant One offered that they funded the purchases of robotics resources from their school budget. However, they admitted that they could not buy everything at once and suggested that a school spread out the expenses over multiple years to lessen the effect on the budget. Participant Ten agreed that they also gradually acquired resources to distribute the burden on the school budget.

4.7.2.2 External sources

Participant One continued that external funding sources will have to be found if the school budget cannot support the expenses. One option is to apply for a grant. According to Participant One, many grants are available to implement Coding and Robotics. In addition, stakeholders in the community might be willing to make donations as well. Participant Three continued that grants from community stakeholders and donations from parents are an option to supplement these resources. However, then the school might have less control over what resources are acquired. Getting a grant could also be challenging when the school management team is not very enthusiastic, for the principal often has to promote the school as a worthy cause.

Participant Five offered that it is necessary to communicate and encourage support from stakeholders from the community, for they could also help fund the inclusion of the subject. Participant Four admitted that the availability of funds would be a restriction in many schools in SA but offered that many parties from the industry would be willing to help support Coding and Robotics initiatives in a school if the necessary networking is prioritised.

4.7.2.3 Fundraising initiatives

Participant Three offered another option to supplement the school budget through fundraising initiatives, which often also rely on support from school management, for initiatives can only be launched with their permission. Participant Five offered that they paid for the inclusion of Coding and Robotics through fundraising initiatives. They added that though it is possible, an enthusiastic teacher would probably find it challenging to raise funds for such an initiative alone without the school management team's support.

4.7.2.4 Government

Participant Six claimed that there should be financial support from the government to implement this subject once it is officially included in CAPS. The no-fee schools will be offered the most significant financial support and the quintile five schools the least. They continued that these funds, if managed effectively, should be able to equip most schools with the necessary resources to achieve the minimum requirements as will be set out in CAPS. Schools that wish to supplement the CAPS by purchasing sophisticated resources, such as LEGO robots, would need to fund this from their own sources.

4.7.2.5 Robotics club

Participant One suggested introducing the subject as an extracurricular Robotics club. Participant Two suggested that the club members pay a quarterly fee, which allows for acquiring robots and resources. They admitted that this might exclude some students who cannot afford the fees but explained that this approach is a starting point to launch the subject. The resources purchased could be used to introduce the subject during school hours in the future, while the robotics club's resources could be updated to ensure incentives for interested students to continue attending the club.

4.7.3 Restrictive budget

The participants were asked to comment on the scenario where the budget is restrictive and offer solutions to the challenge. In the case of a restrictive budget, certain expenses will have to be prioritised. Their opinions on what the Coding and Robotics budget should be spent are expanded.

The participants agreed that the robotics kits are often a significant expense, especially if there are many students in a class and many kits are required. They suggested that one way to mitigate the challenge of a restrictive budget would be to not buy the required amount of kits at once. Instead, they suggested spreading the acquisition of kits out over a couple of years to limit the effect on the budget. Participant One added that they gradually built up the number of kits they acquired but admitted that the limited number of kits initially required creative activity design from the teacher.

The subject could also be introduced as an extracurricular robotics club to allow only the students interested in the subject to start getting exposure to the content. This would mean that fewer robotics kits and computing devices would be necessary, mitigating a restrictive budget. The school could build up resources until there is enough to teach a whole class full of students.

Participant One offered that the infrastructure is the most expensive factor to get up to standard. Participant One feels that Wi-Fi is one of the most important elements to prioritise. They mentioned that their school already had Wi-Fi infrastructure in place. They offered that it might be too expensive to justify the introduction of the subject if the Wi-Fi still needed to be installed. They continued that the range of their Wi-Fi coverage in their school was expanded gradually, for it was too expensive to do at once. In their case, the main priority for the Coding and Robotics budget was acquiring the robotics kits since the school already had computer and tablet devices available. Participant One argued that if the school still needs computers or robots, they would advise acquiring the computing devices first since online coding and robot simulators can be used until robotics kits can be afforded. In addition, most robots require a computing device to control them, so the robotics kit often cannot be used independently. Participant Seven agrees that the computing device is the most critical resource to purchase first if the budget is restricted.

Participant Three agreed that the Wi-Fi infrastructure would be their first priority before attempting to start the Coding and Robotics inclusion. They continued that computing devices and robotics kits are the next most important acquisitions after Wi-Fi.

Participant Ten offered that under a restrictive budget, they would prioritise connectivity. At their school, most students have their own smartphones that can be used in class as long as the Wi-Fi can support the activities. Participant Eleven also stated that they would prioritise computing devices and internet connection over the other elements if they had a restrictive budget.

Participant Four, however, feels that training the teacher should be the first priority because, without a well-informed teacher who understands the subject's scope and practical necessities, the introduction will not be successful. Participant Nine added that purchasing resources and computing devices would achieve nothing if the staff and teachers are not trained properly, which suggests funds for training need to be prioritised. Participant Nine would even suggest that teacher orientation is the first aspect they would spend their money on if they had limited funds.

Participant Five offered that in the case of a restrictive budget, they would leave out the robotics tables and official LEGO mats and instead design their own activity mats. They would also opt to purchase less expensive robotics kits.

4.8 Conclusion

This chapter described the achievement of RO III, the development of the framework of factors that schools should consider when introducing Coding and Robotics for the first time. These factors are the teacher, infrastructure, artefacts, curriculum, support network and budget. The inputs from the semi-structured interviews with the chosen SMEs expanded the factors into attributes. These attributes serve as descriptors to provide a realistic perspective of the considerations in the SA context. In this chapter, the extracted suggestions from the participants are presented objectively, while in the next chapter, Chapter 5, deducted insights from these interviews are presented.

CHAPTER 5

Interview insights in SA context

Contents

The interviews with the SMEs successfully produced and validated the framework of factors that a school should consider when implementing Coding and Robotics for the first time, as described in Chapter 4. The participants' suggestions were collected into the framework objectively. However, a synthesis of the 1073 minutes of interview recordings also revealed some additional insights into the implementation process, which were explored in pursuit of RO IV. The possibility of certain hierarchies existing among the factors was investigated. The dataset size was too small to deliver definitive conclusions, but the observations are presented to suggest possible hierarchies and relationships between the factors. These observations should be studied further in future work to make conclusive suggestions on the implementation of the subject. The discussions also revealed some challenges to be expected in the SA context. The findings presented in this chapter aim to give a school a more thorough perspective of what to expect when considering the introduction of the subject.

5.1 Relationships and hierarchy among factors

The discussions with the participants revealed the possibility of hierarchical structures among the factors. This possibility was explored by asking the participants various questions to detect these rankings and the influences between the factors. For example, suppose it could be proven that certain factors are more important or influential than others; it could indicate which factors to prioritise in the implementation process. Furthermore, if conclusive influences could be detected among the factors, it could be a guide to the impact of specific factors' states.

This study did not aim to prove conclusive results due to the small sample size of the participants. Instead, this section aims to suggest possible relationships and hierarchical structures that may exist

TABLE 5.1: *Participants' ranking of factors with 6 as most important.*

Participant's Category	Teacher							Education expert		Robotics service provider	
Participant	One	Two	Three	Five	Seven	Ten	Eleven	Four	Nine	Six	Eight
Teacher	5	6	6	6	6	6	5	6	6	3	5
Infrastructure	1	4	3	4	1	4	4	2	3	6	6
Artefacts	2	3	5	3	4	2	3	4	5	1	3
Curriculum	3	1	1	1	2	1	6	5	4	2	4
Support Network	6	2	2	2	3	5	2	3	2	5	1
Budget	4	5	4	5	5	3	1	1	1	4	2

among the factors to inform the reader about their potential existence. These phenomena need to be explored further in future work to validate their existence and the extent of their influence. Conducting detailed surveys among Coding and Robotics practitioners once more schools start teaching the subject could allow meaningful relationships and hierarchies to be defined. Nonetheless, the observations made from this restricted dataset are expanded in this section with possible explanations considered.

5.1.1 Ranking of the factors

The participants were asked to rank the factors in order of decreasing importance. The factor that has the most significant effect on the success of the subject's implementation is considered the most important. In contrast, the factor with the least significant effect on the implementation is considered the least important. The results of the participants' opinions are presented in this subsection. This question was posed to consider the possibility that specific factors might be more influential than others and might be worth prioritising over others in the implementation process.

The participants' ranking of the factors can be seen in Table 5.1. The participants are grouped according to their category to explore the possibility of a certain group of SMEs having a particular bias. The factors are ranked from one to six, with one being the least important and six being the most important factor, according to the participants' perspectives.

Figure 5.1 illustrates the participants' ranking of the six factors. The graph shows that the teacher factor has the most occurrences of the highest ranking, which suggests it is deemed the most influential factor in the Coding and Robotics implementation success. The curriculum factor has the highest occurrence of being ranked least important. The sample size of the data allows limited findings. However, there is some correlation between the participant categories. More than 70% of the teachers ranked the teacher factor as the most important, with the remaining teachers ranking the teacher factor as the second most important. This could be due to their subjective perspective as teachers, which could affect their opinion that their influence in the classroom is the highest contributor to the success of the subject's implementation. 57% of the teachers ranked the curriculum as the least important factor. This could be due to their confidence in their profession, leading them to believe that a motivated, creative teacher should be able to design their own lessons without an available curriculum for the subject. The education experts agreed that the teacher is the most important factor and that the budget is the least important. Their academic perspective on the implementation of the subject could influence their opinions by influencing them to consider the teacher most important. Their dismissal of the budget as least important could also be due to their lack of experience with school management, which could possibly mean they do not grasp the extent of influence that the funding has on the operations of a school. The robotics providers were also in agreement that the infrastructure is the most important factor. This could be due to their bias as robotics solution providers, which requires them to promote the sales of their solutions that might rely on available infrastructure to be implemented.

