Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2

by

Megan Jean Ranger

Submitted in partial fulfilment of the requirements for the degree

Magister Educationis

in

Computer Integrated Education

in the

Faculty of Education

at the

University of Pretoria

Supervisor: Prof. Ronel Callaghan

Co-supervisor: Annèl van Rooyen

September 2021

Declaration

I Megan Jean Ranger, student number U13247230_declare the following regarding the dissertation titled *Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2:*

1. I understand what plagiarism entails and am aware of the University's policy in this regard.

2. I declare that this dissertation is my own, original work. Where someone else's work was used (whether from a printed source, the internet, or any other source) due acknowledgement was given and reference was made according to departmental requirements.

3. I did not make use of another student's previous work and submitted it as my own.

4. I did not allow and will not allow anyone to copy my work with the intention of presenting it as his or her own work.

Signature: 

Date: 17 September 2021

Ethics clearance certificate

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Education

RESEARCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE	CLEARANCE NUMBER: EDU059/20
DEGREE AND PROJECT	MEd Utilizing Bee-Bot's to facilitate TPACK designed STEAM activities in Grade 2
INVESTIGATOR	Ms Megan Jean Ranger
DEPARTMENT	Science, Mathematics and Technology Education
APPROVAL TO COMMENCE STUDY	10 November 2020
DATE OF CLEARANCE CERTIFICATE	09 September 2021

CHAIRPERSON OF ETHICS COMMITTEE: Prof Funke Omidire

CC

Ms Thandi Mngomezulu
Prof Ronel Callaghan
Ms Annel van Rooyen

This Ethics Clearance Certificate should be read in conjunction with the Integrated Declaration Form (D08) which specifies details regarding:

- Compliance with approved research protocol,
- No significant changes,
- Informed consent/assent,
- Adverse experience or undue risk,
- Registered title, and
- Data storage requirements.

Ethics statement

The author, whose name appears on the title page of this thesis, has obtained, for the research described in this work, the applicable research ethics approval. The author declares that she has observed the ethical standards required in terms of the University of Pretoria's *Code of ethics for researchers and the Policy guidelines for responsible research.*

Dedication

I dedicate this study to my loving family: Carole Ranger, Charles Ranger, Helen Ranger and Nicholas Kennedy. Thank you for supporting me on this journey of being a lifelong learner.

My thanks are due to the One who has made this all possible and steered me on the journey of education.

Acknowledgements

My thanks are due to the following people:

To Prof. Ronel Callaghan, my supervisor who believed in me when others did not. My sincerest appreciation for your endless advice and guidance. Prof. Callaghan, you are an incredible supervisor and excellent mentor. I admire you and thank you for all you have contributed to my study.

To Annèl van Rooyen, my co-supervisor for helping me look at a chapter and see how it can link to the next; for guiding and supporting me with endless enthusiasm.

To Dr Thiru Vandeyar and Dr Fru Vitalis Akuma for your helpful comments during my defence.

Abstract

The study investigated the design of TPACK activities for Grade 2 learners that support the integration of STEAM subjects and develop computational thinking through coding and robotics.

Coding and robotics are relatively new subjects that are taught in schools to help learners to be equipped for the 21st century. Teachers face the challenges of not being able to integrate subjects nor being able to incorporate 21st century and digital skills in the classroom.

A TPACK conceptual framework was developed as a design tool to observe, evaluate and reflect on lessons which integrate STEAM subjects into a single lesson. An action research approach was used across two cycles including four lessons in order to determine whether STEAM subjects could be integrated in a TPACK designed lesson. These lessons integrated STEAM subjects using Bee-Bots through a play-based and project-based approach.

The methodological choice was qualitative as the data gathered was evaluated to determine the meaning and experiences of the participants. The participants included seven learners in Grade 2 in an all-girl private school. The researcher took part in the research as a participatory action research strategy was used. There was an expert reviewer to help ensure the researcher was not biased.

Analysis of the four lessons presented indicate that the TPACK conceptual framework was a meaningful design tool. The learners all improved their coding skills and enjoyed working with the Bee-Bots.

The study shows that utilising Bee-Bots helped to integrate all STEAM subjects in a TPACK designed lesson presented in Grade 2. Six guidelines were developed to help teachers to create their own lessons.

Keywords: Bee-Bots; Coding and Robotics; Computational thinking; STEAM; TPACK; 21st century skills; Digital skills.

Proof of editing

I HATE MISTEAKS

TK LANGUAGE SERVICE

EDITING | PROOFREADING | TRANSLATION

Prof. Dr. Tinus Kühn
+27 82 303 5415 | tinus.kuhn@gmail.com

17 September 2021

TO WHOM IT MAY CONCERN

I, the undersigned, hereby declare that the master's dissertation titled **Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2** by **Megan Jean Ranger** has been edited.

It remains the responsibility of the candidate to effect the recommended changes.

Prof. Tinus Kühn

List of abbreviations

CAPS - Curriculum Assessment Policy Statements

DBE - Department of Basic Education

EDP - Engineering Design Process

IDMEC - Investigate, Design, Make, Evaluate and Communicate

IT- Information Technology

PCK - Pedagogical Content Knowledge

TPACK - Technological, Pedagogical and Content Knowledge

RQ - Research Question

SRQ - Secondary Research Question

STEM - Science, Technology, Engineering and Mathematics

STEAM - Science, Technology, Engineering, Art and Mathematics

UNESCO - The United Nations Educational, Scientific and Cultural Organisation

Table of Contents

List of figures

List of tables

Chapter 1: Introduction

1.1 Introduction

This study investigated the integration of subjects through coding and robotics with Grade 2 learners as participants. Subjects are normally taught in isolation from one another, whilst in real life subjects overlap (Yakman & Hyonyong, 2012). This has given rise to the development of the integration of Science, Technology, Engineering and Mathematics known as STEM teaching (Katzenmeyer & Lawrenz, 2006). Later Yakman and Lee (2012) suggested that Art should be included in the integration of subjects, resulting in Science, Technology, Engineering, Art and Mathematics (hereafter STEAM) education. Both Land (2013) and Platz (2007) agree that Art should be included in STEAM, as the creativity at the core of Art teaching integrates well with the innovation focus in Technology education.

The integration of subjects in teaching creates the opportunity for learner-centred teaching, promoting the development of skills such as creativity, collaboration and problem solving. These 21st century skills are promoted as important skills to prepare learners to live in the rapidly changing environment (UNESCO, 2017; Department of Basic Education [DBE], 2019a). These changes have seen the advance of digital technologies and as a result the need for the development of digital skills. Computational thinking is at the core of digital skills and is a learner's ability to find a problem and then solve the problem in the same way a computer would be able to (Chalmers, 2018; Chen, Shen, Barth-Cohen, Jiang, Huang & Eltoukhy, 2017).

The 21st century skills are typically soft skills that are impacted in the current century due to the changes in the world, specifically regarding technology (Quieng, Lim & Lucas, 2015; DBE, 2019a). Digital skills link to the technology a person has access to; for example, having access to a computer (Jara, Claro, Enri, San Martín, Rodríguez, Cabello, Ibieta & Labbé, 2015). 21st century skills are a broad range of skills, whilst digital skills refer to the specific involvement of Information and Communication Technology (ICT) (Van Laar, Van Deursen, Van Dijk & De Haan, 2017).

The Department of Basic Education in South Africa (hereafter DBE) supports the development of 21st century and digital skills at a young age (Department of Basic Education [DBE], 2021). A curriculum was developed to be implemented from 2021 onwards and is referred to as *Curriculum and assessment policy Grade R to Grade 3*

Coding and Robotics (Department of Basic Education [DBE], 2021). This curriculum looks at five knowledge strands, including pattern recognition and problem solving, algorithms and coding, robotic skills, internet and e-communication skills and application of skills. These knowledge strands are taught using computational thinking and the Engineering Design Process (EDP). The draft curriculum framework from 2019 titled *Introducing digital skills for all into GET Curriculum framework Grade R to 9* is based on four pillars, namely application skills, internet and e-communication skills, data and information management skills, and computational thinking skills and coding (DBE, 2019a).

At the core of the curriculum is the development of computational thinking. According to Wing (2008), computational thinking is an integral part of Foundation Phase education. Computational thinking is the learner's ability to solve problems to come up with a solution in the same way that a computer can solve problems (DBE, 2021; Chen et al., 2017).

It is important to expose learners to digital skills in the Foundation Phase to gain an understanding of these skills at an early age (DBE, 2019a). These skills are taught through the integration of subjects and each year learners are able to build on the skills that they have learnt in the previous year (DBE, 2019a). According to DBE (2019a) and Resnick, Maloney, Monroy-Hernandez, Rusk, Eastmond, Brennan, Millner, Rosenbaum, Silver, Silverman & Kafai (2009), learners learn to think creatively, reason and collaborate with their peers when they programme together. The skills taught aid them in becoming 21st century learners.

1.2 Problem statement

As stated in the Introduction section, the DBE wants to include computational thinking into the Coding and Robotics curriculum. However, there appears to be a paucity of information and research regarding integration of STEAM subjects, developing 21st century skills, digital skills and coding and robotics in the South African contexts. These underlying challenges are discussed in more detail.

This section focuses on the four underlying challenges that Foundation Phase teachers face and that gave rise to this study. This section explores the challenges of the integration of STEAM subjects, developing 21st century and digital skills for learners, and incorporating coding and robotics into teaching and learning in the Foundation Phase.

1.2.1 Integration of STEAM subjects

According to Johnston, Highfield and Hadley (2018) and Yakman and Hyonyong (2012), many teachers are hesitant to accept the chance to integrate STEAM subjects. Teachers are in the routine of teaching subjects in isolation from one another. According to DBE (2019a) and Harper (2017), there is a need to encourage teachers to integrate subjects successfully.

1.2.2 Developing 21st century skills

21st century skills focus on equipping learners with the skills needed to thrive in the current world (DBE, 2019a). These skills include being able to collaborate with peers, thinking creatively and solving problems. 21st century skills are based on current economic and social developments instead of being based on the past century that propagated industrial skills.

For learners to be effective in the 21st century, they need to be taught skills, knowledge, values and attitudes (Koehler, Mishra, Bouck, DeSchryver, Kereluik, Shin, Wolf & Leigh, 2011; Varkey Foundation's Atlantis Group, 2019); for learners to have futures, they need to have learnt skills of the 21st century at a young age (DBE, 2019a). These are regarded as essential skills to have in this century to develop ideas and solve problems in a digital context. These skills are going to change the form of traditional learning (Van Laar, Van Deursen, Van Dijk & De Haan, 2017).

1.2.3 Developing digital skills

Digital skills are the ability one has to use a computer and the access one has to one (Jara et al., 2015). These skills are closely linked to one's economic, social and cultural background as one needs to have access to digital devices (Jara et al., 2015). The best way to improve digital skills is through practice (Van Deursen & Van Dijk, 2009).

UNESCO (2017) looks at developing the digital skills of learners to function efficiently in the 21st century. South Africa is currently falling behind other African countries that are continuing to grow as a result of the use of technological skills (DBE, 2019a). Teachers still require support to integrate digital skills effectively into the curriculum. This is currently being looked at in South Africa by the DBE (DBE, 2019a; Department of Basic Education [DBE], 2019b).

According to Koehler et al. (2011) most new technologies are not designed with classroom use in mind. Teachers are faced with the challenge of keeping up with technology that changes rapidly; often they are hesitant or do not have the skills needed to re-design activities to be used in the classroom or to create new learning opportunities for learners. Teachers not only need to be able to redesign the activities, but also to design their lessons effectively to include digital skills (Koehler et al., 2011).

Teachers find it challenging to keep up with technology and how to incorporate digital skills into their lessons (Koehler et al., 2011). According to Greca Dufranc, García Terceño, Fridberg, Cronquist and Redfors (2020), teachers need to be able to create lessons using the correct content and pedagogy. This can be a challenge for teachers as it is time-consuming, and they need to have the skills needed to incorporate digital skills into their lesson plans. Incorporating these skills into lessons enables learners to use the digital skills in their learning (Koehler et al., 2011). If teachers are not open-minded and prepared to change their teaching styles in line with global trends, the integration of lessons will not be effective, and learners will not be exposed to the necessary digital skills.

1.2.4 Coding and robotics

The purpose of the Department of Education's framework is to develop computational thinking (DBE, 2019a; DBE, 2021). These skills are taught through coding and robotics that are new subjects in schools. Teachers are currently not prepared to teach coding or robotics and therefore need to be trained.

Coding and robotics can be defined as the learner's ability to solve a problem using their programming skills and can be the algorithm used in the programming (Kanbul & Uzunboylu, 2017). Coding includes being able to code a step-by-step block code (Cakir & Guven, 2019). Robotics includes objects with a sensory motor system that can be coded (Ponticorvo, Rubinacci, Marocco, Truglio & Miglino, 2020). An example of this is the Bee-Bot as a digital tool that can be used for coding.

Coding is when learners learn to program and complete algorithms. Robotics and programmable toys can be used to strengthen and develop the skills taught by teachers (Janka, 2008; Johnston et al., 2018). Teachers need to be provided with skills to implement the use of coding and robotics effectively in their lessons.

As such, this study explored the integration of STEAM subjects, equipping learners with 21st century skills, ensuring that digital skills are used with the classroom in mind and equipping teachers with the skills to teach coding and robotics in the South African context.

This study focused on the Foundation Phase (Grade R to 3) and on the computational thinking skills and coding pillar of the draft digital skills curriculum. Development of computational thinking is regarded as an integral part of Foundation Phase teaching and learning, supporting learners in investigating problems towards the development of solutions.

The study investigated coding and robotics activities with a few learners in two groups of three with an extra learner. The learners were involved in a series of lessons, incorporating practical coding and robotics activities using various concrete objects. Bee-Bots (floor robot) were used as the digital tools in the integrated lessons. More information about Bee-Bots can be found in 1.6.4 and 2.7. The study focused on how the learners could solve a problem given to them at the beginning of a lesson. Due to the Covid-19 pandemic, protocols were in place to ensure the safety of the participants. The core protocols were sanitising, wearing a mask and social distancing.

1.3 Rationale

As a Grade 2 teacher having experienced the challenges discussed in Section 1.2, the researcher wanted to investigated how teachers can be supported when experiencing these challenges. Coding and robotics are new subjects taught in schools to help learners to be equipped for the 21st century.

The focus of this study was on computational thinking skills and coding that relate to the four pillars of the draft digital curriculum in South Africa (DBE, 2019a). The emphasis was on coding and robotics in the Foundation Phase and how these can be integrated into the Grade 2 curriculum through STEAM.

The researcher wanted to investigate how the TPACK framework could assist teachers in designing an activity to incorporate STEAM integration, 21st century skills, digital skills and coding and robotics. The lessons were designed to incorporate all these elements.

1.4 Research questions

The following primary research question guided the study:

Research Question

1.4.1 RQ: How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?

The following secondary research questions were explored to address the primary research question:

Secondary Research Question 1

1.4.2 SRQ1: How can TPACK be utilised to design coding activities?

Secondary Research Question 2

1.4.3 SRQ2: How do learners experience these activities?

1.5 Purpose of the research

The purpose of the research was to investigate the design of TPACK designed activities that support the integration of Science, Technology, Engineering, Art and Mathematics (STEAM) and to develop computational thinking for Grade 2 learners. This study investigated the challenges of supporting teachers to develop 21st century and digital skills in STEAM teaching through coding and robotics in Foundation Phase teaching.

This study aimed to supply guidelines for the design of TPACK integrated activities to integrate STEAM subjects using Bee-Bots via a play-based and project-based approach.

The purpose of the study was to create guidelines for teachers to create their own lessons to be facilitated by Bee-Bots.

1.6 Key theoretical concepts

The key theoretical concepts of the study are explained below. STEAM is introduced and involves the integration of the subjects Science, Technology, Engineering, Art and Mathematics into a single lesson. The concept of 21st century and digital skills are introduced. These skills were developed when coding the Bee-Bots. The lessons were designed to use the TPACK framework as a design tool.

1.6.1 Science, Technology, Engineering, Art and Mathematics (STEAM)

STEAM is the integrated discipline used to prepare learners for Science, Technology, Engineering, Art and Mathematics through inquiry-based learning that is age-appropriate. Learning is combined in non-traditional ways through collaboration and independent problem solving (Jamil, Linder & Stegelin, 2018; Harper, 2017).