FIGURE 5.1: *Participants' ranking of factors.*

Figure 5.2 illustrates a box and whiskers display of the factors' ranking with the interquartile range calculated with the inclusive method. From this graph, it is clear that most of the participants ranked the factor of teacher highest, with the low ranking of 3 being a clear outlier. The infrastructure factor has the second-highest average ranking, which suggests it is the second most important. However, it is much lower than the teacher factor and not significantly higher than the other factors, which suggests that its second-place importance could not conclusively be asserted. The wide distribution of the rankings for the factor of budget suggests that more investigation is necessary before a consensus could be reached on the importance of the factor.

Figure 5.3 illustrates the average of the eleven participants' ranking of each factor. It is clear that the teacher factor is considered the most important among the factors. The averages of the other factor rankings are within a close range, which suggests there are no apparent differences between the importance of the factors. However, these findings suggest that the curriculum factor is ranked as the least important of the factors, but further investigation is necessary.

The average of each category of participant's rankings is illustrated in Figure 5.4. The teachers and education experts considered the teacher factor more important than the robotics providers considered it. The teachers and education experts also ranked the infrastructure lower than the robotics providers. However, no further correlation could be detected between the opinions of the participant categories, for the size of the dataset limited the findings.

The possible hierarchical structure of the factors was investigated further by asking the participants if there was a specific factor that could be removed entirely and still allow for the successful implementation of Coding and Robotics. Figure 5.5 shows the responses from the participants when asked which of the factors could be omitted. It is noteworthy that there was no consensus that a specific factor could be completely disregarded when a school is evaluating their situation before implementing Coding and Robotics. A plausible assumption from these responses is that the teacher factor could be considered nonnegotiable because none of the participants selected the teacher factor as omittable.

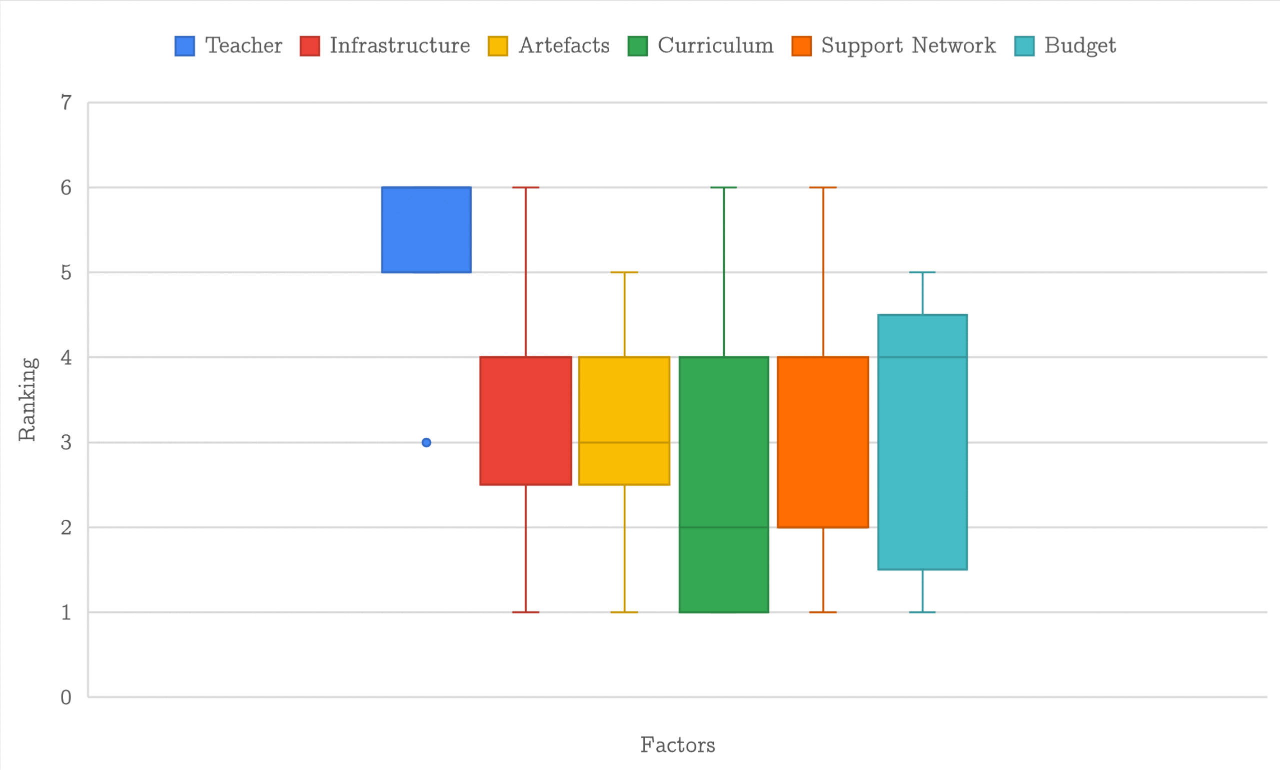


FIGURE 5.2: *Box and whiskers illustration of the ranked factors.*

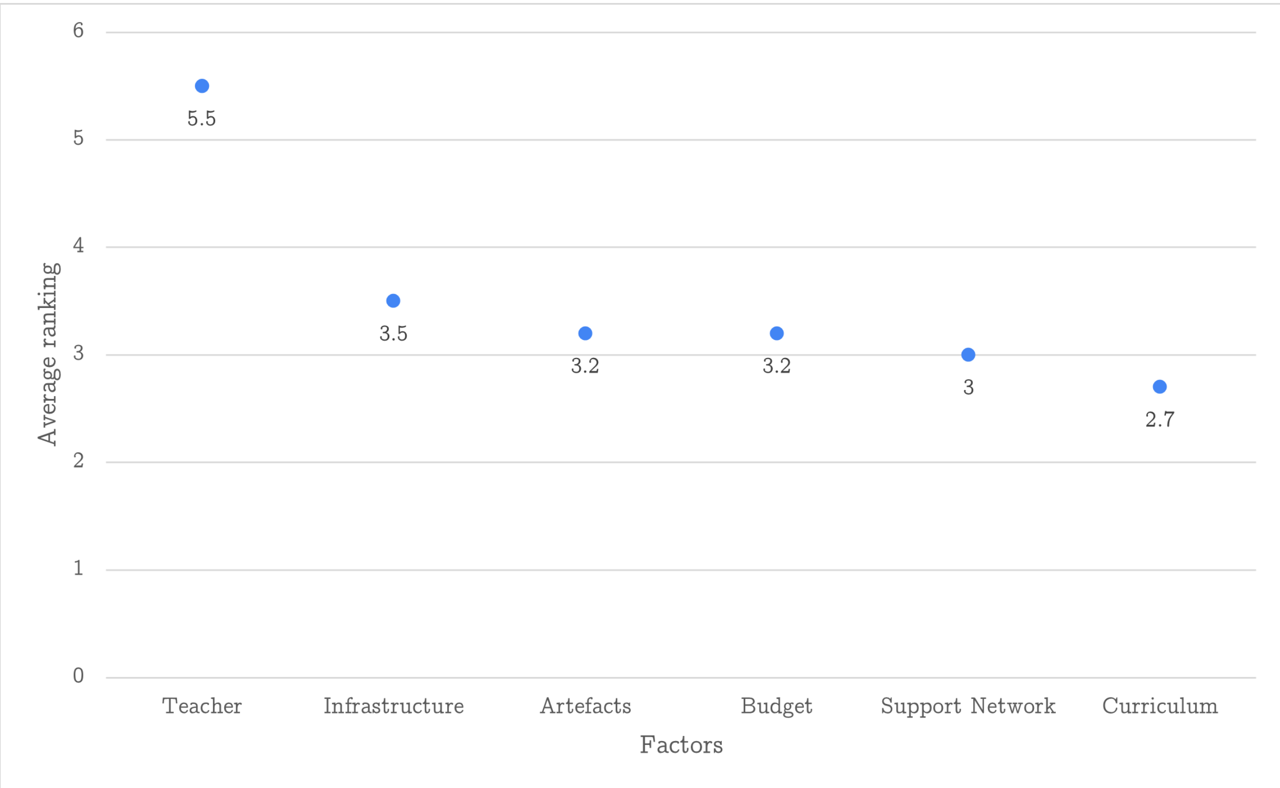


FIGURE 5.3: *Sorted average of all participants' ranking of the factors.*

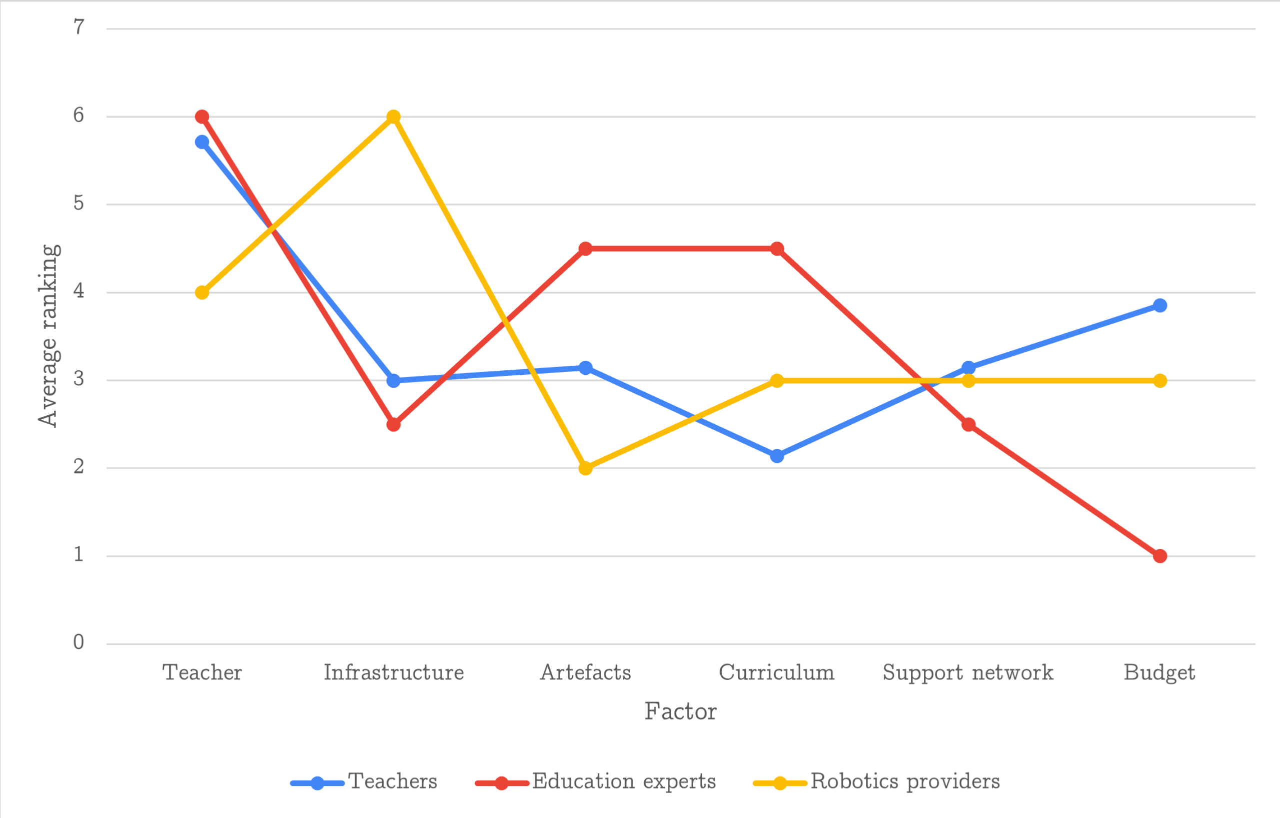


FIGURE 5.4: *Average ranking of the factors per category of participants.*

This assumption was confirmed by asking the participants to indicate the nonnegotiable factor in the subject's implementation process. It was specified that this factor is not simply the most important or influential one but instead crucial to the point where the implementation of the subject will not be successful if this specific factor is in poor condition or absent. Figure 5.6 shows the participants' opinions of which factor could be considered nonnegotiable. Nine of the eleven participants suggested the teacher as this crucial factor.

5.1.1.1 Bias of participants

The participants' opinions should be considered in the context of their professions, work environments and fields of expertise to ensure their opinions are not due to possible bias. Their potential bias is explored as related to their rankings of the factors in Figure 5.4.

The participants that fall in the teacher category ranked the factor of teacher as the most important influence overall in the subject's success. This might be due to their subjective opinion as teachers. They feel that an enthusiastic teacher is nonnegotiable, insisting that all the other factors could be in place, but without the teacher, the subject will not be introduced in a successful and sustainable manner. They also ranked the curriculum as the least important factor for their confidence that a creative teacher will be able to design innovative activities to teach the necessary skills.

The education experts also consider the teacher to be the most important factor. Their area of study in teacher professional development and pedagogy training might influence this conviction. They also ranked the budget as the least important factor. This might be due to their respected position in their field that affords them many connections and possible financial supporters, which might not be the case for all management teams in all schools trying to implement the subject for the first time.