Technology is taught as a subject with the core components of structures, processing, mechanical systems and controls, and electronic systems and controls. These are taught using the design process (Department of Basic Education [DBE], 2018).

1.6.2 21st century skills

Having 21st century skills enable one to adapt, communicate effectively, collaborate, solve problems and develop self-management and self-development (Blackley & Howell, 2019). Teachers and learners can work effectively and responsibly, allowing individual contributions within a diverse group (DBE, 2019b).

1.6.3 Digital skills

Learning of digital skills takes place when digital tools and resources are used to enhance learning. Digital skills are not used in isolation but rather to enhance the learning experience (DBE, 2019b; Johnston et al, 2018).

1.6.4 Bee-Bots

Bee-Bots are programmable floor robots. The Bee-Bots move 15 cm forward or backward or can turn left or right in a single instruction. Learners can enter up to 40 instructions in a single sequence. Bee-Bots move on a flat surface and rotate 90 degrees. The sounds and lighting up of the eyes allow the learners to know that their instructions have been entered in. (Janka, 2008) Bee-Bots are digital tools used in learning and they can assist with the integration of subjects (Kopelke, 2015; Janka, 2008).

1.6.5 TPACK

The TPACK framework stands for Technology, Pedagogy and Content Knowledge. It was designed to evaluate a teacher's knowledge to incorporate Technology effectively into their teaching through the PCK (Pedagogy Content Knowledge) framework (Koehler & Mishra, 2009; Koehler et al., 2011).

Technology was added to the PCK to access teachers' ability to include the use of digital technology, for example the use of computers in their teaching (Koehler & Mishra, 2009).

1.6.6 Computational thinking

Computational thinking is the learner's ability to solve problems and explore different ways to understand the problem (Perignat & Katz-Buonincontro, 2019). The focus of this study was on computational thinking skills and coding that relate to the four pillars of the draft digital curriculum in South Africa (DBE, 2019a).

1.7 Delimitation

This study focuses on Grade 2 only and not on the whole Foundation Phase.

The coding tool used was off-line coding in the form of Bee-Bots that are programmable floor robots. Scratch Junior was not used as set out in the *Digital skills for all in the GET curriculum framework* (DBE, 2019a). In this curriculum the learners are taught to use Scratch Junior that is a form of block coding in line with Mathematical concepts such as pattern work. The researcher focused on the four pillars of the curriculum with the main focus on computational thinking skills and coding. Both Scratch Junior and Bee-Bots allow learners to solve problems, complete a sequence of code and create opportunities for debugging. Scratch was not used as this is an online tool and the focus of the study was to use offline coding. Bee-Bots were chosen for this study as they are a digital tool used for teaching coding.

The study endeavoured to apply the coding concepts mentioned in the syllabus with Bee-Bots as tools as an alternative to this phase of teaching and not block based coding and did not investigate block-based coding but rather an alternative to this phase of teaching.

The study focuses on how teachers can use the TPACK to design activities. The purpose of the TPACK is a framework to support teachers. The study does not focus on learners' experiences even though it was included to some extent. The learner's experiences are included, but the main focus is on the teachers. The TPACK is a tool for teachers to evaluate their teaching practices.

1.8 Methodology overview

The research methodology is unpacked using the research onion of Saunders, Lewis, and Thornhill (2019). The study followed an interpretivist philosophy as meaning was created by the participants and interpreted by the researcher and an expert reviewer. An inductive approach was used as the data was interrogated to find the themes. A qualitative methodological approach was used as the data was not numerical but rather based on the experiences of a small sample of participants. An action research strategy was used and included two cycles. The researcher was part of the data collection process. The action research was participatory action research as the researcher collaborated with the participants. The participants included the researcher, an expert reviewer and seven learners. Seven learners were used and included learners from both classes after school. The two groups of learners worked on the same lesson at the same time. Only these seven learners were present in the lessons. The data instruments used were observations, interviews, artefacts and a reflective journal.

1.9 Chapter overview

Figure 1.1 illustrates the five chapters in this dissertation. The chapters are explained in a short overview.

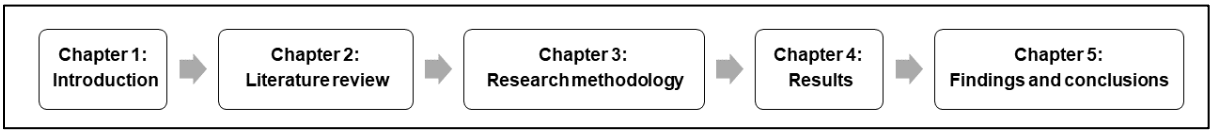


Figure 1.1 Chapter overview

1.9.1 Chapter 1: Introduction

This chapter gives an overview of what STEAM is and the 21st century skills that the DBE focuses on. The four problems found are discussed in the problem statement. The digital curriculum focuses on the four pillars and the focus of this study is computational thinking skills and coding. The title *Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2* is explored using the research questions. The key theoretical concepts for the study are explained. The next chapter explores the literature that is relevant to the problem statement.

1.9.2 Chapter 2: Literature review

Chapter 2 investigates the relationships between the three main headings of Pedagogy (Foundation Phase Teaching), Technology (coding and robotics) and Content (STEAM). This focus interlinks with digital skills, STEAM integration and Grade 2 learning. The TPACK framework is utilised as a design tool in this study.

1.9.3 Chapter 3: Research methodology

The research methodology is outlined using the research onion of Saunders et al. (2019). The study followed an interpretivist philosophy in an inductive qualitative approach through an action research strategy.

1.9.4 Chapter 4: Results

The results are structured according to the TPACK framework and incorporate the two cycles from the action research strategy.

1.9.5 Chapter 5: Findings and conclusions

The conclusion looks at the investigation of the research questions and what findings have been made. The findings helped to develop guidelines for teachers to design their own lessons.

1.10 Conclusion

This chapter outlined what the study deals with and why the study was conducted. The questions needed to guide the investigation are formulated and detailed. An introduction is given as to what STEAM subjects are and how they may be integrated. The importance of 21st century and digital skills is outlined. The DBE focuses on the four pillars of the digital curriculum; the focus of this study is the pillar of computational thinking skills and coding. The robotic instrument for learning computational skills and coding was a Bee-Bot.

A framework for designing STEAM lessons that incorporate Technology is introduced as the TPACK framework. An additional aim of the study includes developing guidelines for the design of TPACK integrated activities to integrate STEAM subjects using Bee-Bots via a play-based and project-based approach. The problems that the researcher identified and the literature that addresses these problems are detailed in the next chapter.

Chapter 2: Literature review

2.1 Introduction

Existing literature on the utilisation of coding and robotics to support STEAM teaching in the Foundation Phase was explored for this chapter. The chapter is divided into two parts: the underlying theory, and the theoretical and conceptual framework section. The study integrates three concepts as seen in Figure 2.1, namely the Pedagogy of Foundation Phase teaching, the content is the teaching of STEAM subjects, and coding and robotics as educational Technology. At the heart of the study is the development of computational thinking. The literature review is unpacked according to these aspects. Sections 2.2 to 0 deal with Foundation Phase Pedagogical concepts, Section 2.5, 2.6 and 2.9 with STEAM subjects and integration, Section 2.8 with 21st century and digital skills, Section 2.7 with coding and robotics as Technology and Section 2.10 with the development of computational thinking as the integration of the three main concepts. Section 2.12 deals with TPACK as theoretical and conceptual framework.

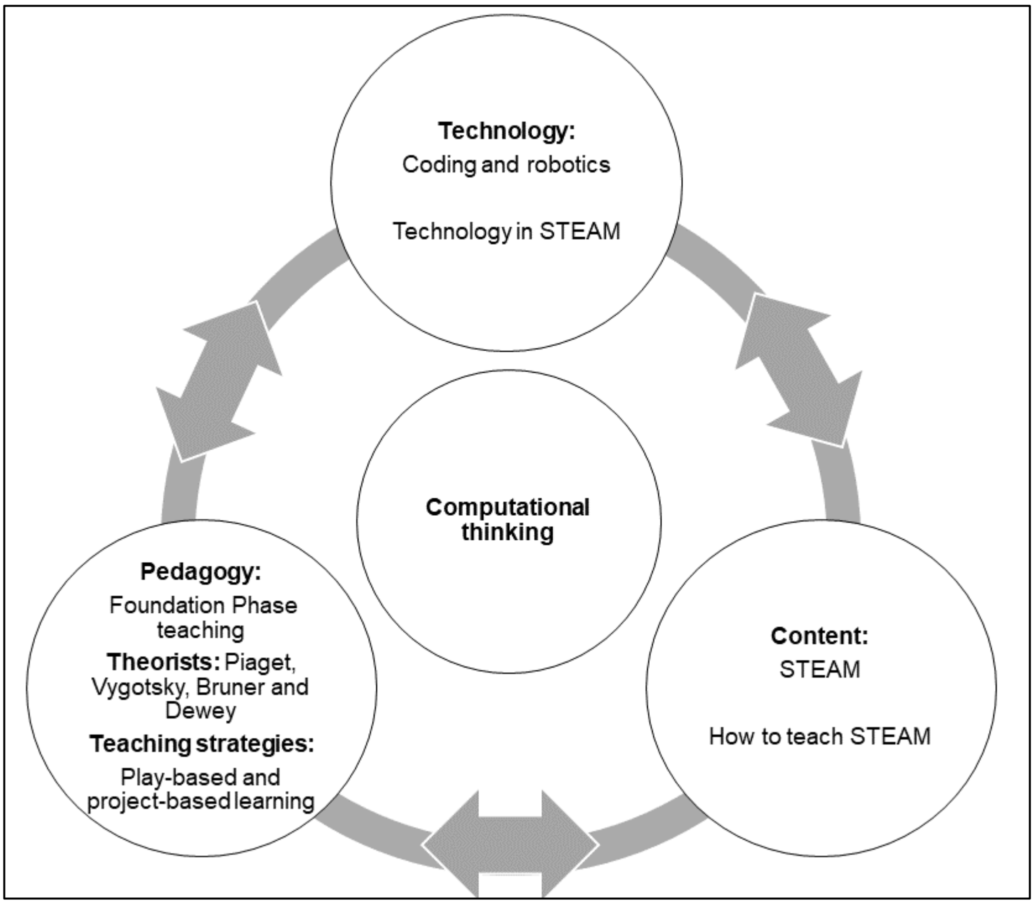


Figure 2.1 Literature review

The literature that was reviewed explored the topics depicted in Figure 2.1. The figure shows the flow between Pedagogy, Technology and Content in the context of the Foundation Phase. Pedagogy is how one teaches and the methods that are used. Technology includes using educational devices and software as tools for teaching in the classroom. For example, smartboards and educational apps and toys. Content is what is taught in different subjects (Koehler & Mishra, 2009). Computational thinking is how Pedagogy, Technology and Content can all be integrated.

2.2 Foundation Phase teaching

In South Africa the Foundation Phase is the first phase in a learner's school life; it starts with Grade R and ends with Grade 3. In this phase the focus is on teaching learners the primary skills, knowledge and values to embed the foundation for further learning (Hannaway & Steyn, 2017; Van Heerden, 2014). The process of inquiry, rather than rote learning, is emphasised as it allows for learners to explore and become more curious about the world around them (Copple & Bredekamp, 2009; Van Heerden, 2014).

In this section, firstly, literature on underlying Foundation Phase theories that could support the investigation into the problem statement was explored. The theories of Piaget, Vygotsky, Bruner and Dewey are regarded as pertinent to the study. Secondly, relevant teaching strategies, namely play-based and project-based learning are explored.

2.3 Theories

This section focuses on four educational theorists: Vygotsky, Piaget, Bruner and Dewey. The developmental processes they proposed as well as the importance of inquiry and play in these processes are explored.

In exploring the views of two cognitive theorists, Vygotsky and Piaget, a link between learners' interests and promoting intellectually challenging activities is observed (Charlesworth & Lind, 2010). According to Vygotsky, learners develop cognitively through play and scaffolding by the teacher or a more experienced learner (Meier & Marais, 2014). When a teacher scaffolds a lesson, they give an example and helpful hints while allowing the learners to solve the problem independently (Snowman &

McCown, 2013). Play is an imaginative activity where the learner is able to create meaning of the world around them (Vygotsky, 1978).

Piaget developed a theory based on four stages of a learner's development. These are explained in Table 2.1.

Table 2.1 Piaget's four stages of development

(Charlesworth & Lind, 2010; Huitt & Hummel, 2003)

Stage	Description
Stage 1 **Sensorimotor**	This is when learners learn about the world around them through their five senses. This stage is from birth to about two years of age. They use their senses to explore and discover that objects exist even when they cannot be seen.
Stage 2 **Preoperational**	This occurs when learners are between the ages of two to seven years old. Language and speech become important in this stage. They learn the most through play in this stage.
Stage 3 **Concrete operations**	Here the learners are between the ages of seven to 11 years old. In this stage they are starting to be able to move from learning from concrete objects towards being able to visualise objects.
Stage 4 **Formal operations**	Formal operations develop around 11 years and older. In this stage they develop the ability to think abstractly and to solve abstract concepts and problems.

According to Piaget**,** learners construct their knowledge through the environment, and this enables them to clarify the new knowledge that they are learning as illustrated in Table 2.1 (Meier & Marais, 2014).

This led to Bruner's three stages through which a learner learns as illustrated in Table 2.2. Bruner was influenced by Piaget and Vygotsky's theories of cognitive development as shown in the description of each stage (Charlesworth & Lind, 2010).

Table 2.2 Bruner's three stages of development

(Charlesworth & Lind, 2010)

Stage	Description
Stage 1. Enactive	This is where the learner manipulates and explores through play activities, using concrete objects.
Stage 2. Iconic	This is when the learner is able to visualise the concrete objects they have been playing with.
Stage 3. Symbolic	In this stage the learner is able to move into thinking abstractly.

Table 2.1 and Table 2.2 illustrate that there is a process that a learner goes through to go from one stage to the next. Learners develop new knowledge based on their own experiences (Charlesworth & Lind, 2010).

The theories of Piaget, Vygotsky and Bruner are incorporated in this study, based on their focus on development processes as well as on the focus on play in the process of learning.

Play allows learners to create meaning in the world around them as well as to make connections of their own (Murris & Verbeek, 2014). This links to Bell's (2010) views on project-based learning as an innovative approach that incorporates inquiry, collaboration and creativity. Learners are able to learn through inquiry while they are exploring through play. When learners take part in project-based learning they are learning in an enriched learning environment (Bell, 2010).

Project-based learning was proposed by John Dewey. He is credited in his book titled *Experience and Education* that was published in 1938, proposing experiential learning as the main theme for his theory (Parker & Thomsen, 2019; Pieratt, 2010). This theory promotes learner inquiry rather than rote learning during the learning process. The teacher's role is to observe and direct the learner's interactions rather than teaching through instruction alone. The emphasis is placed not only on the teacher-to-learner interaction but also on the learners-to-learners interactions. Dewey's theories are still relevant today and link to learners being able to collaborate effectively (Parker & Thomsen, 2019; Pieratt, 2010).

In Table 2.3 the processes proposed by the four theorists are compared for the relevance to this study.

Table 2.3 Comparing Piaget, Vygotsky, Bruner and Dewey

(Charlesworth & Lind, 2010; Dennis, 1940; Parker & Thomsen, 2019; Pieratt, 2010; Snowman & McCown, 2013)

Theorists	Jean Piaget	Lev Vygotsky	Jerome Bruner	John Dewey	Relevance to the study
Scaffolding learners	Learning is not scaffolded.	Learning need to be scaffolded by peers and teachers.	Learning are scaffolded by teachers.	The teacher's role is to observe and direct the learners.	Activities are scaffolded according to the increase in difficulty in each lesson. Learning is scaffolded by both the teacher and their peers.
Play	Learners learn mainly through play	Learners use play to discover and	Learners play with concrete	Play is important when it gives	Learners learn through play-based learning.

Theorists	Jean Piaget	Lev Vygotsky	Jerome Bruner	John Dewey	Relevance to the study
	during the preoperational stage.	describe the world around them.	objects in the enactive stage.	meaning to the work that needs to be done.	
Cognitive development	Four stages as in Table 2.1. Development comes from the learner's own maturity.	Development takes place through developmental (internal) and environmental (external) factors.	Three stages as in Table 2.2.	Learners learn through inquiry and project-based learning.	Learners use concrete objects and move towards an abstract way of thinking.
Knowledge and learning environment	Learners construct knowledge independently through their own discoveries.	Learners use prior knowledge to solve problems.	New knowledge based on previous knowledge. Learning takes place through problem solving and support from the teacher.	Learner-centred learning where the learners controls their own learning.	Learners use their prior knowledge to help them solve problems.