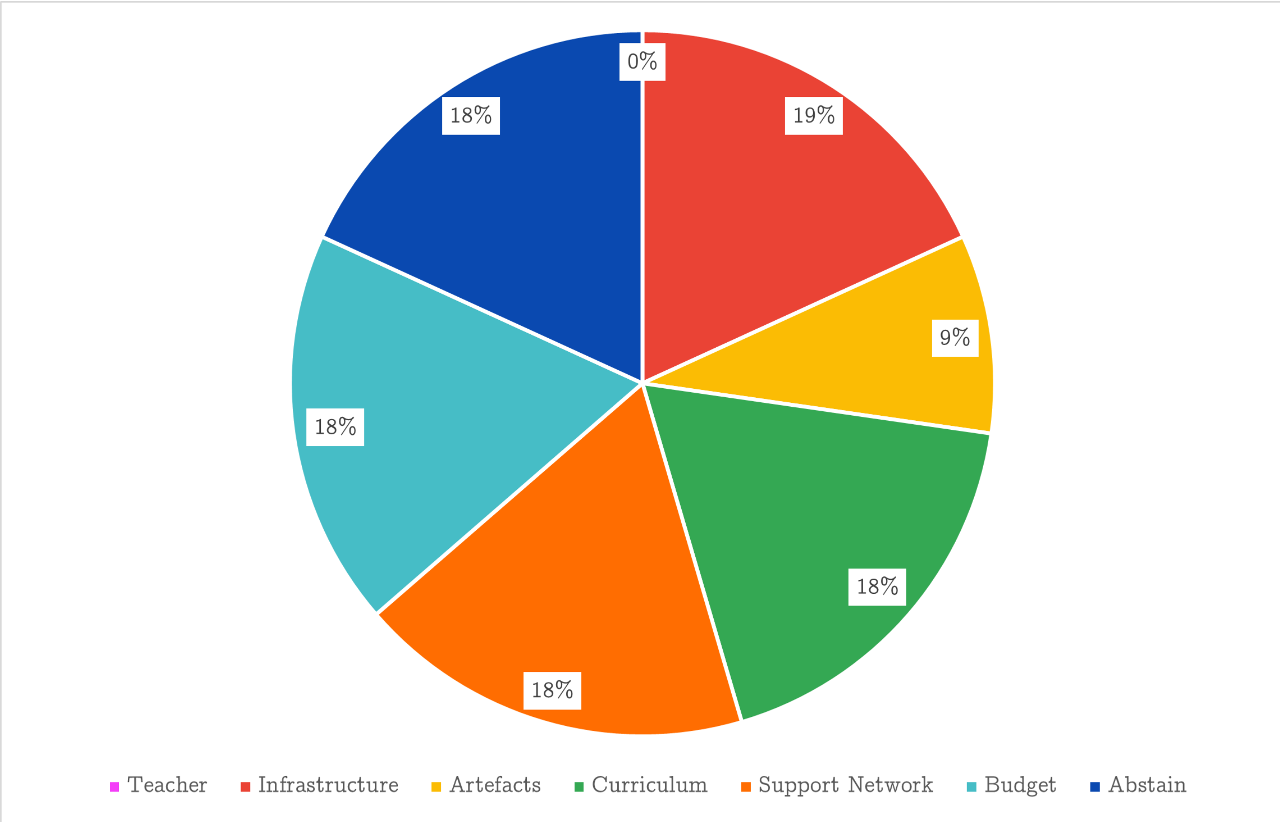


FIGURE 5.5: *Participants' opinions on which factor could be omitted.*

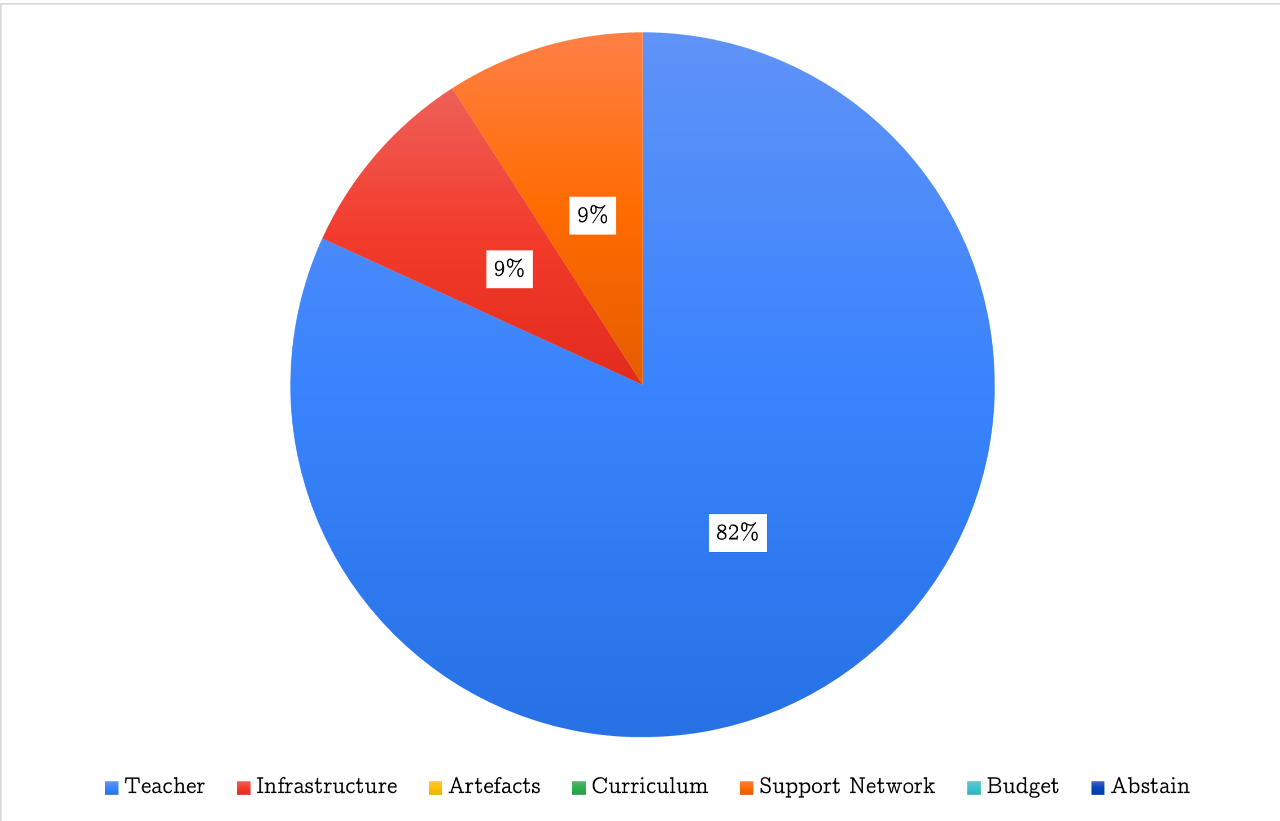


FIGURE 5.6: *Participants' opinions on which factor is nonnegotiable.*

The robotics providers did not rank the teacher as the most important factor as most of the other participants did, but rather the infrastructure. This could be due to their loyalty and faith in the products and teacher training that they offer to schools at their robotics companies. They believe that with proper training and resource material, an inexperienced teacher should be able to teach the subject to primary school students. They consider the infrastructure the most important factor to ensure learning is facilitated in an appropriate classroom. They also ranked the artefacts as the least important. This might be due to their interest in selling their product, which consists of teaching materials containing lesson plans that do not rely heavily on existing teaching tools.

The participants' bias could be eliminated by increasing the sample survey to allow for conclusive findings about the importance of factors to be drawn. However, an extensive sample survey was outside this project's scope due to the low levels of existing Coding and Robotics rollout in SA.

5.1.2 Influence of factors on one another

It was discovered during the interviews with SMEs that the condition of specific factors could influence the implementation strategy by requiring adjustments of other factors. The possibility of relationships existing between the factors and the extent of their influence were explored during the interviews with the participants. If the influence of the different factors could be determined, it could suggest which factors to focus on during the implementation of Coding and Robotics. The relationships between the factors could also suggest areas where there is room for lower performance or where compensation is necessary from a specific factor. The factors could be evaluated individually against a specified benchmark, and the evaluated state of the primary factor could determine adjustments that could be expected in the other factors. The influence of a specific factor could be considered in two contrasting states. The first state is if the factor is evaluated as above average, and the second state is where it is below average. If the primary factor is considered above average, other secondary factors could be afforded slack due to the primary factor surpassing the benchmark. For instance, suppose the teacher factor is considered and evaluated as above average, meaning the teacher is experienced, well-trained, enthusiastic and creative. This could mean the secondary factor of infrastructure could be allowed slack because a creative teacher can still teach the subject successfully even if the facilities are not considered advanced. On the contrary, if a primary factor is ranked below average, it might result in specific secondary factors having to be above average to compensate for the limiting primary factor to ensure that the subject of Coding and Robotics is still implemented successfully. For instance, the primary factor of artefacts could be considered below average because there might not be enough robotics kits available at the school. In that case, the secondary factor of the teacher could compensate for the primary factor's shortcoming because a creative teacher with good classroom management skills will ensure that all students get the necessary technology exposure by facilitating the lessons on a rotational basis.

The relationships between the factors were explored by asking the SMEs what the state of a primary factor could influence secondary factors. The specific state of a primary factor could influence none, one or more than one secondary factor. The participants were asked to suggest which secondary factor or factors they believe would be influenced in a specific way, considering the state of a particular primary factor. The dataset size limits the accuracy of conclusions that could be drawn. However, the observed results are explored in this section.

TABLE 5.2: *Number of participants that consider a secondary factor (columns) to be afforded slack if a primary factor (rows) is considered above average.*

Primary \ Secondary	Teacher	Infrastructure	Artefacts	Curriculum	Support network	Budget	Total
Teacher		6	2	5	6	3	**22**
Infrastructure	1		0	1	3	8	**13**
Artefacts	0	1		1	3	9	**14**
Curriculum	2	2	3		4	2	**13**
Support network	4	5	5	5		7	**26**
Budget	5	8	9	6	7		**35**
Total	**12**	**22**	**19**	**18**	**23**	**29**	

The totals on the right-hand side of Table 5.2 indicate the extent of the influence of each of the above-average primary factors. The most significant findings are explained:

- The highest total for a primary factor's influence is 35 for the budget factor. This suggests that if a school has more than enough money, it allows for the highest total amount of secondary factors that could be afforded slack. This seems a valid prediction since it would not be a deal-breaker if most of the other factors were evaluated as below average. If ample money is available, all those shortcomings could easily be rectified to ensure the successful implementation of the subject.

- The lowest total for a primary factor's influence is the total of 13 for the curriculum and infrastructure factors. This finding suggests that even if the factors of infrastructure and curriculum were considered above average, it would not result in many other factors being allowed slack. It is noteworthy that in the case of an above-average condition of the primary factor of infrastructure, the secondary factor of the budget was considered to be allowed slack by the highest number of participants. This makes sense if one considers that overperforming infrastructure would mean that less money is necessary because there would not be a requirement to invest heavily in the infrastructure, which is often a significant expense.

The totals below Table 5.2 indicate the extent of slack that a secondary factor in the relevant column could be afforded due to the above-average state of primary factors. It gives an indication of how easily the secondary factor is influenced by overperforming primary factors. The most significant observations are discussed:

- The highest total for a secondary factor's allowed slack is 29 for the budget factor. This indicates that if the other factors are considered above average, there is immediate relief of pressure on the amount of money needed. This makes sense, for if the other factors are evaluated to be in good condition, less money would be necessary to update specific resources and ready the school to implement the subject successfully.

- The lowest total for a secondary factor's allowed slack is 12 for the teacher factor. This is also intuitive, for even if all the other factors are considered fantastic, a school should still not slack on the quality or training of the teacher. Allowing a below-average teacher will directly compromise the success of the subject's implementation.

TABLE 5.3: *The number of participants that identified that a secondary factor (columns) would need to be above average to compensate for an underperforming primary factor (rows).*

Primary \ Secondary	Teacher	Infrastructure	Artefacts	Curriculum	Support network	Budget	Total
Teacher		1	4	8	6	5	**24**
Infrastructure	9		4	6	4	6	**29**
Artefacts	10	1		5	2	10	**28**
Curriculum	11	2	4		5	6	**28**
Support network	8	4	7	5		6	**30**
Budget	8	5	5	5	8		**31**
Total	**46**	**13**	**24**	**29**	**25**	**33**	

The numbers in Table 5.3 indicate how many participants identified that a secondary factor would need to be above average to compensate for an underperforming primary factor to ensure that the subject of Coding and Robotics is implemented successfully. If the primary factors on the left-hand side of the table are evaluated as a below-average state, the secondary factors in the columns might be able to compensate for this shortcoming.

The totals on the right-hand side of Table 5.3 indicate the extent of influence a below-average primary factor will have. It suggests the general compensation required from the other secondary factors if the primary factor in the relevant row is underperforming. The most significant observations are expanded:

- The highest total for a primary factor's influence is 31 for the factor of budget. This suggests that if a school has a restricted budget, the other factors must be in top condition to successfully implement the subject. This makes sense because limited funds will not allow many upgrades or purchases to be made; therefore the other factors will have to be above average already.
- The lowest total for a primary factor's influence is the value of 24 for the teacher factor. This suggests that if the teacher factor was considered below average, there is not an extensive resulting requirement for compensation from the other factors. This could be explained by the participants' general conviction that there is little success to be expected from the implementation if the teacher is not up to standard. They feel there is no compensation for a poor teacher because the teacher is nonnegotiable, which could explain why they did not select many secondary factors that could compensate for a teacher's absence or inadequacy.

The totals below Table 5.3 suggest to what extent the secondary factor in a specific column could compensate for below-average states of other primary factors. The most significant observations are discussed:

- The highest total for a secondary factor's compensation ability is 46 for the teacher factor. This is significantly higher than the other factors, which indicates the participants' confidence in the teacher's ability to compensate for a below-average state of most primary factors. This observation is in line with the assumption that a creative, well-trained teacher could still successfully teach the subject under compromised circumstances
- The lowest total for a secondary factor's compensation ability is 13 for the infrastructure factor. This indicates that overperforming infrastructure could rarely compensate for another primary factor's underperformance.

5.2 Challenges faced

The participants were asked to offer their predictions of the most significant challenges a school would face in introducing the subject of Coding and Robotics in the SA context. These include concerns such as time management, the management and limited availability of resources as well as change management challenges. The SA schools' diversity and the availability of teachers to teach the subject were also suggested as challenges.

5.2.1 Time management

Participant One offered that time management is one of the biggest challenges in introducing Coding and Robotics. Many schools do not have an available timeslot in the timetable to include Coding and Robotics. This would require that a period spent on another subject be sacrificed to make time for Coding and Robotics. They continued that one way to counter this challenge would be to introduce the subject as an extramural robotics club. This would allow students genuinely interested in the subject to be exposed to it without demanding time from the already full school hours. Participant Two also offered that adequately preparing students for competitions such as the First LEGO League and World Robotics Olympiad takes a lot of time, more than can be fitted in during school hours. This is why they split their robotics program into two streams: a school period and an extramural robotics club. This ensures that all students are exposed to Coding and Robotics once a week for an hour during school time but also that the students who wish to compete and are very invested in the subject have plenty of training time after school during the robotics club sessions. Participant One argued that while the extracurricular plan could solve certain problems, the subject should preferably be included in the school timetable to ensure all students get a fair chance of kindling their interest in the subject. They continued that if the subject is presented after school hours, it might clash with the sports activities that already take up a lot of afternoon time. Participant One continued that many students who typically focus on sports activities could also have an aptitude for Coding and Robotics and might have to choose between the two interests if they were presented after school hours.

5.2.2 Limited availability of resources

Participant One also mentioned that a common challenge is the shortage of robotics kits. They admitted that acquiring a set of robotics kits would most realistically be achieved over a few years due to the financial impact of buying many kits at once. This would require the teacher to get creative in the class to ensure that all the students are engaged even though there are limited kits available at one time. Participant One explained that before they had many kits available, they had different stations in the class and had different groups of students rotate weekly between the stations. For instance, there would be three activity stations set up in the class at one time. The first station would be where the students would complete a certain challenge with a specific robot; at the second station, another challenge would be completed with another robot; and at the third station, the students would complete coding activities on the desktop computers. Participant One admitted that this method required a lot of classroom management and preparation. The different activities had to be explained and assisted in a space where group work was encouraged, meaning the noise levels were quite high. This resulted in Participant One creating explanation videos or PDF documents explaining the different activities beforehand to allow the students to commence with the activity without having to wait for the teacher to explain activities to all three groups first. This self-paced structure allowed Participant One to walk around the class and facilitate rather than teach at the front of the class and enabled more interactive learning. However, they admit that this only works with a well-disciplined class situation.

Participant Two mentioned that they found the sharing of the same devices for different classes and groups to be a challenge. If one class was busy with a particular activity, the robotics kit had to be disassembled at the end of the class, and the next class had to reassemble it tailored to their particular activity. A lot of time is lost by taking apart and rebuilding the robots every period. This could be mitigated by having all the classes that share a specific robot use it in the same structure.

However, this would inhibit the creativity and design thinking of the student. It would also limit the scaffolding of the curriculum, for it could mean that different year groups need to complete the same activity. Participant Eleven agreed that the building or designing aspect of the subject is neglected when different grades share the same robotics kits. For instance, if the grade fours are busy with an activity that requires them to build and code the robot to lift a ball with a crane structure, the grade fives cannot use the same kits in the next period for an activity that requires a car structure because then the kit will have to be disassembled at the end of every period and reassembled at the beginning of the next. If the period sessions are only one hour long, too much time is wasted on the assembly and management of parts. Participant Eleven continued that they currently have all grades that work with the same robots assemble the robots for a specific operation and then leave them in that form for the different classes to code them in that assembled state. They admitted that this limits the student's creativity, for they do not get to build their own designs to solve the problem, which should be addressed. Participant Eleven continued that in an ideal world, every student would have their own robot that could be stored in its various states of assembly from one period to the next. Participant Two agreed but admitted that acquiring this number of kits would be costly. Participant Eleven suggested the school periods could be longer to allow ample time to reassemble the robot to the specified challenge at the beginning of every session.

Participant Three offered that collaboration between schools could alleviate the challenge of lacking resources. They continued that the sharing of resources and knowledge between fortunate and less fortunate schools could allow schools to present the subject that would not otherwise have the opportunity.

Participant Nine offered that the idea of shared resources at a communal centre could manage to offer students from various schools in a less fortunate community the opportunity to work with resources that one school would not be able to afford alone. They continued that the Science Centre initiative run by the South African Agency for Science and Technology Advancement is an excellent example of how people from rural communities can be granted awareness and exposure to advanced technology at a communal hub. Participant Nine continued that these models could also be followed for Coding and Robotics resources in rural areas, presuming that these hubs are within a reachable distance to allow sufficient access without introducing external transportation challenges.

Participant Six continues that the availability of sophisticated resources would be an influencing factor. While a school should always aim to give the students the best possible education, the aim of the subject should be carefully evaluated. Coding and Robotics, as presented in First World countries and an ideal world scenario in this framework, would prepare students to be future citizens and pursue technical tertiary education such as Engineering. They continued that "Coding and Robotics, as it will probably be presented in CAPS, will not aim to make an engineer of every student, but rather equip them with basic 21st-century skills for their future workplaces, in which case state-of-the-art LEGO robots are not a necessity".

5.2.3 Resource management

Participant One offered that one of the biggest challenges faced in the South African context is the management of resources. The safety and security of the devices and robots would have to be handled strictly. The responsibility for the resources would also have to be assigned to a specific staff member. The risk in the South African context would be that the schools will be equipped with the necessary resources but would go unutilised due to a lack of knowledge and training.

Participant Six agrees that managing resources would be the biggest challenge in SA. They continued that what they have witnessed in many less fortunate schools is that the government would provide resources such as computers, but these resources would be neglected or left unused in a storeroom. This is often due to the teachers and school management not being trained to use or maintain the resources. Participant Six continued that even if schools from all communities are equipped with the necessary resources from the government to start teaching Coding and Robotics, success will only be achieved if the necessary training and empowerment are provided to the staff that need to manage it. Participant Eight agreed that they had experienced mismanagement as an obstacle in implementing the subject. They continued that some schools that received robots as donations or as part of the pilot program for the draft CAPS did not use the resources at all and immediately left it locked up in the safe, for they were not adequately trained or equipped to utilise the resources. Therefore, even if the barrier of resource availability could be overcome, for instance, by the government providing the resources, the teachers and IT staff must be trained as well; otherwise, the attempt to equip the school will be futile.

Participant Six continued that the availability and management of resources could be mitigated by having a communal "teaching hub". This is a centre where all the infrastructure and resources for Coding and Robotics education are set up, and neighbouring schools can come to have their students learn Coding and Robotics at the hub. This hub could be at one of the schools or a community centre, which would relieve the pressure on all schools to acquire and manage resources while still offering students exposure to the subject. Participant Six offered that they also found with their involvement in setting up computer centres in less fortunate communities that security issues and break-ins were much less common when there was buy-in from the community. If all members of the surrounding community benefit from a particular initiative and take ownership of the same centre, the security risk would be much lower than every school having to secure their resources themselves. With the hub system, extracurricular Coding and Robotics programmes could be run, digital literacy training for adults could be offered, and all community members could have an interest and collaboration in the centre. However, the responsibility for funding and staffing management could introduce a challenge in the case where a communal hub is utilised for the teaching of children from multiple schools.

Participant Ten suspects that security and maintenance of the resources will be the biggest challenge in the SA context. They offered that, unfortunately, corruption and mismanagement stand in the way of progress and quality education in many schools in the country. Therefore, they feel that accountability and careful distribution of resources will be critical.

5.2.4 Change management

Participant Eight commented that there needs to be a clear implementation plan to ensure that the subject is sustainably integrated into the school. They continued that even before it becomes a compulsory subject, schools with the necessary means should start to introduce it on a small scale to give themselves a headstart in acquiring resources and setting up the supporting infrastructure. A smaller scale will allow the school to test the model before it is implemented in multiple grades. Participant Eight recommended introducing the subject as an extramural club or only to a few grades first to avoid spending a lot of money on many resources by trying to implement it all at once. They continued that change happens slowly, for many factors influence the implementation of Coding and Robotics. Therefore, the change management strategy should be carefully implemented to ensure that the students, teachers, parents and other stakeholders are on board. Participant Eight claimed, "You need to get buy-in from all relevant parties. Otherwise, you spend millions on robots and never open them." The change management strategy should also include support for the teacher to help them free up the necessary capacity to manage to learn and attempt to teach the new subject. Time will have to be freed up in the teacher's schedule to allow them the opportunity to be trained and familiarised with the content of the new subject.

5.2.5 Diversity of schools in SA

Participant Six offered that the diversity of situations in schools in SA will be the main challenge in implementing the subject. They continued that the curriculum should be defined so that the fundamental learning outcomes can be achieved without the necessity of sophisticated infrastructure to not exclude many schools from giving their students exposure to these vital skills. However, they strongly feel that each school will have to assess their situation and treat their case as unique to supplement the existing national curriculum to as sophisticated a level as possible under their unique circumstances. They conceded that the national benchmark of complexity would probably not be on the level of advancement that one would aim for in an ideal world. However, they suggested that each school give their students the best possible exposure to ensure that future generations are as prepared as possible for 4IR challenges.

Participant Three agreed that the challenge in the South African context would be the diversity of schools in the country. They believe this subject should aim to expose students to a very sophisticated level of technological advancement but admitted that this would have to be filtered down in situations where the resources do not support it. For example, in a community where children's safety and infrastructure quality are generally lacking, funds should be allocated to improving the general education standard instead of acquiring expensive robotics kits. In such a situation, the subject should focus on general computational thinking and critical thinking skills that can be taught with limited to no resources. However, this suggests that the national benchmark of learning outcomes in the CAPS curriculum would probably not meet the desired sophistication required to keep up with the 4IR. Therefore, the onus will land on each school individually to supplement the CAPS curriculum to as much complexity as possible to ensure that each student is given the best possible exposure under the circumstances. This implies that the implementation could rely on the drive of the school staff, which might not result in a sophisticated approach in some schools where teachers and school management lack enthusiasm due to challenging circumstances.