Table 2.3 illustrates the importance of scaffolding in Vygotsky and Bruner's work. Play is important to all the theorists when used in a meaningful way. Each theorist had their own unique ideas about cognitive development, and the way learners learn best.

Importance for this study

Piaget's theory was implemented in this study through planning lessons that are in the third stage of cognitive development where it is important that learners are able to manipulate concrete objects. The learners needed to be able to visualise how to move the concrete object of a Bee-Bot.

Vygotsky's theory of scaffolding was implemented in the lessons as there was an increase in difficulty in each lesson. The learners were facilitated by the researcher and the expert reviewer.

Bruner's concepts were implemented where learners needed to use their previous knowledge in order to solve problems through the iconic stage of learning.

Dewey's concept of project-based learning was implemented in the design of lessons. Each lesson was structured as a project where the learners needed to problem solve by coding a Bee-Bot to move around a Bee-Bot mat.

2.4 Strategies

The value of learning through play-based and project-based learning in the Foundation Phase was introduced in Section 2.3. These strategies are explored further in this section.

2.4.1 Play-based learning

There are different types of play-based learning. These include playing by oneself, playing with or beside a peer or playing cooperatively with another learner. Learners play *pretend* to develop an understanding of the world around them. They also play through exercise, for example climbing or running, during which they develop their gross motor muscles. Learners engage in more challenging activities like to pretend to fight or wrestle with one another. Teachers can observe play activities and as learners get older, teachers introduce them to games with rules. This allows learners to progress from free play activities to structured play activities. (Bergen & Fromberg, 2008; Mayesky, 2012; Snowman & McCown, 2013)

Play-based learning helps to scaffold learning and can add great value to the integration of subjects. Through play-based learning learners can experience the feeling of self-determination as they make their own choices, are challenged by the activity and feel connected to those around them. Learners can develop their own skills and enjoy what they are learning through play (DBE, 2019a; Johnston et al., 2018).

2.4.2 Project-based learning

Project-based learning allows learners to be guided by a real-life problem that needs to be solved. This creates the opportunity to inquire more about the problem to be solved. Through project-based learning learners are able to direct their own learning through inquiry and are able to use multiple strategies to help them complete the project successfully. Project-based learning can help to incorporate multiple subjects into one project. This allows learners to use their skills of self-determination to complete a project (Bell, 2010; Eguchi, 2014).

Importance for this study

Project-based learning can include multiple subjects and can be integrated into one project. The integration of STEAM subjects forms an important part of each lesson presented.

Play-based and project-based learning were incorporated in the design of the activities planned during the study. Activities were designed around problems and created the environment for learners to use their prior knowledge collaboratively during activities while trying to find solutions through inquiry.

2.5 Content: STEAM

STEM is the teaching of the subjects Science, Technology, Engineering and Mathematics in integration whereas STEAM includes the teaching of Art. According to Braund (2020), STEM is a misleading curriculum concept and is seldom implemented correctly. This study investigates how STEAM subjects can be implemented correctly with the correct guidelines. According to DBE (2019a) and World Economic Forum (2020), learners learning in an all-rounded curriculum that integrates the subjects of STEAM can develop the skills needed to be 21st century learners.

It is important that teachers are prepared through professional development to integrate STEAM subjects (García-Carrillo, Greca & Fernández-Hawrylak, 2021). Teachers should be flexible to allow learners to explore independently (Harper, 2017; Johnston et al., 2018; Martin-Hansen, 2018). According to Vale, Westaway, Nhase and Schudel (2020) another challenge in a learner’s education is the high student-teacher ratio, as it creates challenges for highly learner-centred learning facilitation and assessment.

2.5.1 Science

Science in Foundation Phase learning focuses on the skills of observing, comparing, measuring, experimenting and applying the scientific method of inquiry. Learners have a desire to inquire and find out more about the world around them. They are able to process the new information they have been taught by conducting experiments. The skills that they have acquired enable them to conduct an experiment using the scientific method (Charlesworth & Lind, 2010; Kok & Van Schoor, 2014; Tsai, 2006).

In the South African context Science is taught as Natural Science and falls into the subject of Life Skills (Beni, Stears & James, 2017; Department of Basic Education

[DBE], 2011b). Life Skills incorporate the subjects of Science, Geography and History. Science education teaches learners scientific knowledge, concepts and the scientific process (Dixon, Janks, Botha, Earle, Poo, Oldacre, Pather & Schneider, 2018).

2.5.2 Technology

Technology is regarded as a relatively new subject, both internationally and in South Africa (Pool, Reitsma & Mentz, 2011). The Department of Education characterises Technology in education as "… the use of knowledge, skills, values and resources to meet people's needs and wants by developing practical solutions to problems, taking social and environmental factors into consideration" (Department of Basic Education [DBE], 2003, p.8). The subject Technology taught in schools in South Africa comprises four core content areas, namely structures, processing, mechanical systems and controls, and electronic systems and controls (DBE, 2018).

When completing a Technology task in the classroom, the design process is used to solve problems (DBE, 2018). There are five steps in the design process that need to be followed: Investigate, Design, Make, Evaluate and Communicate (IDMEC). These steps are explored in Table 2.4 and can take place in different directions as the process is non-linear (DBE, 2018).

Table 2.4 Design process

(DBE, 2018)

IDMEC	Description
Investigate	Learners need to find, use and acknowledge information to investigate the problem.
Design	Learners need to design a brief, given specifications, constraints and initial idea sketches; choose the best design; select materials for their project.
Make	Learners need to draw plans; develop the manufacturing sequence; make the item or model.
Evaluate	Learners evaluate both their design stages and their final product.
Communicate	Learners present their solutions; they compile all notes and drawings into a project report in their workbooks.

The technological design process develops the learner's ability to IDMEC (Investigate, Design, Make, Evaluate and Communicate) effectively when solving problems (DBE, 2011b). The design process is an established tool used in Technology education (Jones, Buntting & de Vries, 2013; Burghardt & Hacker, 2004; Mawson, 2003). Problem solving is important in Technology education of which it is an essential activity (Schooner, Nordlöf, Klasander & Hallström, 2017). The subject Technology normally includes teaching with the integration of other subjects as Technology is interlinked to other subjects (DBE, 2018).

2.5.3 Engineering

The Engineering Design Process (EDS) consists of five steps that need to be followed: IDMEC (DBE, 2018). These are the same five steps found in the technology design process. Engineering in CAPS is taught through the EDS as it creates the opportunity for learners to design solutions to ill-structured problems that they are exposed to (Braund, 2020; Charlesworth & Lind, 2010; DBE, 2021). In the Foundation Phase Engineering is taught through the design process. Learners learn through play, problem solving and inquiry (DiFrancesca, Lee & McIntyre, 2014).

STEM education has created a place to incorporate Engineering into Foundation Phase teaching. This ensures that integration takes place between different subjects (Bagiati, Yoon Yoon, Evangelou & Ngambeki, 2010).

2.5.4 Art

Art is taught using the elements of Art, including line, colour and shape (Pénzes, van Hooren, Dokter & Hutschemaekers, 2018; DBE, 2011b). In South Africa Art falls under Visual Art and is taught in the subject of Life Skills in the Foundation Phase (DBE, 2011b). The subject covers both 2-dimensional and 3-dimensional art works where learners are able to develop their fine and gross motor skills when creating artwork (DBE, 2011b).

It is important that learners develop their Art skills to nurture their creative and imaginative knowledge. The teacher in the Foundation Phase should nurture the learners' artistic talents and encourage creativity. Therefore, the learning environment needs to be encouraging for the learners to express themselves freely. (Mayesky, 2012; Murris & Verbeek, 2014).

2.5.5 Mathematics

According to the Department of Basic Education [DBE] (2011a), Mathematics is the use of symbols and notations to describe numerical, geometric and graphical relationships. It relates to a learner's ability to observe, represent and interpret patterns. Mathematics helps to develop learners' mental processes that enhance problem solving and their ability to think critically. There are five focused content areas in the Foundation Phase. These are presented in Table 2.5. (DBE, 2011a).

Table 2.5 Five content areas of Mathematics in Grade 2

(DBE, 2011a)

Five content areas	Description of Grade 2 outcomes
Numbers, Operations and Relationships	• The ability to count forward and backward in an age-appropriate number range. • Recognise, identify and read number symbols and names. Describe, compare and order numbers. • Recognise the place value of two-digit numbers and multiples of 10. • The ability to complete addition, subtraction, multiplication and division calculations. Solve fractions and metal mathematics sums.
Patterns, Functions and Algebra	• Copy, create and extend geographic and number patterns.
Space and Shape (Geometry)	• Properties and features of shapes and objects. Looking at both 2-dimensional and 3-dimensional shapes. • Knowing the language of position and direction; for example, left, right, up and down.
Measurement	• Looking at the mathematical concepts of time, length, mass, volume and capacity, and perimeter and area of shapes.
Data Handling	• The learner's ability to interpret and depict data on a graph. This includes bar graphs and pictographs; the ability to collect, organise, represent, analyse and interpret data.

There is an extensive emphasis in Africa on the subject of Mathematics due to efforts to remedy poor performance. It is therefore important that teachers are trained on how to teach Mathematics effectively.

2.6 How to teach STEAM

When teaching STEAM, the subjects of Science, Technology, Engineering, Art and Mathematics are taught through integrating all the subjects. Kok and Van Schoor (2014) state that in South Africa the subjects Science and Technology are taught in a subject called Life Skills. The goal is to ensure that learners are taught about social relationships, technological processes and natural Sciences (Kok & Van Schoor, 2014). The aim is to teach Science in an integrated manner with the correct Pedagogical Content Knowledge (Kok & Van Schoor, 2014). According to Charlesworth and Lind (2010) and Chalufour, Hoisington, Moriarty, Winokur and Worth (2004), learners learn how to solve problems in Science, Technology, Engineering and Mathematics. When learners build with blocks, they integrate Science, Engineering and Mathematics and this helps to develop their spatial awareness (Charlesworth & Lind, 2010).

When teaching learners though an integrated approach, the teacher can first model how to solve a problem or skill. This helps to guide the learners through solving the problem and then the teacher can see what the learners have learnt (Knight, Wright, & DeFreese, 2019). When teachers use STEM in their teaching, they move away from teacher-centred learning to learner-centred learning (Jang, 2016). STEM education focuses on the skills learners need rather that what the teacher thinks is important (Jang, 2016). This study focuses on the integration of these STEAM subjects into one subject. It is important to integrate subjects as it allows learners to learn through multiple viewpoints that create neural pathways (Highfield, 2010; Land, 2013).

According to Perignat and Katz-Buonincontro (2019) there are five ways that STEAM integration can happen. These are transdisciplinary, interdisciplinary, multi-disciplinary, cross-disciplinary, and arts-integration. Transdisciplinary is when the STEAM subjects are included without boundaries and the lessons focus on inquiry. Interdisciplinary is when the STEAM subjects are discreet, but theme related. Multi-disciplinary is when collaboration is included between a few subjects but not all. Cross-disciplinary looks at the subject through the perspective of another. Arts-integration is the inclusion of Art into STEM. The method adapted for this study was interdisciplinary as the focus was on the inclusion of all STEAM subjects into a single lesson. The lessons were designed to include all the STEAM subjects and a final lesson was done to see if the learners could incorporate all the STEAM subjects when given a less structured lesson. The lessons were then observed to see if all the STEAM subjects were incorporated in a single lesson. This uses the Interdisciplinary way of integration as STEAM subjects are all incorporated and relate to the theme of the story *If I were a wizard* by Paul Hamilton (Hamilton, 2017).

When teaching STEAM with project-based learning, there are steps and methods to follow as seen in Figure 2.2 (Ridwan, Rahmawati & Hadinugrahaningsih, 2017).

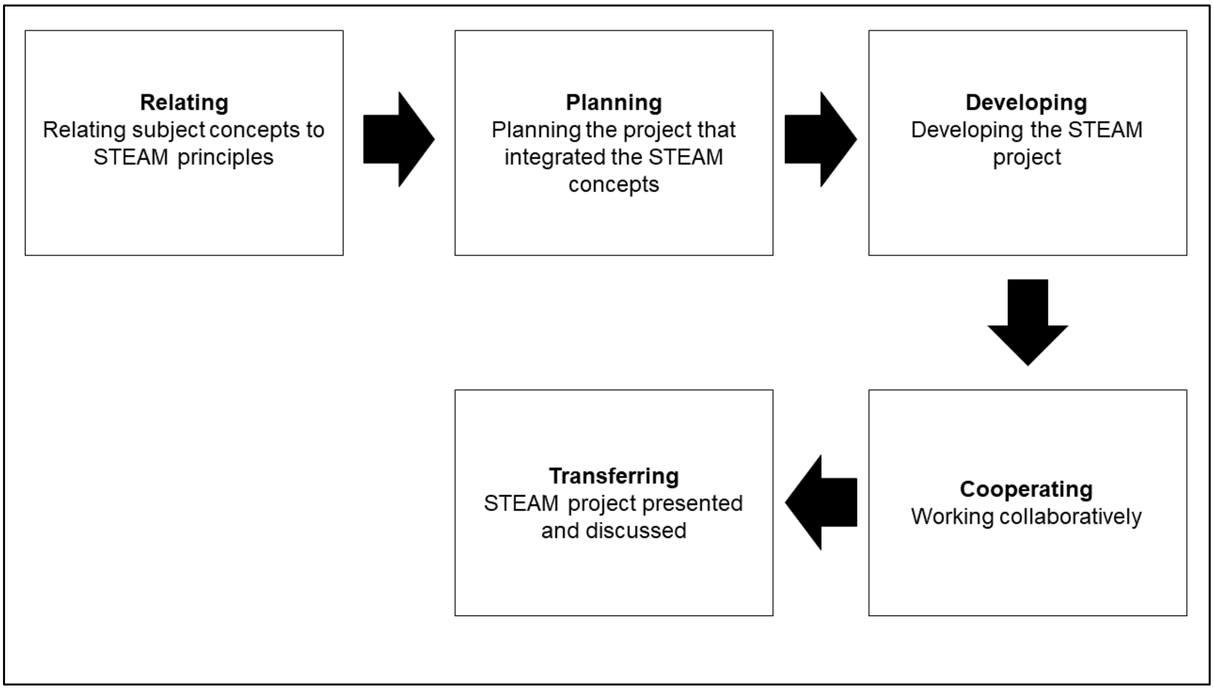


Figure 2.2 Project-based learning STEAM project

Source: Ridwan et al. (2017)

Project-based learning is a student-led pedagogy and therefore links to STEAM as a learner-centred approach. Learners are able to solve problems through STEAM integration. Figure 2.2 shows that learners are able to solve a problem by working through the five steps of the project. They start by finding a problem through relating to the topic, then plan how to solve this problem, develop a project to solve the problem, work collaboratively as a group while they are facilitated by the teacher; lastly, they present their findings to the problem they have solved (Ridwan et al., 2017).

2.7 Coding and robotics

According to Highfield (2010) and Hamilton (2017), learners are able to develop their problem solving skills through coding and robotics. Robotics is the device used to code a string of code as well as any mechanical object that can be sent instructions through coding (Highfield, 2010; Hamilton, 2017).

2.7.1 Coding

Coding is the means by which we teach computational thinking and it can be taught with the integration into other subjects (Francis & Davis, 2018). According to DBE (2019b), when learners are able to code it helps them to build their problem solving skills and to communicate their ideas effectively. Teaching learners to code enables them to develop their skills of creating an algorithm and computational thinking (Turan & Aydoğdu, 2020).

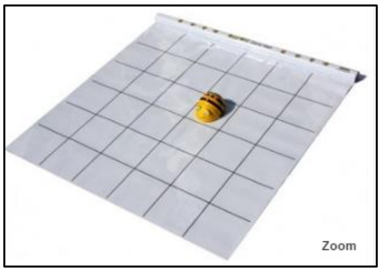
The coding tasks that are created can have multiple solutions; which creates flexible thinking and encourages learners to reflect on what they have learnt and solved (Highfield, 2010). Using Bee-Bots as a tool for learning enables learners to problem solve and have the confidence to think creatively. Bee-Bots allow learners to watch the concrete movement of their coding steps (Highfield, 2010). Concrete operations are a learner's ability to use a concrete object to learn from and draw conclusions about problems that have been solved (Mayesky, 2012). Learners can manipulate the objects for example Bee-Bots in this context; this helps them to deepen their understanding (Mayesky, 2012).