Participant Three was adamant that this subject could benefit all students in SA but admitted that the specific approach would have to be tailored from school to school. They were adamant that there is no "one-size-fits-all" approach to the implementation and that equality vs equity should be kept in mind with this subject. A school should assess their situation critically before deciding how to introduce Coding and Robotics. They continued that the school should be honest about the needs of the students and be realistic about the capabilities of the available resources.

Participant Seven commented on the risk of widening the disparities in education access by a non-uniform approach to the implementation of the subject. The justification for including the subject is complicated, considering the broad spectrum of schools operating in SA. They continued that it is difficult to imagine the feasibility of implementing the subject in a school where students do not have proper water and sanitation facilities or electricity access. In such a case, feeding actions or proper literacy and numeracy teaching would arguably add much more value to students' lives. However, on the other hand, this subject is very relevant, crucial even, to equip students for the inevitable digital innovation of the workplace. Participant Seven added that the enthusiasm and motivation of teachers are often very different in varying teaching environments. A teacher's drive and devotion have a significant impact on the student's education and should not be overlooked as a possible contributor to inequal learning opportunities. The reality of the disparities in schools suggests that privileged schools will, as with most other subjects, be able to present Coding and Robotics on a much higher level from the start than their less affluent counterparts. Participant Seven said this would probably widen the disparities between education access even more, which is unfortunate. However, they agreed that "the subject cannot be ignored or watered down to try and compensate for inequalities that exist for other reasons" and that the ideal-world perspective should be taken to clearly define the starting point, for one has to start somewhere. Even if it means that more privileged schools will present the subject at a higher level than unprivileged schools at first, that would still be worth it if all students benefit from the implementation in a few years.

5.2.6 Availability of teachers

Participant Three is concerned that the availability of teachers with the necessary enthusiasm and digital skills will be limited in the SA context. They continued that the general state of teacher competence in SA does not inspire confidence in the ability of in-service teachers to learn to present a new subject.

Participant Five agreed that the most challenging and vital part of the rollout of the subject would be to ensure that teachers are properly trained and that resources are distributed well. They continued that pre-service, as well as in-service training, will have to be adapted to ensure that the next generation of teachers is equipped to teach Coding and Robotics and that current in-service teachers are empowered and trained to take on the task of the new subject. Ensuring all schools are equipped with resources and infrastructure to support the subject will be challenging. Participant Five was adamant that this challenge can only be overcome by collaboration between different schools and industry partners. They continued that schools will benefit greatly from learning from each other and sharing resources through sustainable partnerships.

Participant Eleven addressed a shortcoming that they suspect could hinder the introduction of Coding and Robotics as a subject in all public schools. They offer that the availability of teachers with adequate technical knowledge to ensure that the complexity of the subject remains on a standard that successfully prepares students to pursue tertiary education in technical fields will be challenging. They suspect that equipping an in-service teacher with adequate content knowledge could be more challenging than training an existing subject matter expert with adequate pedagogical knowledge to empower them to teach. They feel that in an ideal world, the most suitable teacher for this subject would be someone with technical expertise or a qualification such as Engineering or Computer Science with a PGCE to ensure their sound pedagogical knowledge. However, Participant Eleven suspected that the reality of a prospective teacher's salary compared to the compensation offered in the industry only attracts a few interested parties. They continued that equipping enough teachers with adequate content knowledge to ensure that every school in the country can start teaching Coding and Robotics at once when the subject is formally rolled out will be a challenge.

5.3 Conclusion

This chapter presents the additional insights gathered from a synthesis of the validation interviews with the SMEs. These insights were deducted based on a cross-sectional view of the inputs from all the participants. They are captured in pursuit of RO IV to suggest considerations when implementing the subject of Coding and Robotics for the first time. The possibility of hierarchies or relationships between the factors is presented to suggest which factors a school should prioritise. Finally, common challenges that could be faced in the SA context are presented.

CHAPTER 6

Evaluation strategy

Contents

This chapter highlights the evaluation strategy followed in this study to ensure the comprehensiveness and usability of the developed framework to achieve the outcome described by RO V. The evaluation process is divided into two main categories: verification and validation. The evaluation was conducted incrementally to improve the validity and reliability of the framework. The verification and validation of the research process are described in this chapter.

6.1 Verification and validation design

According to Carson (2002), verification of a model refers to the techniques used to assure that the model is correct and meets the specifications and agreed-upon assumptions. Verification processes were performed in this study to ensure that the research objectives were met accurately. Banks (1998) suggests that verification should preferably take place as a continuous process. Therefore, the design of the research methodology ensured continuous checkpoints where the correctness of specific processes could be confirmed. Klügl (2008) offers that a valid model is one that produces reliable results within its experimental frame. Validation aims to prove that a system accurately represents the real-world scenario (Banks, 1998). The validation process in this study was designed to prove the usability of this framework to ensure that it provided an accurate portrayal of the considerations in the South African school context. The validation also occurred at various stages throughout the research.

6.2 Theoretical verification

Theoretical verification was performed by reviewing the literature not only to prove the usefulness of this research but also to support the selection of specific draft factors for the framework.

6.2.1 Relevance of the study

A thematic literature review was conducted as captured in Chapter 2 to prove the relevance and usefulness of this study in the context of the 4IR as described by RO I. The benefits of Coding and Robotics as a subject were highlighted in Sections 2.3.3 by exploring the 21st-century skills students would develop through the successful implementation of the subject. The thematic literature review process was selected to ensure that the scarcity of literature related to Coding and Robotics in the specific context of SA was demonstrated to support the contribution of this research. In addition, the context of SA public schools was researched through literature as elaborated in Section 2.4 to verify that the practical assumptions and suggestions SMEs made about the diversity of schools in the country were supported by existing research.

6.2.2 Inclusion of draft factors

The inclusion of specific factors in the development of the framework was verified by conducting a thematic literature review in Chapter 3 to identify draft factors as the first step of the development process. Literature and policy statements from other countries that already teach Coding and Robotics related subjects (such as Computer Science or Robotics) were studied. This provided a frame of reference to ensure that the considerations suggested by SMEs during the development process were not utterly disparate from the description of similar subjects' implementation. The mentioned differences were noted and verified through the snowball method as discussed in Section 6.3.3.

6.3 SME validation

The development and expansion of the framework of factors were done through inputs gathered from the SMEs. Various evaluation methods were included throughout the process to ensure the accuracy and validity of the gathered data.

6.3.1 Selection of SMEs

The process of finding and curating the selection of participants included in the study required a careful verification process.

The credibility of an SME was verified by following a specific vetting method as described in Section 4.1. Their qualification and relevance to the research were carefully evaluated before including them in the study. Their experience, training, and perceived aptitude, as summarised in Table 4.3, provide credibility as contributors to the study.

The inclusion of a specific SME in the study was also verified by following a snowball approach to the interview process design. As elaborated in Section 4.1, the number of participants was not confirmed before the interview process commenced. Instead, the verified SMEs were asked to suggest other relevant SMEs from their field that could be approached to include in the study. A participant having the approval of a peer in their field provided further proof of the particular participant's suitability for this study.

6.3.2 Inclusion of final factors in framework

The face validity of the included factors was affirmed. Face validation refers to the process where the draft factors, as selected from the literature, were proffered to credible SMEs for them to approve their inclusion Klügl (2008). All eleven participants confirmed the plausibility of the six factors in the framework. Furthermore, none of the participants proposed any additional factors, and they agreed that none of the included factors was redundant.

6.3.3 Expansion of factors

The snowball method that was followed for the interview process, as described in Section 4.1, ensured that continuous verification of the description of each factor was performed. Each participant was presented with the collection of considerations as presented by the preceding participants, which allowed continuous suggestions and approval during the framework's development. The participants had the opportunity to evaluate the extracted opinions of the other participants and either agree or offer an original contribution relating to each topic. The snowball structure resulted in the eventual saturation of unique contributions offered. This saturation verified that each factor was adequately expanded to include as many relevant practical considerations as possible.

6.3.4 Insights on hierarchy and relationships between factors

Internal verification was performed throughout the process of exploring the hierarchical structure of the factors. The participants were asked to rank the factors and explain the influences of the factors on one another. The captured data was continuously verified by considering how each participant's context could bias their opinions. As elaborated in Section 5.1.1.1, this process ensured to some extent that subjective suggestions do not influence the interpretation of the collected primary data. However, it is strongly recommended that the observed ranking and influences of factors as captured in Chapter 5 be confirmed by analysing a larger dataset in future work.

6.3.5 Comprehensiveness and usefulness of the framework

The comprehensiveness and usefulness of the framework were validated through the SME interviews. The snowball method was followed, where the participants were presented with the full collection of factors and attributes as captured up to that point. Then, they were asked to comment on the completeness and usability of the framework. The participants all agreed that the six factors form an encompassing perspective of the considerations of the subject's implementation. They all concurred that the framework provides an accurate overview of the practicalities of Coding and Robotics teaching, validating that the model represents the real world. They also agreed that the framework would be useful in providing a school with perspective when introducing the subject for the first time, as was the intended aim described by RO III. Although the implementation plan and change management strategy required to adjust the school's situation once their position has been determined using this framework was out of the scope of this study, the participants also suggested that a careful strategy be created in future work to ensure success. Participant Nine offered, "This framework will help a school to ask the correct questions to determine where they stand in readiness to introduce Coding and Robotics. However, what the school will be able to do to improve their situation once they determine their position remains to be seen."