In the Coding and Robotics Curriculum set out by DBE (2021) the curriculum has in place that Foundation Phase learners must be taught to code by converting simple algorithms to block-based code. In the curriculum, Grade 2 learners need to be able to create patterns using their skills of pattern recognition and problem solving to complete a sequence of code (DBE, 2021). They must also be introduced to algorithms and be exposed to different terminology, such as repeating sequences and loops (DBE, 2021). Chalmers (2018) underscores the importance of teaching learners how to sequence and create loops in their coding as this expands the learners' coding skills.

Importance for this study

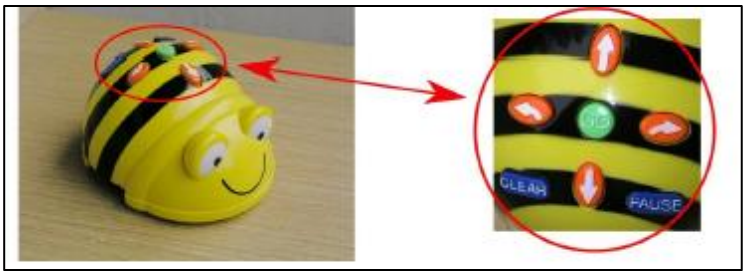
Bee-Bots are used as an educational technology device. The Bee-Bots move 15 cm forward or backward or can turn left or right in a single instruction. Learners can enter up to 40 instructions in a single sequence. Bee-Bots move on a flat surface and rotate 90 degrees. The sounds and lighting up of the eyes allow the learners to know that their instructions have been entered in (Kopelke, 2015; Janka, 2008).

Picture of a Bee-Bot



Picture of 6 x 6 transparent Bee-Bot mat

The Bee-Bot mat is used to create a grid reference to aid the learners with their coding. The blocks show the 15 cm the Bee-Bot can move in. In this study, the learners will be given an instruction card with the grid to first plan the route the Bee-Bot will move in.



Bee-Bot interface (Janka, 2008).

The interface shows the orange arrows that allow the Bee-Bot to move forward, backward, left and right. When the sequence of code has been entered the learner presses the green *Go* button and the Bee-Bot starts moving. When the sequence is complete the blue *Clear* button needs to be pressed to clear the memory and start a new code. The Bee-Bot can be paused to stop in the middle of a coded sequence. The eyes flash and the Bee-Bot beeps when it has completed the sequence of code. The Bee-Bot is turned on and off on the bottom where the wheels are also visible.

2.7.2 Robotics

In the draft Coding and Robotics Curriculum set out in DBE (2021), there are two fields of robotics, namely coding and Engineering. Learners follow the EDS to create a path for the robot to follow. In the draft curriculum, Grade 2 learners need to be introduced to the mechanical components of a robot. They must know the basic chassis, fasteners, axles and wheels of a robotic car. (DBE, 2021).

Robotics is an effective learning tool to incorporate STEM subjects and project-based learning because it stimulates an interest in learners wanting to explore the technology around them (Eguchi, 2014). There is a variety of different robotic tools that can be used in the classroom; for example, making a car and making a robot (DBE, 2019a). Learners should be able to build robots as well as to code them to do a specific task (DBE, 2019a).

The movement of the robot is the success factor of integration of Engineering, Mathematics and computer skills as the movement will not be possible if one of these skills is not met or successfully integrated (Highfield, 2010; Land, 2013). Young learners can use robotics to develop their skills of sequencing, cause and effect as well as Engineering skills (Turan & Aydoğdu, 2020).

2.8 21st century and digital skills

2.8.1 21st century skills

The 21st skills focus on creativity, innovation, critical thinking and problem solving (DBE, 2019a; Geist, 2016). These skills are important as a focus in the classroom to prepare learners effectively for becoming 21st century learners. Learners need to have mastered the skills of the 21st century to be able to work collaboratively; these lead to cross curriculum collaboration (Hamilton, 2017; Land, 2013). It is not only learners that need to work together but also teachers. Teachers need to work collaboratively to achieve the goals of integration of subjects (Harper, 2017). Teachers therefore empower their learners to think innovatively and to be able to solve problems that help the learners to gain important 21st century skills needed for life and work (Dell'Erba, 2019).

2.8.2 Digital skills

Digital skills include the integration of computational thinking, 21st century skills and coding. They need to be taught in the Foundation Phase to equip the learners with the skills they will need in the higher grades. These skills can be taught in collaboration with other subjects to incorporate them into the curriculum. Digital skills that can be taught at school include coding and using other digital tools (laptops, tablets, smartboards, etc.) to enhance learning (DBE, 2019a).

The 21st century has shown rapid growth in technology, including technology in the classroom (Cakir & Guven, 2019). The classroom is an important place to prepare learners for the world around them. To make learners future-fit they need to be exposed to technology that grows with worldwide trends (Cakir & Guven, 2019). When teachers use digital skills in the classroom, they help equip learners with the skills they need to be 21st century learners (Blackley & Howell, 2019). Furthermore, teachers teach learners digital safety skills and how to use devices in a way that keeps them safe (World Economic Forum, 2020). For example, safe search engine usage, adult permission and using websites that are age-appropriate (World Economic Forum, 2020).

2.9 Technology in this study

The concept *Technology* features in two aspects in this study. The first is the reference to educational technology as presented in the TPACK framework (Section 2.12.1). The second is in the technology subject in STEAM education (Section 2.5.2).

The educational technology relevant to this study focuses on coding and robotics, implementing a programmable toy (Bee-Bot) to support STEAM subject integration. Learners in the Foundation Phase learn well through play and using concrete objects to explore and discover. Using Bee-Bots allows learners to use a concrete object while learning through play and they can explore and discover new concepts with their class (Janka, 2008). Coding and robotics were discussed in detail in Section 2.7.

The Technology subject was discussed in Section 2.5.2. It is mentioned that the subject comprises four core content areas, namely structures, processing, mechanical systems and controls, and electronic systems and controls (DBE, 2018). In this study three of these areas are evident in activities presented to the learners, as learners built structures, planned and execute processes, worked with electronic systems and the controls of the Bee-Bot.

The definition of the TPACK framework can be found in Table 2.6; it includes the TCK as part of the framework as TCK refers to the way teachers use Technology to teach content. This is important, because the teacher needs to find the best technology to fit the subject matter being taught.

Using Bee-Bots in the classroom is an example of the integration of educational technology and Technology as a subject to support STEAM teaching.

2.10 Computational thinking

Computational thinking is developed through learners practising their programming skills whilst solving complex problems. Robotics is an effective way to introduce computational thinking as learners code step-by-step movement instructions, and are able to see the concrete object (Bee-Bot robot in this study) move according to their coded instructions (Chalmers, 2018). Computational thinking should be introduced at an early age for learners to develop their digital and coding skills (Papert, 1972; Wing, 2008).

The DBE introduced a Digital Skills Framework for Grade R to Grade 9 that is divided into four pillars: application skills, internet and e-communication skills, data and information management skills, and computational thinking skills and coding. The focus of this study is on the fourth pillar, computational thinking skills and coding. Computational skills that are taught in Grade 2 include pattern recognition, problem solving and steps to code and creating algorithms (DBE, 2019a). The skills from the *Curriculum and assessment policy Grade R to 3 Coding and Robotics* (DBE, 2021) taught to Grade 2 learners are pattern recognition and problem solving, algorithms and coding, robotic skills, internet and e-communication skills and application of skills. Computational thinking helps learners to solve complex problems. The focus in these two curriculums (DBE, 2019b; DBE, 2021) are on pattern recognition, problem solving, algorithms and coding, robotic skills and the application of skills. The focus is not on e-communication skills. Digital skills in the Foundation Phase equip learners with the foundation needed to build onto these skills, as they integrate these skills into their learning subjects (DBE, 2019a).

The core concepts of 21st century and digital skills, coding and robotics and Foundation Phase Teaching are incorporated into the framework *Introducing digital skills for all into GET curriculum framework Grade R-9, Draft* (DBE, 2019a). According to the DBE in South Africa, digital skills are multiple sets of skills that learners require to be 21st century learners. Digital tools used by teachers help them to strengthen and improve the learning outcomes of learners. Teachers develop their skills through professional development that provides them with the skills and knowledge needed to create 21st century learners that are exposed to digital skills and tools (DBE, 2019a).

2.11 Literature review conclusion

Figure 2.3 is an elaboration of Figure 2.1 and illustrates how the literature is pieced together.

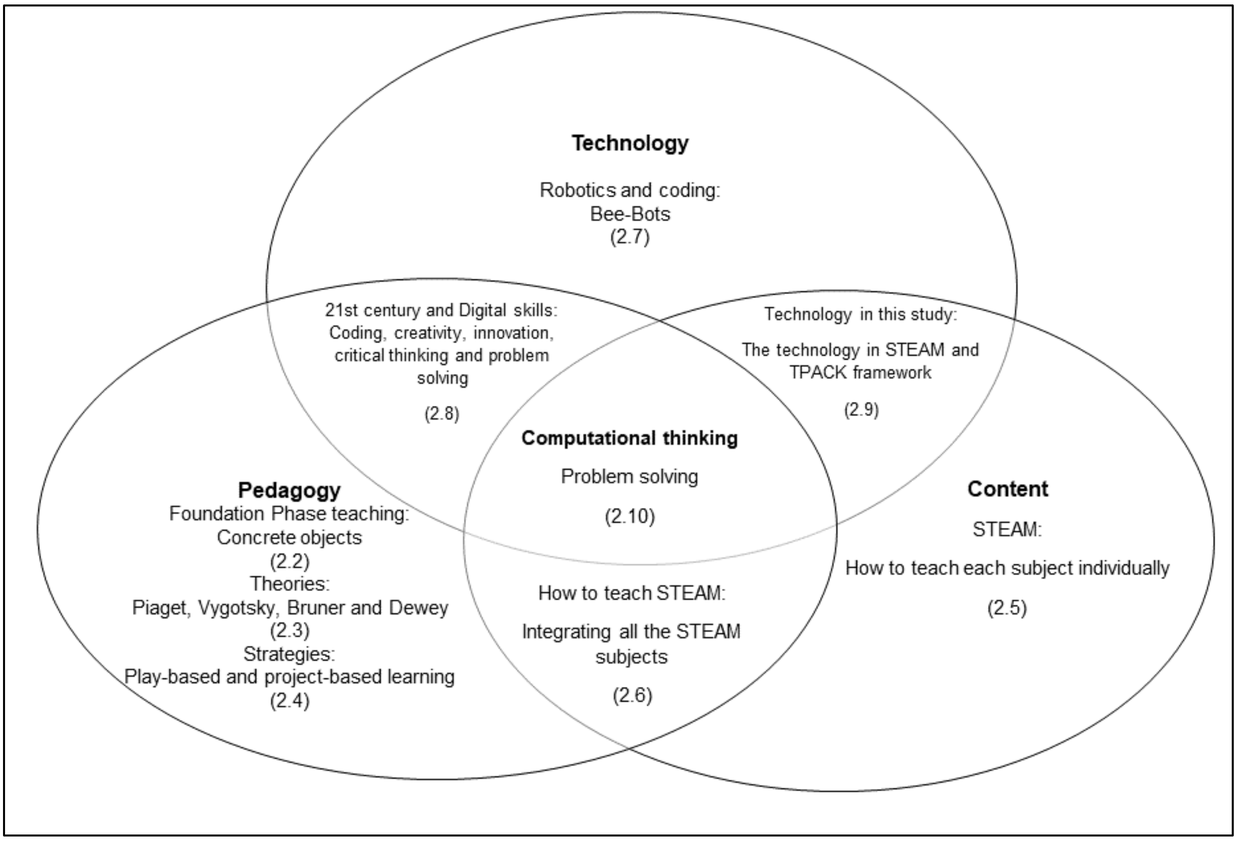


Figure 2.3 Literature review concluded

Figure 2.3 is an elaboration of Figure 2.1 and illustrates how the literature is integrated. The pedagogy in this study is Foundation Phase teaching, the theories of Piaget, Vygotsky, Bruner and Dewy and the strategies of project-based and play-based learning. The content is STEAM subjects in the Foundation Phase. The Technology is coding and robotics.

The overlap between Pedagogy and Content is how to teach STEAM. This becomes evident when the teacher has knowledge of the content of all STEAM subjects as well as how to teach them. The overlap between Technology and Pedagogy is 21st century and digital skills. This is seen when a teacher knows how to make use of technology in the classroom to teach any subject matter and thereby effectively teaching 21st century skills to learners. The overlap between Technology and content is the integration between educational technology and the subject Technology.

2.12 Theoretical underpinning

This section focuses on TPACK as the theoretical underpinning and conceptual framework for this study. Firstly, TPACK is discussed theoretically, and secondly, it is presented as a conceptual framework to serve as a design tool for creating, observing and evaluating the lessons.

2.12.1 TPACK framework

TPACK is the theoretical framework for this study as shown in Figure 2.4. The emphasis is placed on Technology as the TPACK model is an expansion of Shulman's (1981) PCK framework. Koehler and Mishra adapted PCK to include Technology, and this became the TPACK framework (Chalmers, 2018). The TPACK framework is used to identify and evaluate the teacher's knowledge of the aspects and integration of Content, Pedagogy and Technology into teaching (Koehler & Mishra, 2009). Teachers need to have Pedagogical Content Knowledge (PCK) that enables them to master the content they will teach and the specific teaching methods they need to use (Chalmers, 2018; Shulman, 1986).

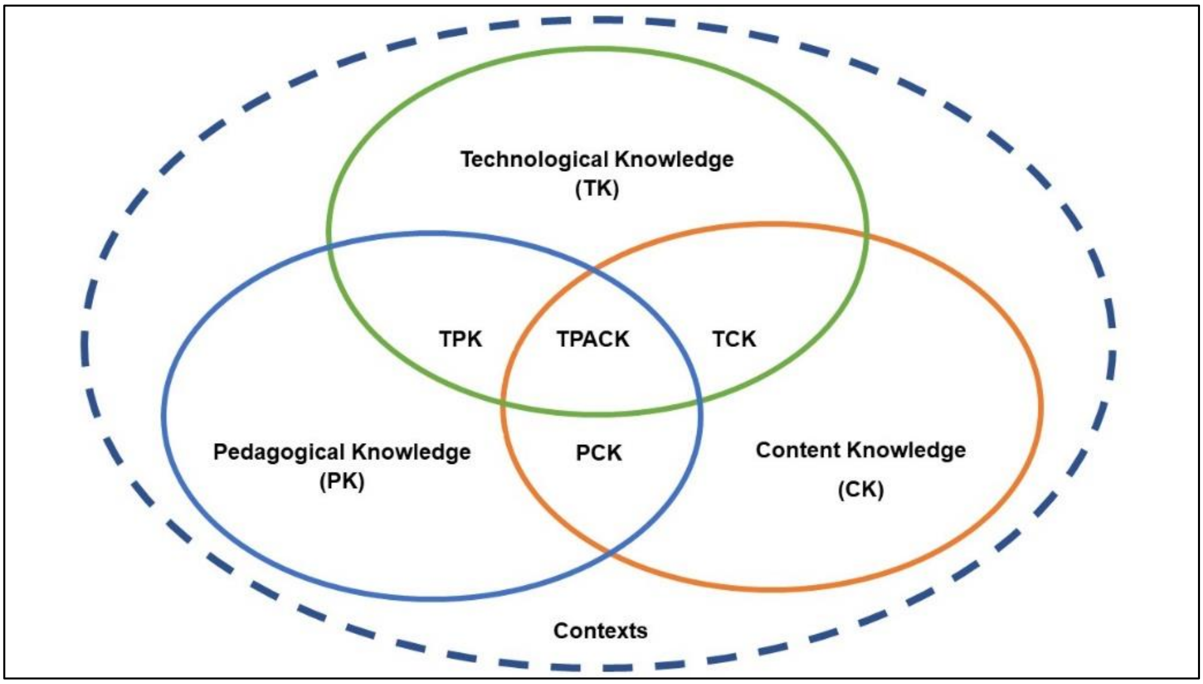


Figure 2.4 TPACK framework

From Koehler, Mishra and Cain (2013)

The overlap between the elements of TPACK is evident in Figure 2.4. The emphasis of the TPACK framework is on Technology as a tool available to teachers to teach different content. The classroom needs to be a technologically rich environment for both the teacher and the learners for lessons to be integrated using Technology (Baran, Chuang & Thompson, 2011; Koehler & Mishra, 2005).

Technology is changing rapidly and needs to be included in the classroom. It has become a powerful tool to support what is being taught. It is important that teachers are trained to teach using technology in the classroom. They may need to adapt and change their teaching to integrate technology effectively (Bennison & Goos, 2010; Can-Yaşar, Inal, Özgün & Kandir, 2012; Venketsamy & Wilson, 2020).

Teachers gain knowledge and insight from multiple teaching sources and this helps them to teach effectively. They can use their knowledge to see which learning outcomes are beneficial when taught with technology. Through this way of teaching, teachers can gain insight into the content that they teach and what to focus on. When using the TPACK framework, teachers can adapt lessons to incorporate technology (Koehler et al., 2011).

The first generation of TPACK is used to describe the construction of the TPACK framework. The focus of TPACK is on evaluating the teacher's knowledge of the subject content, the teaching process and how technology is incorporated into a lesson. This can be assessed by the learners being able to learn effectively from the lesson taught by the teacher (Baran et al, 2011; Schmidt, Baran, Thompson, Mishra, Koehler & Shin, 2009).

In Table 2.6 the TPACK framework is unpacked into eight sections to create a picture of what each of the components represents.

Table 2.6 TPACK framework

TPACK	Description
Pedagogical Knowledge (PK)	• Pedagogical Knowledge is the teacher's knowledge of the process and methods of teaching and learning (Bers, Seddighin & Sullivan, 2013; Chalmers, 2018; Koehler & Mishra, 2009). • These strategies need to be content-specific as the teacher needs to have an in-depth knowledge of the pedagogy (Bers et al., 2013; Mavhungaa & Rollnicka, 2013).
Technology Knowledge (TK)	• Technology Knowledge is the way the teacher understands how to use technology in the classroom (Bers et al., 2013; Koehler & Mishra, 2009). • Technology needs to be integrated into the classroom. It is important that learners are able to problem solve regardless of whether they are using Technology or not (Bers et al., 2013).

TPACK	Description
Content Knowledge (CK)	• Content Knowledge is important for teachers because the content covered in Grade 1 is different from the content covered in other grades (Bers et al., 2013). • When teaching Science there is an emphasis on the scientific method; this is content that needs to be taught (Koehler & Mishra, 2009). The scientific method is used and the difficulty changes between grades.
Technological Pedagogical Knowledge (TPK)	• Technological Pedagogical Knowledge relates to being able to understand how teaching and learning can change as Technology changes (Koehler & Mishra, 2009). • Teachers may need to be able to adapt the programmes that are normally created for business to be suitable for the classroom (Koehler & Mishra, 2009).
Technological Content Knowledge (TCK)	• Technological Content Knowledge is important for a teacher to understand how best to use Technology to aid effectively in the teaching of the content (Koehler & Mishra, 2009). • The teacher needs to know which technologies will best fit the subject matter that needs to be taught (Koehler & Mishra, 2009).
Pedagogical Content Knowledge (PCK)	• Pedagogical Content Knowledge is derived from Lee Shulman's idea and was adapted by Koehler and Mishra to include Technology (Koehler & Mishra, 2009). • Pedagogical Content Knowledge is how teachers understand what they need to teach and how to teach the content (Koehler & Mishra, 2009; Mavhunga & Rollnick, 2013).
Technology, Pedagogy and Content Knowledge (TPACK)	• TPACK is the overlap of Technology, Pedagogy and Content Knowledge. TPACK is how teachers are able to adapt their teaching strategies in how they teach using technology in their lessons (Koehler & Mishra, 2009). • TPACK can be used in play and formal teaching. The TPACK framework shows that Content, Pedagogy and Technology all have an important role and can be used in isolation but also together in the form of the TPACK framework (Bers et al., 2013; Koehler & Mishra, 2009).
Context	• The context is where teaching and learning take place, which is in the classroom and the grade the learners are in (Koehler & Mishra, 2009).

Table 2.6 shows how the TPACK framework comprises the eight sections that are linked. The table provides an outline of each part of the acronym. It is important to understand the TPACK framework and how it is used in the conceptual framework developed in this study.

2.12.2 Conceptual framework

For the purpose of this study the TPACK framework is used as a design tool to create lessons with the emphasis on integrating Technology into a STEAM lesson. It is a tool used to integrate Technology effectively into the three core concepts of Content, Pedagogy and Technology (Koehler & Mishra, 2009; Rahman, Krishnan & Kapila, 2017). Furthermore, Rahman et al. (2017) regard the TPACK framework as a means of helping teachers to improve their teaching, enrich learner understanding and create improved learning outcomes.

The framework and how it relates to the theories in this study was explored in Figure 2.4. There are eight different focus areas that are created in the framework and have been numbered from one to eight in Figure 2.5. Angeli, Voogt, Fluck, Webb, Cox, Malyn-Smith & Zagami (2016) used the TPACK framework to determine what teachers need to know to teach the subject Computer Science effectively. They also used the TPACK framework to discover the computational skills that teachers need to be able to teach. Bers et al. (2013) used the TPACK framework to evaluate a teacher professional development workshop. They looked at how robotics, engineering, programming and pedagogies were taught in an early childhood classroom.

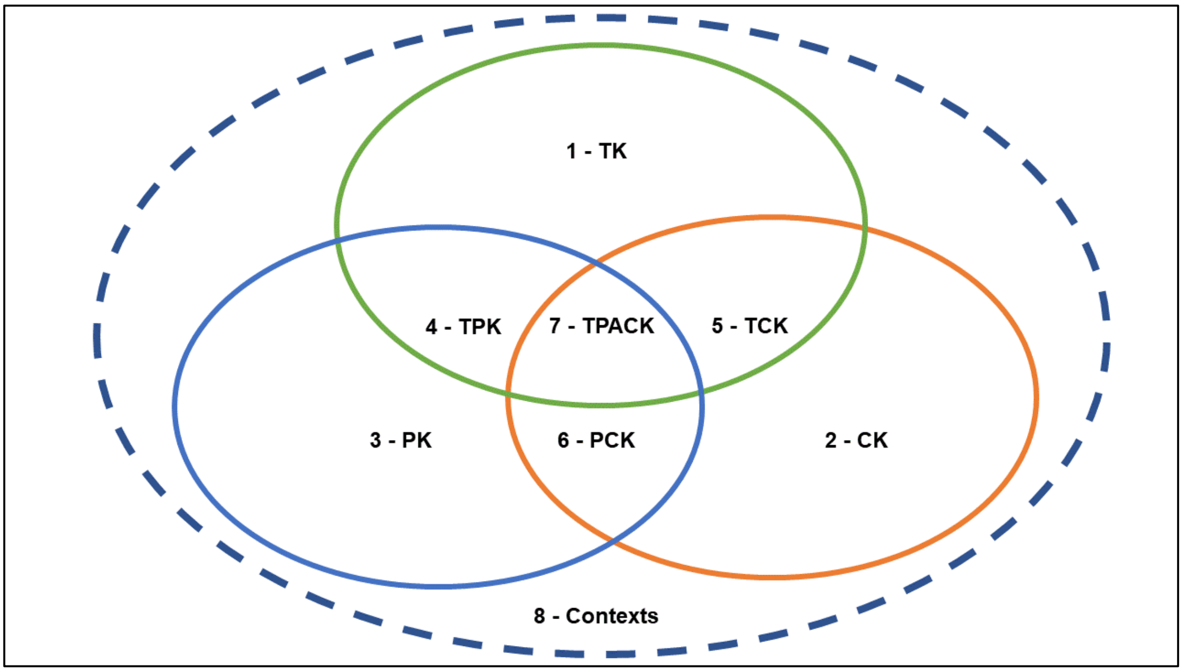


Figure 2.5 TPACK framework and its knowledge components

Adapted from Koehler, Mishra and Cain (2013)

The figure has been adapted for this study and is used as a design tool as shown in Figure *2.5* and was not used as an evaluation tool as illustrated in Figure 2.4. In Table *2.7* the framework is explained to see how it is used as a design tool.

Table 2.7 The TPACK framework focus areas

Numbers 1 to 8	**TPACK focus areas**	**Application in this study**
1	Technological Knowledge (TK) (Coding and robotics)	• In the lessons the educational technological knowledge was addressed through making use of Bee-Bots. • These are mechanical robots that move on a grid. • The learners needed to code the Bee-Bots to move on a planned route.
2	Content Knowledge (CK) (STEAM)	• The Content Knowledge included content from all STEAM subjects in a lesson.

Numbers 1 to 8	TPACK focus areas	Application in this study
3	Pedagogical Knowledge (PK) (Foundation Phase teaching, theories and strategies)	• Pedagogical Knowledge used concrete objects to complete the lesson as this is a focus in the Foundation Phase using the strategies of play-based and project-based learning.
4	Technological Pedagogical Knowledge (TPK) (21st century /digital skills)	• Technological Pedagogical Knowledge is the focus on the 21st century and the digital skills needed to complete the lessons.
5	Technological Content Knowledge (TCK) (Technology in this study)	• Technological Content Knowledge is how Technology as a subject is included to facilitate STEAM integration of STEAM subjects.
6	Pedagogical Content Knowledge (PCK) (How to teach STEAM)	• Pedagogical Content Knowledge relates to how teachers teach STEAM subjects.
7	Technological Pedagogical Content Knowledge (TPACK) (Computational thinking)	• Technological Pedagogical Content Knowledge relates to how computational thinking is incorporated into the integration of STEAM lessons.
8	Context: Grade 2 class	• The context is where the lesson took place; this was in the Foundation Phase using learners from Grade 2.

Table 2.7 shows how the researcher utilised the TPACK conceptual framework to design activities. The conceptual framework will look at each focus area separately and as a result there will be some overlaps. The TPACK framework was used as a design tool to create and assess lessons. The lessons can be found in Appendix G. This table indicates how each TPACK focus area was used in the study.

2.13 Conclusion

The Technology, Pedagogy and Content Knowledge (TPACK) framework was explored in this chapter.

The focus of Pedagogy is inquiry-based learning rather than rote learning in the Foundation Phase. The importance of inquiry was explored through the theories of Piaget, Vygotsky, Bruner and Dewey. Each of their theories was implemented in the study. Collectively they incorporated learning through manipulation of concrete objects, incorporating scaffolding into the lessons, making use of previous knowledge as well as ensuring lessons encouraged project-based learning. Play-based and project-based learning were incorporated in the design of the activities.

The focus of Content was the integration of all STEAM subjects as well as how to teach the content. STEAM was taught through project-based learning and being guided by the teacher as a facilitator. The activities were learner-centred and focused on problem solving, thereby developing the learners' ability to think computationally.

The focus of Technology was on how coding and robotics could be used in an integrated lesson. It is important to be able to distinguish between the two types of Technology discussed in this chapter. The technological tool in this study is the Bee-Bot. The subject Technology from STEAM is taught using the design tool in Figure 2.2; in this study the focus is on structures and the electronic systems and controls of the subject Technology.

The TPACK framework was central to this study and was used to develop a conceptual framework for designing and evaluating lessons.

Chapter 3: Research methodology

3.1 Introduction

Saunders et al. (2019) proposed a process to support the unpacking of the research methodology from abstract to practical. This is presented as a research onion, depicted in Figure 3.1**.** The six layers are the philosophy, the research approach, the research methodology, the research strategy, the time horizons and the techniques and procedures (Stainton, 2019).

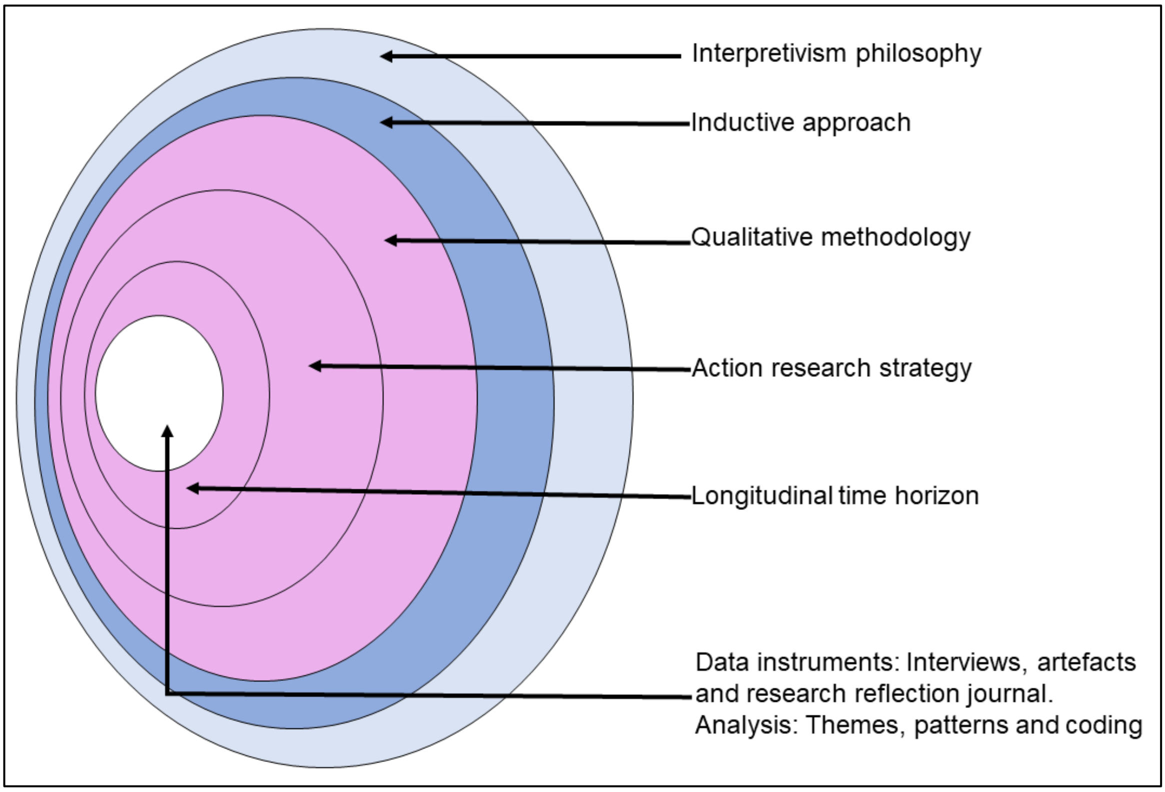


Figure 3.1 Research design according to the research onion

Adapted from Saunders et al. (2019)

The research design is illustrated in Figure 3.1. The design is presented in the text from the outer layer of the research onion, to the inner layers. The research onion includes interpretivism as philosophy, an inductive approach, a qualitative methodology, an action research strategy, a cross sectional time horizon and finally the data collection and analysis.

3.2 Philosophy: Interpretivism

Interpretivist research philosophy implies that reality is not objectively determined but is socially constructed (Nieuwenhuis, 2016c; Saunders et al., 2019). In this philosophy no distinction is made between the researcher and the event being studied (Jansen, 2016). The focus is on the learner as an individual and how the researcher investigates the unique experiences of each learner (Nieuwenhuis, 2016c; Saunders et al., 2019).

The advantage of this approach is the richness and complexity of the data gathered (Nieuwenhuis, 2016b). The challenge is for the researcher to understand and correctly interpret the views of the learners (Saunders et al., 2019). To conduct the study effectively, the researcher has to be empathetic and look at the views of individuals (Saunders et al., 2019).

In this study the interpretive philosophy is manifested in how learners make sense of what they learn through the environment and their own actions. Interpretivism was used to determine whether the learners had unique experiences and outcomes. In this study the researcher applied the interpretivist philosophy to assess the way in which the learners used Bee-Bots to integrate STEAM subjects as well as the individuals' views on their experience.

3.3 Approach: Inductive

The study followed an inductive approach. An inductive approach implies that research commences with gathering of data (Creswell, 2009). In the inductive approach the collected data is analysed to find themes and meanings through categorisation (Creswell, 2009; Yin, 2011). When the inductive approach is used, a researcher can move from the participants' points of view to finding the patterns and themes in the data collected (Willis, 2012).

There is a strong link between qualitative research and inductively analysed research as the data in both is examined in detail (Hatch, 2007; Saunders et al., 2019). The qualitative study is based on a research question rather than a hypothesis; therefore, the inductive approach was used so that the researcher could explore and investigate rather than trying to predict the outcome (Finlay & Ballinger, 2006; Woods, 2006).