6.3.6 Relevance in SA context

The participants were asked to comment on the framework's applicability in the unique South African context. The participants all agreed that the framework adequately presented an accurate perspective of the context in SA schools. They hinted at the financial challenges that might be faced in the SA context.

Participant One agreed that the six factors included in this framework comprehensively describe the considerations an SA school should consider when implementing the subject. Participants Three and Five offered that all the factors included in the framework are relevant to SA. Participant Nine offered that in the SA context, the availability of funds will be the biggest challenge. They continued that this framework adequately describes the factors that should be considered but admitted that the possibilities for adjustment, once these factors have been assessed as sub-standard, will rely on funds, for which this framework did not aim to provide a solution. Participant Nine confirmed that all the important aspects often inquired about in practice are accurately addressed in this framework. Participant Ten agreed that this framework provides an accurate overview of the factors that should be considered. However, they suspect that the artefacts, specifically the robots, will not be as sophisticated as this framework describes them due to a lack of funds in many schools, especially quintile one and two schools. Participant Eleven also approved of the comprehensiveness of the framework but commented that once the school has used this framework to assess their standing in terms of readiness, the primary variable that would enable them to improve the factors with shortcomings in SA will be the availability of money. They continued that they suspect that once this framework has successfully been used as a measuring tool, the solution to the lack of funding will have to be addressed, which also hints at the recommendation for implementation strategy to be developed in future work.

6.4 Publication of related research

The context and relevance of the study, as well as the identification of draft factors from the literature, are captured in an independent publication. In conjunction with this thesis, a paper was presented and published in the SAIIE33 Proceedings titled "Factors that Influence the Success of Coding and Robotics Implementation in South African Schools" (Heyns et al., 2022). The identification process of the draft factors described in this peer-reviewed paper provides further validation of the satisfactory achievement of the outcomes described by ROs I and II.

6.5 Conclusion

Admittedly, no model is ever absolutely validated or verified (Carson, 2002). However, the techniques and processes included in the research design of this study succeeded in ensuring the credibility and plausibility of this developed framework, meeting the requirement set out in RO V. The theoretical verification processes, the SME validation steps and the related publication described in this chapter offer satisfactory evidence that this study met the research objectives accurately. The developed framework provides a trustworthy practical perspective of the factors that a South African public school should consider when implementing the subject of Coding and Robotics for the first time.

CHAPTER 7

Conclusion

Contents

In this chapter, a summary and reflection on the project are presented. A summary of the process of framework development is provided. The contribution documented in each chapter is outlined with a discussion on achieving the designed objectives. The research limitations are presented, and related future work is recommended.

7.1 Research summary

The problem description in Chapter 1 elaborates on the origin of this study. The subject of Coding and Robotics is planned to be introduced to the national curricula in SA from grades R to 9 (Khoza, 2021). However, there is a lack of research available to prepare schools for the practical aspects of introducing the subject in the SA context. Therefore, this study, supported by a Subcommittee B grant from Stellenbosch University, aimed to develop a framework of factors that a school needs to consider when introducing the subject of Coding and Robotics in South Africa.

7.1.1 Project summary

The process of developing the framework is explained in Chapter 4. The draft factors identified from literature in Chapter 3 were used as inputs for the series of interviews for data collection. Interviews were conducted with selected SMEs to populate the framework. The interviews were analysed to extract practical considerations that expand each factor while maintaining the voice of the participants. This expansive collection of considerations is captured in Chapter 4, while the summarised version is presented in this section for convenience. Table 7.1 presents the concise framework of factors with a brief description of the attributes, as established in Chapter 4. The evaluation strategy implemented to verify and validate the framework is elaborated in Chapter 6.

TABLE 7.1: *Framework summary.*

Factor	Attributes
Teacher	**Suitable teacher profile:** A few attributes were suggested to identify an appropriate Coding and Robotics teacher. The teacher must be motivated and enthusiastic about the subject and willing to learn. Basic digital literacy and English literacy are attributes of a suitable teacher. They must be self-confident, adaptable, and passionate about their students' education. They must have logical and mathematical thinking skills and be inquisitive. The teacher must have adequate classroom management skills, and they must have available time and emotional capacity to take on the new subject. A possible identifier of an appropriate teacher is someone with gaming experience. **Teacher training:** Pre-service and in-service training is crucial to ensure teachers are prepared to teach the new subject. Certain attributes were suggested for the training. Training should address misconceptions and stigmas that exist about the subject to ensure all teachers are clear on the definition of the concepts. Training should be continuous, not just a one-time session. A low barrier to entry is vital; the teachers should not be expected to have any basic knowledge of the subject. The training content should be carefully scaffolded to ensure reasonable progress is made. Presenting the training sessions in person has advantages. If possible, the training should include demo lessons, where the teachers can see how students are taught practically. The training content should be relatable to the teacher's point of reference and include pedagogical, technological and content knowledge education.
Infrastructure	**Teaching space:** A suitable teaching space is the most important infrastructure element. The most important feature of a suitable classroom is that it should be spacious, allowing various learning activities to be performed simultaneously. **Safety and security:** Carefully designed security measures are non-negotiable. The participants emphasised the importance of safeguarding the resources against theft or vandalism in the SA context. **Electricity:** Electricity needs will depend on the specific context of the school, but continuous supply and availability of electricity access are crucial to ensure the technological sophistication of the subject. **Wi-Fi:** Internet connection is critical to ensure the complexity of the subject content is maintained. **Computing devices:** There are different options for computing devices that need to be considered depending on the school's needs. **Air-conditioning:** Temperature regulation might be necessary for a room full of desktop computers. **Projector:** A projector can be used to display videos and simulations to the whole class.
Artefacts	**Robotics kit considerations:** Certain considerations were suggested for choosing a robotics kit. The most influential consideration is the cost of the kit. The popularity of the robot is important to ensure a large support community for resource sharing. The kit must be customisable and have changeable parts. The kit's versatility should be considered, meaning the kit must be compatible with different coding platforms to ensure that the complexity of activities can be scaffolded. The kit should also be compatible with the available computing devices at the school. The robot should be robust and not contain hazardous parts to be suitable for younger students. The robot's battery life should be considered, and the ratio of kits to students will determine the number of robots necessary. Another consideration is whether the kit can be programmed with offline applications or if internet connectivity is needed at all times. **Robotics table as an artefact:** The robotics table is useful to ensure the safe use of the robotics kits while also supplying a map of activities around which the lessons can be planned. **Limited availability of robotics kits:** When the necessary number of robotics kits is unavailable, alternative methods can be used to teach the fundamental principles of the subject. Online educational games or simulation environments should be considered.

Table 7.1 continued from previous page

Factor	Attributes
Curriculum	**Examples of lesson plans followed by the participants:** Examples were offered of what lesson plans the participants follow to teach Coding and Robotics. **Curriculum considerations:** Attributes of a suitable Coding and Robotics curriculum were suggested. The curriculum should be carefully scaffolded to ensure reasonable progress is made. The barrier to entry must be low to allow students without background knowledge to learn the content. The lessons should ideally expose students to an advanced level of technology over multiple years to ensure adequate 21st-century skills are developed. Unplugged activities should be included in the curriculum to introduce basic concepts. The curriculum should include a mechanical building aspect to develop creative and design thinking skills. The scope of the concepts should be carefully curated to ensure that the topics can be thoroughly covered. The curriculum should continuously be updated to stay relevant in the context of the 4IR. The focus of the content should be to develop 21st-century skills, not to learn a specific programming language, although general coding principles should be covered. The curriculum should include pedagogical guidance as well as content knowledge. Teamwork should be prioritised in the activities. The lessons should include structured play to allow problem-solving skills to be developed. The content should be relatable to the students; theoretical concepts should be introduced by connecting them to real-world examples. The covered content should equip students with the general skills necessary to pursue further education in these fields. The minimum requirements should not rely on sophisticated technology to avoid discrimination. Content assessment should be approached creatively, not following traditional assessment methods. **Integration with other subjects:** The basic concepts of Coding and Robotics could be introduced in other subject areas, but ensuring sophisticated technology exposure would require the subject to be afforded individual attention.
Support network	**School management:** Support from the principal and school governing body is crucial to ensure the successful implementation of the subject. **IT support:** IT staff are essential for managing and maintaining resources and assisting teachers with technical difficulties. **Parents:** Support from the parents plays an important role in the subject's implementation. **Teacher peer support:** A network of teachers can support one another by sharing challenges and resources.
Budget	**Coding and Robotics budget elements:** Examples of expenses involved with the subject's introduction were offered. The most significant expenses are elements of infrastructure and artefacts. These include Wi-Fi installation and the purchasing of computing devices and robotics kits. The purchasing of an inverter system to combat loadshedding, security measures, teacher training and maintenance expenses were also mentioned. **Sources of funding:** Various sources of funding were presented. The school budget is the most common source of funds, but external sources such as grants or donations could be considered if the school budget is not sufficient. Fundraising initiatives could be launched, or funds allocated from the government could support the inclusion of the subject. If the subject is introduced as an extramural club, membership fees could be used to purchase resources. **Restrictive budget:** In case of a shortage of funds, specific budget elements would need to be prioritised.