This study analysed the data collected and was guided by the key themes in the conceptual framework. Meaning was interpreted through categorising the data according to the TPACK framework. The TPACK framework was used as a design tool to create and evaluate the lessons. The researcher posed questions about the data collected. The outcome was not predicted but rather explored to answer the research questions.

3.4 Methodological choice: Qualitative

A qualitative research methodology is used when the sample size of participants is small and the data gathered is open-ended (Saunders et al., 2019). Qualitative data needs to be interpreted by the researcher to extract meaning (Nieuwenhuis, 2016b; Saunders et al., 2019). Qualitative data is based on experiences and meaning rather than number values, which are quantitative data (Nieuwenhuis, 2016b). For data to be qualitative, the research question needs to be exploratory in nature and open-ended (Creswell, 2009; Nieuwenhuis, 2016b). The researcher needs to be attentive and able to extract meaning from the data gathered (Nieuwenhuis, 2016b). The meaning needs to be found in the individuals and how they experience different things (Nieuwenhuis, 2016b; Saunders et al., 2019).

The advantage of the data being gathered with a small group of participants is that the researcher can reflect on the data gathered, identify any gaps in the data and provide data for further researchers to work on (Nieuwenhuis, 2016b). The researcher and the expert reviewer enjoyed working with small groups of learners. The small groups enabled the researcher to have time to discuss the lesson with each learner during the lesson time. The challenge was to understand the experience of each individual participant (Saunders et al., 2019). It can be time-consuming for the researcher to make sure no data is left out (Queirós, Faria & Almeida, 2017; Yin, 2011). The researcher did not find it a challenge to understand the experiences of the learners as they discussed the activity during the lesson; she helped to add insight to the experiences of the learners. The process was time consuming to ensure all the data was correctly analysed and nothing was missed.

Qualitative data analysis was applicable to this study as the researcher explored the experiences of individual learners and extracted meaning through observations intended to answer open-ended questions. The researcher and the expert reviewer reflected on each lesson to see what they understood the learners' experience and then compared what they had observed to find a common theme.

3.5 Strategy: Action research

Participatory action research was used as the researcher was immersed in the study with other participants. This enabled the researcher to be a part of the inquiry and reflection process (Fran, MacDougall & Smith, 2006). Participatory action research allows the researcher to collaborate with the participants in the study (White, Suchowierska & Campbell, 2004).

3.5.1 Action research

Action research is used in qualitative methodologies. The researcher is important to the research design and takes part in the study to gain insight into the experiences of the participants (Mouton, 2001). Action research is used in small-scale research projects where the researcher takes a hands-on approach (Denscombe, 2014; Ebersöhn, Eloff & Ferreira, 2016). This methodology focuses on a real-world problem (Coghlan & Brydon-Miller, 2014; Denscombe, 2014; Tomlinson, 1997); it is a mode of inquiry where the researcher needs to be able to observe, plan and cooperate (Ebersöhn et al., 2016). This mode of inquiry leads to a cyclical movement between the problem, research questions and the results. The cycles are interactive, and the process includes planning, implementing (represented as observe and act), and reflecting (Denscombe, 2014; Ebersöhn et al., 2016) as illustrated in Figure 3.4.

A disadvantage of Action research is that it is hard for the researcher to remain impartial (Denscombe, 2014). According to Baum, MacDougall and Smith (2006) Action research can be very time consuming. The qualitative methodology was used for the methodological choice, which incorporated a small sample size. This can be seen as a disadvantage as the researcher needs to make sure that they do not generalise the results but rather describe what they saw. A small sample size can be justified as it is still a representation of the of the population (Boddy, 2016). Despite these disadvantages Action research was still a good decision as the researcher could be involved in the research.

According to Coghlan and Brydon-Miller (2014), McKernan (1988), Kemmis (2009) and Tomlinson (1997), John Dewey helped to give action research its practical quality. According to Kemmis (2009) and McNiff (2014), John Dewey regarded research as a process of inquiry. Therefore, it is important that the researcher is able to observe the learners' process of inquiry as well as being a part of the planning. According to

McKernan (1988), the researcher first needs to define the problem, then apply a plan of action to solve the problem and lastly reflect on the outcomes. This is seen in Figure *3.2* which illustrates an action research cycle of plan, act, observe and reflect.

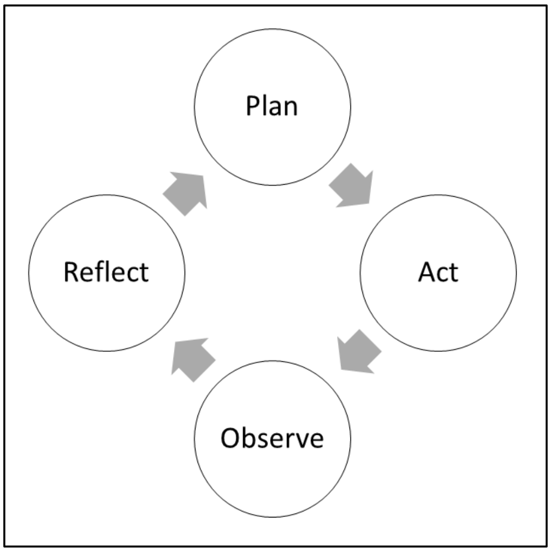


Figure 3.2 Action research: plan, act, observe, reflect

Adapted from Costello (2007)

In Figure 3.2 a typical action research cycle is illustrated. At first, the problem needed to be identified. The researcher then needed to plan how this problem could be solved. After this, the plan was implemented through action and collaboration. The action was observed by the researcher and the data gathered through these actions was analysed. Lastly, the researcher reflected on the findings of the actions to determine what could be changed. The process was cyclical and continued until the problem had been solved sufficiently.

In this study, the identified problem was to design STEAM integrated lessons to support the development of computational thinking through incorporating coding and robotics. The planning stage involved the creation of lessons using the TPACK framework as a design tool. During the act phase, the lessons were conducted, followed by interviews and analysis of the lessons. The researcher and the expert reviewer assessed the lessons based on the TPACK framework on an observation sheet after each lesson (Consult Appendix I, Reflection stage) and changes were considered. This cycle was repeated three times with three different lessons as Cycle 1. Cycle 2 included a fourth lesson and was completed by the learners based on their experiences and reflections made in Cycle 1.

According to Kemmis (2009), there is a relationship between the participants and the researcher as the researcher decides what is done or changed and conducts the observations. The aim of action research is to change the practices, the understanding of the practices and the conditions in which they are practised (Coghlan & Brydon-Miller, 2014; Eilks & Markic, 2011; Kemmis, 2009). Therefore, the researcher was involved in the planning, conducting and observations of the study, using the TPACK framework as a tool to create integrated lessons.

Action research has the primary purpose of improving and enhancing one's own practice to create an intervention (Coghlan & Brydon-Miller, 2014; Kemmis, 2009). According to Denscombe (2014), the aim is to improve the teachers' educational practices and the way they teach. Coghlan and Brydon-Miller (2014) suggest that an external researcher will help with the inquiry process as they will aid in identifying areas for improvement. In this study, there was an expert reviewer to assist with the interpretation of the data and to help the researcher remain impartial and validate the research. The study was guided by the goal of improving their own educational practices as well as creating guidelines for other teachers.

3.5.2 Setting of the study

Table 3.1 shows who the participating learners were and the setting the study was conducted in.

Table 3.1 Learners and school setting

The learners	• Only girls • Grade 2 learners • Previous exposure to digital devices
The school	• South Africa • All-girl private school • Adapted CAPS (Curriculum Assessment Policy Statements) curriculum • Foundation Phase • Implementing STEAM in subjects based on TPACK

The learners were from Grade 2 and the expert reviewer was a retired teacher from the school. The focus was on integrating subjects in the Foundation Phase as the subjects were taught in isolation at the time of data gathering. The researcher aimed to provide guidelines that could be used by teachers to create integrated STEAM lessons.

3.5.3 Conducting the action research

For this study the lessons were designed using the TPACK framework shown in Figure 2.5. in Chapter 2. For the framework to be effective, Content, Pedagogy and Technological Knowledge all needed to be included. Content Knowledge featured in each lesson by ensuring that all STEAM subjects were included. The assessment of the Pedagogy Knowledge in each lesson was done through the inclusion of Foundation Phase teaching methods, including the use of concrete objects, incorporation of scaffolding and the use of a story. Technology Knowledge was observed by using Bee-Bots in each lesson. The focus of this study was on the integration of STEAM through collaboration in project-based lessons with the incorporation of Bee-Bots.

3.6 Research design

The research design was based on the action research strategy and followed the cyclical design of plan, act, observe and reflect as seen in Figure 3.3.

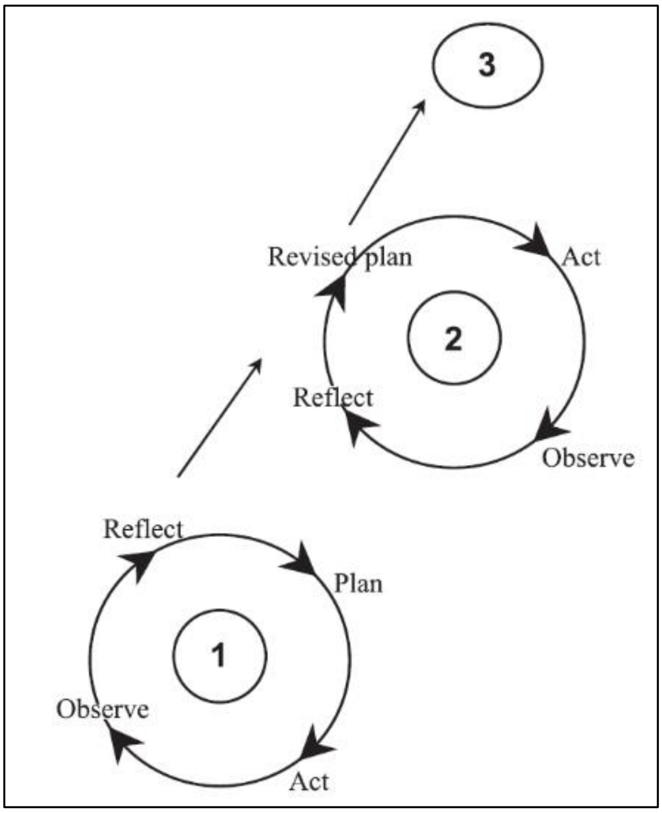


Figure 3.3 Action research process

Source: Altrichter, Kemmis, McTaggart and Zuber-Skerritt (2002)

In Figure 3.3 the flow is seen in the arrows – from plan to act to observe and to reflect. It is seen in the first cycle and is then repeated in Cycle 2 and flows into Cycle 3.

The researcher used action research to collect data when the lessons were presented. Figure 3.4 indicates that the first step is to plan the lesson. The second step is to implement the lesson. Reflection is the third step and took place during each cycle in the form of observation completed by the researcher and the expert reviewer. These observations used questions based on the TPACK conceptual framework and the lesson plans to reflect on which aspects were seen in the lesson found in Appendix E.

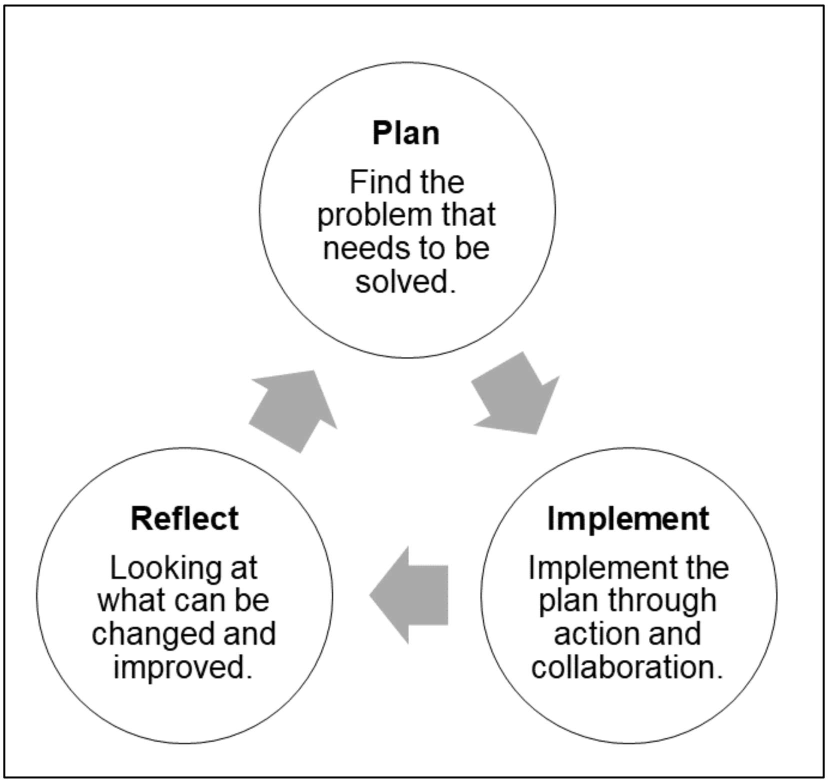


Figure 3.4 Action research: Plan, Implement, Reflect

Adapted from Ebersöhn et al. (2016)

For the purpose of this study, Figure 3.4 was adapted into a figure that illustrates the action research process used for this study. The action research process of planning, implementing which encompass the act and observe phase of the action research, and reflecting took place in two phases, and each focused on a set of lessons. Two action research cycles took place. The first cycle included Lessons 1 to 3 and the second cycle included Lesson 4.

The cycles followed the arrows, moving from plan to act and observe, then to reflect. For these cycles, act and observe were included in a single step. This is because one consciously observes what happened during the lessons by making notes, and taking photos. The researcher and expert reviewer could expand the reflection just after the lesson to ensure one does not forget important observations.

The research design for this study is depicted in Figure 3.5. There were two cycles in this study. The first cycle included the three lessons designed, using the TPACK framework. The second cycle was the fourth lesson where the learners used what they had learnt from the first cycle to complete the lesson. The output of Cycle 2 was used to create guidelines for teachers to create their own lessons.

The action research cycle depicted in Figure 3.5 was adapted from the cyclical movement found in Figure 3.3 and the steps in Figure 3.4. Each aspect of Figure 3.5 is explained in more detail in Chapter 4. The research process summary is illustrated in Table 3.2 and shows the process that the researcher followed. The research process aimed to answer the research questions posed by the researcher.

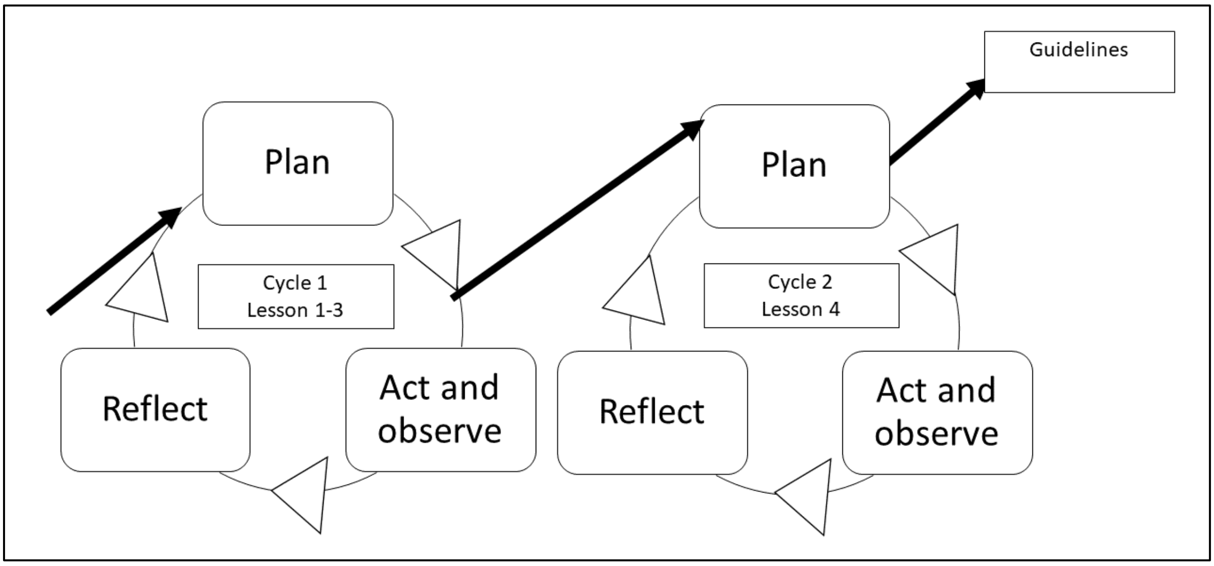


Figure 3.5 Action research in this study

Adapted from Altrichter et al. (2002)

Table 3.2 shows the five steps needed for the research process and includes the data instruments for each step as well as who the participants were. Each step has a focused research question and the table shows which part of the action research cycle the step falls in.

Table 3.2 Research process summary

Steps	Data Instrument	Participants	Research Question	Action Research Cyclical Stage	Appendix
1 Design the activity	• TPACK Guidelines sheet • Journal record	• Researcher • Expert reviewer	SRQ 1. How can TPACK be utilised to design coding activities?	Planning	Appendix C Appendix G
2 Evaluate the activity	• Review sheet based on TPACK • Journal record	• Researcher Expert reviewer	SRQ 1. How can TPACK be utilised to design coding activities?	Planning	Appendix D
3 Activities and observation	• Observation sheet based on TPACK • Photographs • Journal record	• Researcher • Expert reviewer • Seven learners	SRQ 1. How can TPACK be utilised to design coding activities? SRQ 2. How do learners experience these activities?	Act and observe	Appendix E
4 Analysis of the activity	• Photographs • Interviews • Artefacts • Research Reflection journal	• Researcher • Expert reviewer • Seven learners	SRQ 1. How can TPACK be utilised to design coding activities? SRQ 2. How do learners experience these activities?	Reflect	Appendix F Appendix J
5 Guidelines	• Guidelines for teachers to create their own activities	• Researcher	RQ. How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?	Guidelines / Output	Appendix L

Table 3.2 shows the steps that were followed to adhere to the action research cyclical stages. There are five steps that were followed in a specific order. The researcher and the expert reviewer designed the activities and then evaluated them. They observed and analysed the activities that the learners took part in. The analysis (reflection) and design of guidelines were the last step.

Figure 3.6 is an extension of Cycle 1 from Figure 3.5. In Figure 3.6 the dark arrow points to where the researcher started the process by finding the problem that needed to be solved and led to the plan.

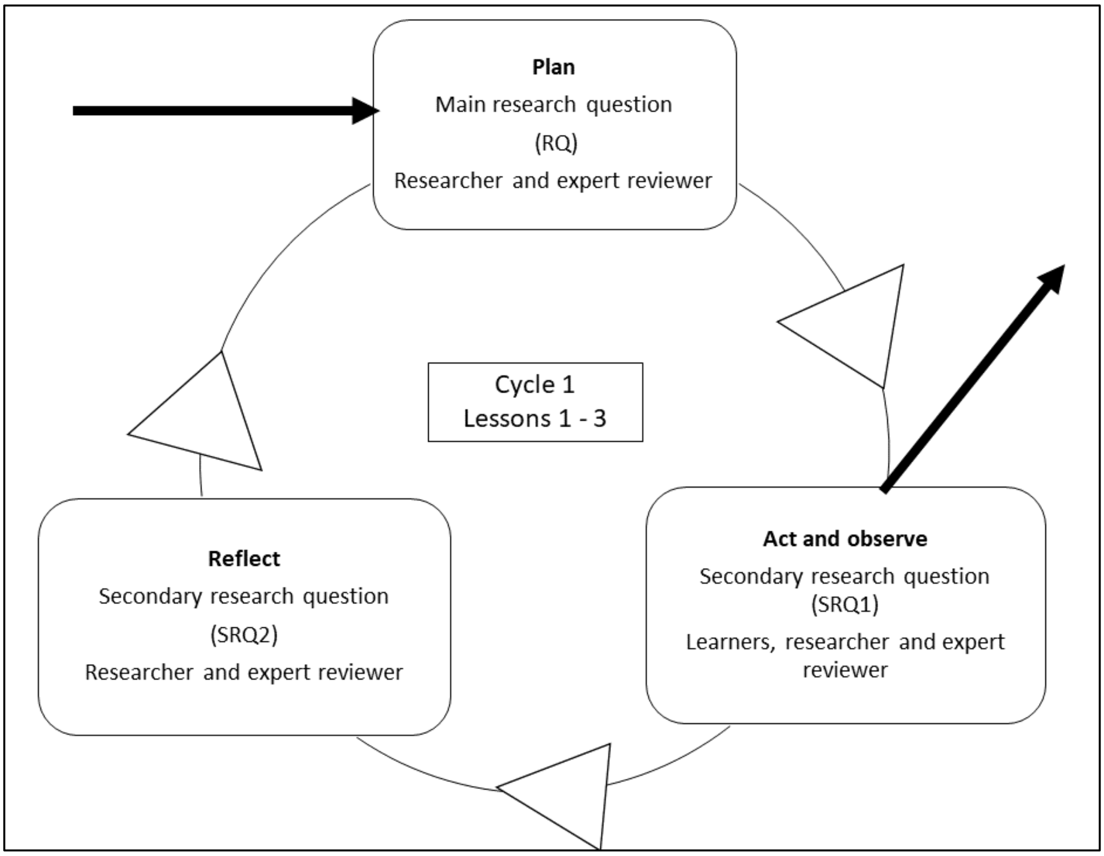


Figure 3.6 Action Research Cycle 1

Each lesson was planned and reviewed based on the TPACK conceptual framework before it was presented. The open arrows indicate the movement of the cycle from *plan* to *act and observe* to *reflect* and back to *plan*. Each of the three lessons had to be planned, observed, and then reflected on before moving to the next lesson. Figure 3.6 shows the individual stages, the research question that was being observed and the participants involved.

Figure 3.7 is an extension of Figure 3.5 to show Cycle 2. The reflections made in Cycle 1 were used as input for planning in Cycle 2 where the final lesson took place.

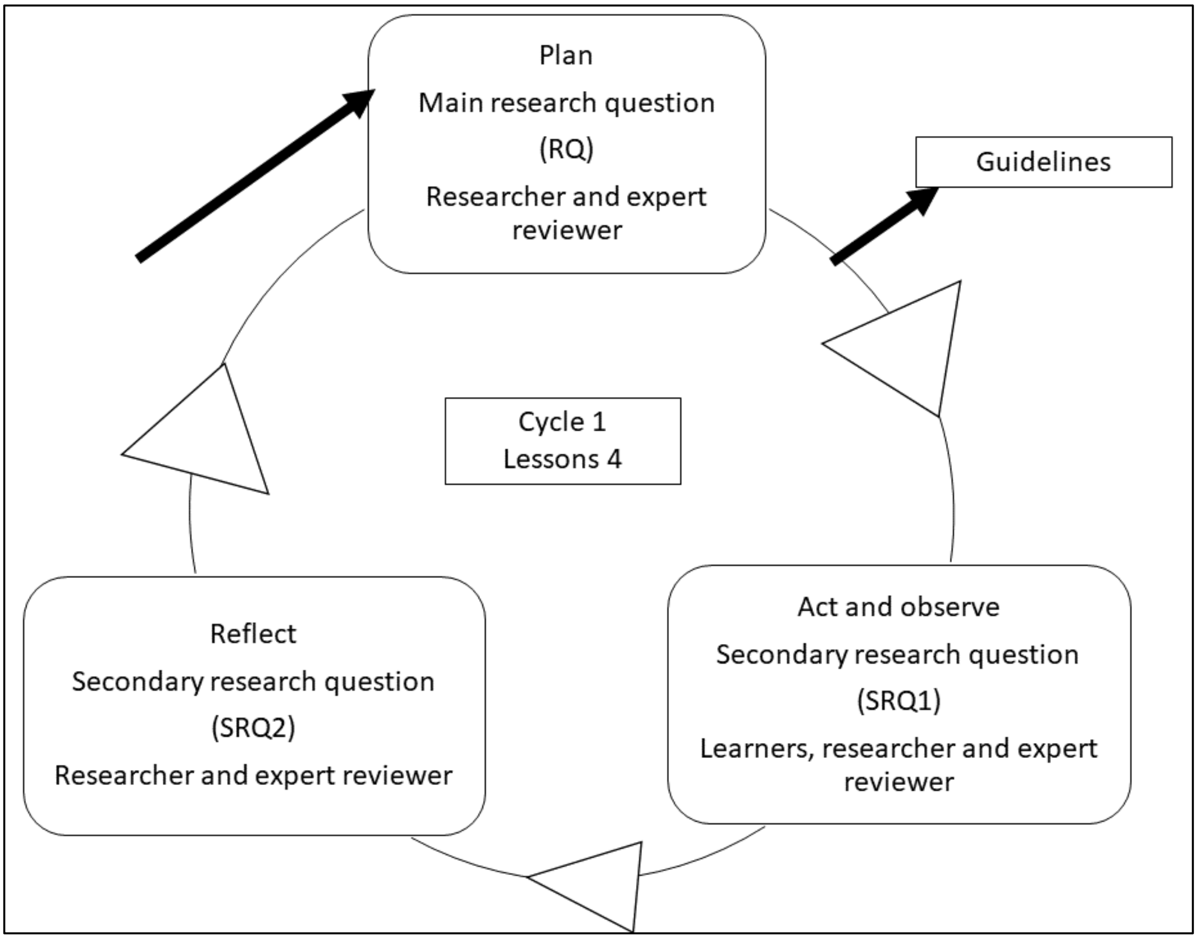


Figure 3.7 Action Research Cycle 2

In the final lesson the learners chose the problem that they wanted to solve and the researcher observed whether they could include all STEAM subjects when completing a lesson. Figure 3.7 shows the individual stages, the research question that was being observed and the participants involved. The final output from Cycle 2 after reflection included the guidelines for teachers to design their own lessons.

3.7 Longitudinal time horizon

The time horizon was longitudinal as the data was collected over a period of time and was compared (Melnikovas, 2018). The strategy of action research is often used with the longitudinal time horizon (Saunders & Tosey, 2012/2013). There were two action research cycles and the data was collected over two weeks. This allowed the data in Cycle 1 to be compared to the data collected in Cycle 2. Four lessons were presented, each lasting 45; time was set aside for the interviews with the expert reviewer and the learners. Cycle 1 took place with one lesson a day from the 17th to 19th of November

2020. Cycle 2 which included a single lesson, took place on the 20th of November and the interviews happened on the 23rd of November.

3.8 Data collection and analysis techniques and procedures

For the data collection to begin the participants for the study needed to be selected. The data instruments were needed to ensure enough information was collected from the data. The data was then analysed for themes.

3.8.1 Selection of participants

The learners were selected based on stratified purposive sampling as they were chosen with a specific purpose in mind (Nieuwenhuis, 2016c). Stratified purposive sampling was chosen as the group was homogeneous as they are all had the same important characteristics needed for the research (Nieuwenhuis, 2016c). The learners were selected from the school where the researcher works, which is an all-girls school and therefor all the participants were girls. The learners worked in groups of three and there were two groups, one group from each Grade 2 class. They were chosen randomly if they could stay after school hours. The parents/guardians had to give their consent for their daughters to be participants.

The participants and their roles are discussed in Table 3.3. For this study there were three different participant types: The learners, an expert reviewer and the researcher.

Table 3.3 Participants

Participant	Characteristics	Consent	Role in the Study
Learners	• In Grade 2 • Consent and assent given	• Signed assent from learners • Signed consent from parents/guardians	• Take part in the lessons in a learner's role. Group A and Group B. • Take part in an interview.
Expert reviewer	• Qualified Foundation Phase teacher • Knowledge of integrating subjects • Knowledge of IT integration • Knowledge of digital devices, including Bee-Bots	• Signed consent form • Appendix B	• Design, evaluate, observe and reflect on the lessons. • Analyse the content of the lessons. • Take part in an interview. • Help the researcher to remain unbiased.
Researcher	• Qualified Foundation Phase teacher		• Design, evaluate, observe and reflect on the lessons. • Facilitate the lessons in a teacher role. • Create lesson guidelines for teachers to use.

As shown in Table 3.3, the expert reviewer worked closely with the researcher to design and evaluate the activities. The expert reviewer was a good choice as she met all the requirements. She was a retired Foundation Phase teacher with 31 years teaching experience; she was an IT integration teacher and had extensive knowledge of Bee-Bots. They also observed and analysed the activities together after they had been presented. The learners solved the problems presented in the activities. The learners were all girls from an all-girls private school and took part in the 4 lessons.

3.8.2 Data collection and instruments

There were five steps that the researcher followed for the collection of data. Table 3.4 depicts the role players in each step, the research question being explored and the data instruments that were included to document the outcomes of each step. There were five data collection instruments: review of activities, observation of activities, interviews of the learners and the expert reviewer, artefacts in the form of photographs and a reflection journal of the researcher. The research journal was used to make notes of the researcher's observations. The observations were made to make it easier to remember what had happened in the lessons and to recall important aspects that stood out.

Table 3.4 Steps in the research progress

Step Number	Step Description	Role Players	Relationship to Research Questions	Data Instrument Used
1	• Design the activities that are to be presented. The lessons can be found in Appendix C	• Researcher	• SRQ1. How can TPACK be utilised to design coding activities?	• Lessons plans
2	• Evaluate the activities based on the review sheet as found in Appendix D.	• Researcher and expert reviewer.	• SRQ1. How can TPACK be utilised to design coding activities?	• Review sheet
3	• Observe the activities using the observation sheet found in Appendix E.	• Researcher and expert reviewer observe the participation from the learners.	• SRQ1. How can TPACK be utilised to design coding activities and SRQ2. How do learners experience these activities?	• Observation sheet • Photographs • Reflection journal
4	• Reflect on the activities that were presented. Appendix F • Conduct interviews with the learners and expert reviewer. Appendix J	• Researcher and expert reviewer.	• SRQ1. How can TPACK be utilised to design coding activities and SRQ2. How do learners experience these activities?	• Artefacts • Interviews

Step Number	Step Description	Role Players	Relationship to Research Questions	Data Instrument Used
5	• Guidelines for teachers to create their own lessons based on the TPACK framework.	• Researcher and expert reviewer	• RQ. How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?	• Guidelines

The first instrument for making observations was a checklist to ensure that all the criteria were implemented in the integrated lessons (Consult Appendix C, Appendix D). The checklist was linked to the TPACK framework and was used to help set up the activities to include all the STEAM subjects in a single lesson. Appendix C used the TPACK design tool to ensure that all STEAM subjects were included, Appendix D was used once the lessons were created to ensure nothing had been left off. Observations are more than just being able to see what the learners are doing (Appendix E); a researcher needs to plan what is going to be observed and gain an understanding of what has been observed (Naudé & Davin, 2017). The observations helped the researcher and the expert reviewer to see what aspects were present in the lesson based on the TPACK design tool. The observations were made during the third step in the research process as indicated in Table 3.4.

The second and main data collection instrument used was interviews (Appendix J). The intention of the interview is to establish the participant's views and ideas from the study that has been conducted (Nieuwenhuis, 2016c). The researcher conducted interviews with the expert reviewer and the learners. The interviews were structured with detailed open-ended questions. Transcripts were made from the interviews that created a link between the researcher and the participants (Nieuwenhuis, 2016c).

The third instrument included artefacts from the activities (Appendix K). The artefacts were pictures taken during the activities with the consent of the relevant parties. Other artefacts included instruction cards, scientific method sheets and Bee-Bots jackets as well as obstacles.

The fourth instrument was a researcher reflection journal in which the researcher recorded what had been observed (Consult Appendix F). This was used by the researcher from the moment the lessons were designed to when the activities were carried out. The purpose of the journal was to keep track of what happened. The journal was not analysed as it was used to support the observation process.

3.8.3 Data analysis

The data was explored to find the themes and patterns that featured when using the TPACK framework. The focus was on the experiences that the individuals had while the data was collected (Saunders et al., 2019). More than one reality was to be found in the data (Maree, 2016). The data collected showed the learners' views of the world around them (Saunders et al., 2019). The data was coded to determine the different categories in the data that linked to the TPACK framework (Maxwell, 2012). Coding was needed to extract the meaningful information from the data; it was done in the form of a label (Nieuwenhuis, 2016a). The researcher and the expert reviewer observed the lessons and then discussed them to see what they had both experienced and noted in the lessons. This enabled the researcher to make links and see how the integration of subjects took place. In this study, the coding of the data was done using different colours as seen in Table 4.3 to Table 4.11.