The interviews with the SMEs revealed that certain relationships exist between the factors in the framework. Data gathered from the interviews were interpreted in Chapter 5 to explore the possible rankings and influences of the factors on one another. These hierarchies could influence the success of the implementation of the subject by indicating which factors to prioritise under certain conditions. The dataset is not large enough to present conclusive findings, but the possible hierarchies observed were discussed.

7.1.2 Reflection on objectives

The research design discussed in Chapter 1 defined the ROs and methodology of the study.

RO I was achieved in Chapter 2. A literature study was conducted to provide context for the study. Definitions of relevant terms, namely 4IR, Education 4.0 and IoT, were established. The definition and benefits of a STEM-based education were explored. The definition of Coding and Robotics as a subject and the benefits that the subject presents were discussed. Finally, the SA public school context was studied to present a perspective of the unique conditions in the school system.

Chapter 3 presents the accomplishment of RO II. Proposed factors that a school should consider when introducing the subject of Coding and Robotics were identified. Literature and policy statements from countries that already implement Coding and Robotics-related education in schools were studied to present theoretical factors for the framework.

The framework development process described in Chapter 4 achieved RO III. Data collection was performed by interviewing selected SMEs following a snowball method. Their suggestions and experiences were developed into the framework of factors. Finally, each factor was expanded into attributes to present a practical perspective of the considerations when introducing Coding and Robotics in the SA context.

In Chapter 5, further insights from the interviews with SMEs are presented. Although the limited number of participants does not allow conclusive findings, RO IV was met by synthesising the data. Observations were discussed to propose possible hierarchies and relationships that exist between the factors.

Chapter 6 describes the evaluation strategy that was followed throughout this study. RO V was achieved by thoroughly verifying and validating the development of the framework using carefully designed processes. As a result, the framework was confirmed to present a reliable and realistic perspective of the considerations of introducing Coding and Robotics in SA schools. The SMEs agreed that the framework is comprehensive and that the expansion of the factors includes practical aspects to consider.

As the study progressed, the researcher discovered aspects related to this study that would be beneficial to explore in future work. Recommendations for some of these topics are described in Chapter 7 to achieve RO VI.

7.2 Limitations

The limitations discussed in this section are the characteristics that influence the design, methodology or application of the study:

- The first limitation is the time-consuming aspect. A considerable amount of time was spent obtaining ethics clearance for the data gathering. The ethics process was more complex than anticipated because specific gatekeeper permission from various bodies was required. The process of identifying and assembling the group of participants to include in the study also consumed considerable time. The snowball method, encouraging suggestions for future participants by current participants, added credibility to the SMEs but delayed the data-collection process.

- The lack of availability of research regarding the Coding and Robotics curriculum as planned to be included by the DBE is the second limitation. Although the subject was set to be formally included in the national curricula in 2023, to the researcher's knowledge, the available information on the implementation plan at the time of this study (2021-2023) was limited. This study proposed that a sophisticated approach to technology exposure be included in the subject to ensure students are prepared for the digital workplace. However, the researcher suspects this might not be the requirement of the final curriculum to be released in 2023. This discrepancy suggests that the framework developed in this study will have to be used with discretion since it presents a perspective of a more technologically advanced curriculum than is to be expected from CAPS. Schools should preferably supplement the CAPS requirement where possible to ensure students are presented with as advanced an education as possible. This framework is suggested to be used as a perspective to guide a school through considerations when taking an advanced technological approach.

- The number of participants that could provide a practical perspective into Coding and Robotics education in quintile one and two schools was limited. This is due to the subject not yet being an official requirement at the time of this study.
- This study produced a framework of factors that a school should consider to evaluate their situation when attempting to introduce the subject of Coding and Robotics. However, it does not aim to provide an action plan or implementation strategy to follow once the condition of the factors has been considered. Furthermore, this framework does not aim to provide a quantifiable scale or performance metric by which to assess the attributes of each factor; it simply provides an overview of the practical perspectives encountered by SMEs.

These limitations provide the context of the constraints defined for this study. Some of these limitations could be translated into recommendations for future work to ensure that the body of research related to the topic is expanded meaningfully.

7.3 Suggested future work

As established in Chapter 1, this study makes use of mostly qualitative research methods. The information in this study could be used as the basis for future studies that seek quantitative answers to implementing Coding and Robotics in SA schools. The possibilities for future work are discussed in this section:

- This study only presents a framework of "which" factors to consider when implementing the subject but does not suggest "how" to implement it. The development of a change management strategy to ensure that sustainable practices are followed while introducing the subject could provide a valuable contribution.
- Once the DBE releases the final Coding and Robotics curriculum, the development of a quantitative performance metric system by which to measure the attributes of each factor could allow a school to assess their readiness to introduce the subject.
- Once the subject has officially been introduced in the SA school context, case studies should be conducted to investigate the practicalities of presenting the subject in different communities. For example, a collection and comparison between the approaches taken in the different quintile schools could provide valuable insight for a school in a specific scenario.
- The hierarchies and relationships between the factors, as suggested in Chapter 5, need to be studied in depth. The dataset in this study was not large enough to confirm the rankings and influences of the factors on one another. If the ranking and the extent of a specific factor's influence could be confirmed, it could provide valuable insight into which factors to prioritise in the implementation of the subject.

These suggestions are but a few of the possible studies that could be conducted based on the information presented in this thesis.

7.4 Conclusion

This study originated from the DBE's decision to introduce the Coding and Robotics subject in SA schools to equip students with 21st-century skills that will allow them to adapt to the developments of the 4IR. The framework of factors developed in this study provides an overview of considerations that would influence the success of the implementation of the subject in SA primary schools. If these factors could be implemented successfully on the level of technological sophistication described in this study, SA children could be equipped with the skills necessary to thrive in a technology-driven society and workplace.

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APPENDIX A

Ethics clearance

The research approval letters from the Research Ethics Committee of Stellenbosch University for Social, Behavioural and Education Research and the Western Cape Department of Education are illustrated in Figures A.1 and A.2, respectively.

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

CONFIRMATION OF RESEARCH ETHICS APPROVAL

REC: Social, Behavioural and Education Research (SBER) - Initial Application Form

3 May 2022

Project number: 24646

Project Title: Development of framework of factors essential to the optimal implementation of the Coding and Robotics subject in South African schools.

Dear Miss J Heyns

Identified supervisor(s) and/or co-investigator(s):

Prof G Van Rooyen, Dr J Van Eeden

Your REC: Social, Behavioural and Education Research (SBER) - Initial Application Form submitted on 13/04/2022 16:33 was reviewed and approved by the Social, Behavioural and Education Research Ethics Committee (REC: SBE).

Your research ethics approval is valid for the following period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
3 May 2022	2 May 2025

GENERAL COMMENTS PERTAINING TO THIS PROJECT:

INVESTIGATOR RESPONSIBILITIES

1. Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.
2. Your approval is based on the information you provided in your online research ethics application form. If you are required to make amendments to or deviate from the proposal approved by the REC, please contact the REC: SBE office for advice: applyethics@sun.ac.za
3. Always use this project ID number (24646) in all communications with the REC: SBE concerning your project.
4. Please note that the REC has the prerogative and authority to ask further questions, seek additional information, and monitor the conduct of your research and the consent process, where required.

RENEWAL OF RESEARCH BEYOND THE EXPIRATION DATE

You are required to submit a progress report to the REC: SBE before the project approval period expires if renewal of ethics approval is required.

If you have completed your research, you are required to submit a final report to the REC: SBE to close the active REC record for this project.

Project documents approved by the REC:

Document Type	File Name	Date	Version
Proof of permission	Proof of Institutional Permission Request Submitted	24/03/2022	1
Request for permission	INSTITUTIONAL PERMISSION LETTER	27/03/2022	1
Default	COVID-19 strategy	12/04/2022	1
Informed Consent Form	SU HUMANITIES Consent template_online survey	12/04/2022	2
Data collection tool	INTERVIEW GUIDE	12/04/2022	2
Request for permission	Proof of Institutional Permission Request Submitted (1)	12/04/2022	1
Request for permission	Western Cape Goverment Research Application - Heyns J	12/04/2022	1
Research Protocol/Proposal	Heyns, J - Proposal	12/04/2022	2

Page 1 of 4

FIGURE A.1: *Confirmation of Research Ethics Approval from the Research Ethics Committee of Stellenbosch University for Social, Behavioural and Education Research.*

Western Cape Government
Education

Directorate: Research

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

REFERENCE: 20220505-1869
ENQUIRIES: Mr M Kanzi

Ms Jana Heyns

Dear Jana Heyns,

RESEARCH PROPOSAL: AN EXPLORATION OF THE ELEMENT NEEDED TO SUPPORT AN ENABLING FOOD ENVIRONMENT AT EARLY CHILDHOOD DEVELOPMENT CENTERS (ECDC) IN THE WESTERN CAPE PROVINCE SOUTH AFRICA.

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

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **5 May 2022 till 30 September 2022.**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Mr M Kanzi at the contact numbers above quoting the reference number.
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

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

We wish you success in your research.

Kind regards,
Meshack Kanzi
Directorate: Research
DATE: 5 May 2022

1 North Wharf Square, 2 Lower Loop Street,
Foreshore, Cape Town 8001
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Private Bag X 9114, Cape Town, 8000
Safe Schools: 0800 45 46 47
wcedonline.westerncape.gov.za

FIGURE A.2: *Research approval from Western Cape Department of Education.*