The research shows the individual participants' perspectives (Willis, 2012). The data collected from multiple sources are rich in information and the analysis clarifies the implied meaning in the text and aims to find to find the exact meaning (Nieuwenhuis, 2016a).

Chapter 4 is colour-coded as seen in Figure 3.8 to show the links with the literature in purple, the emerging guidelines for teachers in green and the lessons from Cycle 1 in blue and Cycle 2 of the action research in pink. Each lesson was unpacked using the TPACK to ensure that each aspect of the TPACK conceptual framework was present in the lesson.

Cycle	Project-based learning
Cycle 1	The problem was chosen by the researcher for the participants to solve. The problem the learners had to solve became increasingly difficult with each task. STEAM subjects were all integrated when they solved the problem using skills from each subject.
Cycle 2	The problem was chosen by the participants to solve in their project. STEAM subjects were all integrated without the guidance of the researcher.

The emerging guideline is the importance that teachers should have the knowledge of what STEAM integration is to teach the subjects effectively. When project-based learning is used to teach STEAM, it creates steps to follow to ensure the content is being taught (Ridwan et al., 2017). This is seen in Table 4.8 as the participants used project-based learning to solve the problem.

Figure 3.8 Example of colour coding

Photographs were included to show how TPACK was used in the lesson. The responses from the interviews with the learners are colour-coded according to three themes of (PK) Foundation Phase teaching, (TK) coding and robotics and (TPK) 21st century and digital skills.

Chapter 0 examines the DBE framework and compares it to the lessons presented. The research questions are discussed in detail.

3.9 Trustworthiness

In qualitative research, the trustworthiness of the study is about establishing the following four criteria: the Credibility, Transferability, Dependability and Confirmability of the research (Guba, 1981). These concepts are discussed further in Table 3.5.

Table 3.5 Trustworthiness concepts

Trustworthiness	Definition	Implemented in the Study
Credibility	• The researcher has to ensure that she has frequent debriefs with her supervisor as well as make use of a journal (Nieuwenhuis, 2016a). • Have interviews to verify the data collected to ensure that the same meaning is found (Nieuwenhuis, 2016a; Guba, 1981).	• Made sure that the researcher developed relationships with all the participants. • Got the expert reviewer to review the data collected with the researcher.
Transferability	• Two strategies need to be applied. First the researcher needs to give a thick description of the context of the study, who the participants are and the research design. • The second is stratified purposive sampling as the participants need to be chosen with the context in mind (Nieuwenhuis, 2016a).	• There were clear indications of the context of the study as well as who the participants were. • The research design was clearly represented with figures to aid in the understanding of the design. • The researcher ensured that the research process was credible by using the well-established TPACK framework to create and evaluate the lessons. • The research onion was used to unpack the research design clearly and systematically from abstract to concrete.
Dependability	• It is recommended to keep journals of what changes have been made and the data collected to have something to reflect on (Nieuwenhuis, 2016a).	• The researcher kept a journal that contained the notes from the lessons and reflections that were made. This helped when reflecting with the expert reviewer to see the researcher's point of view.
Confirmability	• The importance is placed on the participants' findings and not the researchers' bias; this can be done by leaving an audit trail (Nieuwenhuis, 2016a).	• The researcher had the help of the expert reviewer to ensure there was no bias. • The researcher had participants from the Grade 2 class.

It is important in qualitative research that the research process is trustworthy. It was important that the researcher facilitated the lessons, ensuring that they were learner-centred and that the learners were able to collaborate in their groups.

To ensure that there was consistency in the lessons, the researcher made sure that the three lessons were all presented in the same manner and that the participants remained the same throughout.

The expert reviewer played an important role in the trustworthiness of the study as they worked with the researcher to observe the lessons and reflect on the themes observed. The way the data was interpreted was a process to ensure trustworthiness.

3.10 Ethical considerations

The researcher had to ensure that she was always morally and ethically correct when conducting research (Saunders et al, 2019). According to Denscombe (2014), it is important for participants to be given permission before observations and data collection can commence. According to Denscombe (2014) and Creswell (2007), the safety of the participants should be the researcher's top priority.

The letters of consent gave the guarantee that the participants would remain anonymous during data dissemination (Found in Appendix B). Even though the researcher knew all the learners, their anonymity during data dissemination was adhered to by not referring to their names. It was also ensured that their faces were not recognisable on the photographs included. A letter of consent was sent to the learners and guardians of the learners to sign. The school's headmistress gave the researcher permission to conduct the study on the school's premises and she wrote a letter on a school letterhead to show the school's support of the study being conducted. The expert reviewer signed letters of consent, allowing the participants to be interviewed and to be observed.

The learners were required to sign assent letters and forms as well as have signed letters and forms from their parents/guardians. The format of the letters can be found in Appendix B. The learners were expected to participate during the three collaborative activities and the observation process. They were required to take part in an interview that formed part of the data of the activities. If learners or their parents did not give consent, another learner was given a consent letter to be filled in to take part. This was done to ensure that a total of six learners took part as mentioned above.

The participants took part voluntarily. During the data collection, the learners' safety is important. The privacy of the learners was upheld by ensuring that they were not recognisable in images. The researcher accommodated learners who had not given consent to having their photographs taken by giving them a sticker on their clothing to identify them by the expert reviewer and researcher so that their photographs were not taken. The consent forms were reviewed before each of the lessons and if required, the participants were given a sticker at the start of each lesson.

The participants wore a face mask at all times and sanitised regularly. It was mandatory in South Africa to wear a mask (Olsen, Azziz-Baumgartner, Budd, Brammer, Sullivan, Pineda, Cohen, Fry, 2020). These regulations were in line with the school's Covid-19 regulations to help prevent the spread of the pandemic in the school. The school's Covid-19 committee was consulted to ensure that all the protocols were in place during the study.
Before this study commenced ethics clearance was granted by the University of Pretoria. This was to ensure the safety of the participants.

3.11 Conclusion

The research onion was used as main research methodology in this study with examples from literature. The methodology followed an interpretivist philosophy in an inductive qualitative approach through an action research strategy.

Ethical considerations from literature have been presented and the details of how they were implemented are discussed. All participants needed to agree to take part in the study and a guarantee was given, particularly to the learners taking part that they would remain anonymous.

With the principles of the research onion as well as ethical considerations a final research design was presented. The design included an action research cycle adapted from Altrichter et al. (2002) where each cycle is adapted from the research process of Ebersöhn et al. (2016). This resulted in the research design used in this study; it included two cycles consisting of *plan*, *act and observe* and *reflection* stages. Cycle 1 included lessons 1 to 3 and the results from the *reflection* stage were used as input in

Cycle 2’s *plan* stage. The results from the *reflection* stage of Cycle 2 were used to develop guidelines for teachers to create their own lessons. The next chapter examines the data collection instruments.

Chapter 4: Results

4.1 Introduction

This chapter presents the results of the study and is structured according to both action research cycles and the TPACK conceptual framework. Figure 4.1 shows the two action research cycles and how the lessons were first planned, then the researcher and the expert reviewer presented and observed the lessons and finally reflected on the lessons.

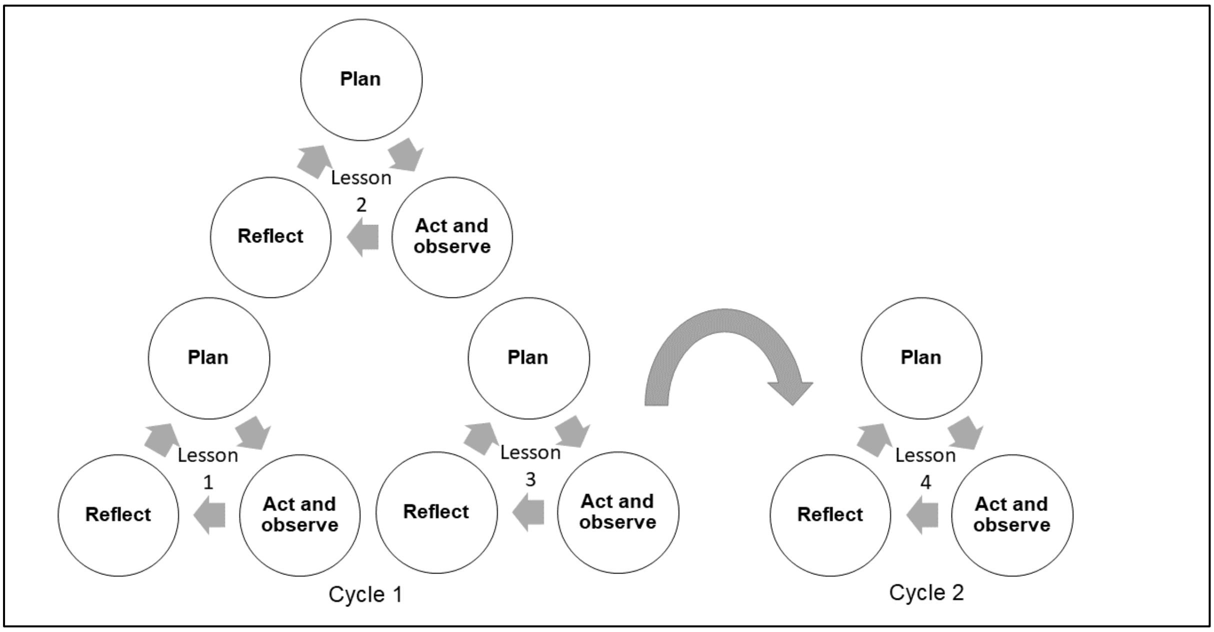


Figure 4.1 Results structure

Adapted from Costello (2007)

Figure 4.1 shows how each lesson from 1 to 4 had its own action research cycle. The lessons were planned using the planning sheet and then reviewed to ensure that all aspects of the TPACK framework had been included. The underlying coding concepts increased in difficulty level from lesson 1 to lesson 4. The lessons were planned based on the TPACK framework found in Appendix C. The RQ, "How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?" was the focus as the lessons needed to be designed utilising the TPACK framework to ensure that all relevant aspects, including STEAM integration, were included.

The lessons were implemented using the guidelines of the relevant lesson plan. This ensured that each lesson had a structured beginning, middle and conclusion. The beginning was reading the story book, *If I were a wizard* by Paul Hamilton (Hamilton, 2017). This allowed the learners to picture the problem that they were going to solve.

The middle section of the lesson involved the problem solving process using Bee-Bots and coding a sequence. The conclusion was for the learners to discuss what they had learnt and to ensure that everything was packed away.

The researcher and the expert reviewer observed each lesson, utilising the observation sheet found in Appendix E. After each lesson they reflected, utilising the observation sheet and discussed the lesson to see if all the outcomes had been met and what they had observed during the lesson. They also needed to consider whether the 21st century skills and digital skills were implemented in the lesson. The next lesson was then presented in the same way following the cycle of plan, present (act and observe) and reflect.

The TPACK framework was used to unpack the data collected; it was used to create, observe, evaluate and reflect on all the lessons created. In Tables 4.3 to 4.12 the researcher compared the four lessons based on the unpacking of the TPACK framework. These findings are presented in the following section. There is a flow from one lesson to another with correlations in the way the lesson is presented. The data was reviewed in a table that can be found in Appendix I to compare the four lessons.

The instruments of data collection and where they can be found are included in Table 4.1. The different instruments served as a tool to ensure there was evidence of the data collected. The activities are unpacked using the TPACK framework and were substantiated by the observations by the researcher and expert reviewer as well as the photographs that were taken. The interviews helped to get a sense of what the individual's experience was in the process. The reflection journal helped the researcher to document thoughts of what happened when reflecting on the day.

Table 4.1 Instruments of data collection

Data collected	Discussed
Observe activities Artefacts	4.3 discussed the results from the lessons and made use of the photographic artefacts to substantiate the result.
Interview with expert reviewer	4.3.2 and 4.3.3
Interview with learners	4.3.2 etc.
Reflection journal	Chapter 5: Findings and conclusion

The data collection has been coded in the results to create a guide to how the results link back to the literature, the emerging guidelines for teachers and the two cycles of action research.

4.2 Results guide

Colours have been used in in the text Chapter 4 to create meaning. Table 4.2 shows the different colours and what they indicate. The table acts as a guide when reading Chapter 4.

Table 4.2 Colour coding in Chapter 4

Description	Colour
Link to Chapter 2: Literature review	Purple
Emerging guidelines	Green
Cycle 1 Lesson 1 to 3	Blue
Cycle 2 Lesson 4	Pink

4.3 TPACK findings unpacked

SRQ 1, "How can TPACK be utilised to design coding activities?" was investigated during this step. The researcher and the expert reviewer filled in an observation sheet at the end of each lesson found in Appendix I. The researcher and the expert reviewer sat together to compare their observations of the lessons and looked for any themes.

The interviews were conducted at the end of the data collection when all four lessons had been completed.

The observation notes for each lesson of both the expert reviewer and the researcher are captured in Appendix I. The learners were divided into two groups, Group A and Group B throughout all the lessons. The learners in these groups were known as Participants 1 to 7 to ensure anonymity. Participants 1 to 3 were in Group A and Participants 4 to 7 were in Group B. Lessons 1 – 3 formed part of Cycle 1 and Lesson 4 of Cycle 2.

The following paragraphs provide the collective results of all the lessons, as extracted from the observation notes for each of the TPACK knowledge areas.

4.3.1 Pedagogical Knowledge (PK)

Pedagogical Knowledge results are shown in Table 4.3. In this study, the Pedagogical Knowledge is illustrated through the concrete objects used in Foundation Phase teaching as well as the story linked to each lesson. These are concepts that are important in the Foundation Phase. Both Piaget and Bruner regarded the importance of learners learning through the use of concrete objects as a stage in their development (Charlesworth & Lind, 2010; Huitt & Hummel, 2003). The learners made use of a variety of different concrete objects; each lesson included Bee-Bots and other concrete objects to make obstacles. The learners used much of their prior knowledge when completing the activities. This is linked to the theorist Vygotsky who said that learners learn from their past experiences (Mayesky, 2012).

Table 4.3 Pedagogical Knowledge

<table>
<tr><th colspan="3">Pedagogical Knowledge (PK) in Foundation Phase teaching</th></tr>
<tr><th></th><th>Concrete objects</th><th>Story</th></tr>
<tr><td>Lesson 1</td><td>The learners used concrete objects in the form of Bee-Bots to navigate around the structures they had created using Lego.</td><td>The first lesson was a story about how Hazel, the main character, helped Aunty Matilda get to work the fastest way if she was a wizard.</td></tr>
<tr><td>Lesson 2</td><td>Both groups used concrete objects to build and create obstacles for the Bee-Bots to navigate around. They used pipe cleaners to make glasses.</td><td>The second lesson was to see if Hazel could help Grandpa Leo retrace his steps to find his missing glasses.</td></tr>
<tr><td>Lesson 3</td><td>Both groups used Bee-Bots and Lego to build obstacles. Group A also made the lost blueberries.</td><td>The third lesson was to see whether Hazel could help her dad to create a new dish following the steps of preparing a dish.</td></tr>
<tr><td>Lesson 4</td><td>Both groups used concrete objects to create the obstacles for the different settings.</td><td>Group A chose to help Cousin Milo surf 10 perfect waves. Group B chose to teach Frank the caterpillar to sing, sit and dance.</td></tr>
<tr><th colspan="3">Photographs</th></tr>
<tr><td>Each group received a box with the concrete objects they could make use of for the activity.</td><td>
Picture 1: All lessons</td><td>Picture of the concrete objects each group received in a box.
HB and coloured pencils, glue, white board markers, cardboard, straws, pipe cleaners, ice cream sticks, elastic bands, and Lego blocks.
These objects were used to build structures and create Bee-Bot jackets.</td></tr>
</table>

As illustrated in Table 4.3, each lesson had a story associated with the lesson. This is an emerging guideline as it was important that the learners had something to relate to. Having a story to follow helped them to create a picture of the problem they were going to solve. This allowed the learners to visualise what they were going to create and what they would add to the Bee-Bot mat. The Bee-Bots were concrete programmable toys that were used in each lesson. As stated by the expert reviewer, it was easy for the learners to use them and the buttons made the coding manageable. There were multiple concrete objects in the box that the learners made use of. These helped the learners to create and make the obstacles and structures on the Bee-Bot mat.

Piaget and Bruner both regarded learning with concrete objects as a stage in their development. The learners in this study were in the stage of concrete operations and according to Piaget, this allowed them to visualise what the concrete objects would do (Charlesworth & Lind, 2010; Huitt & Hummel, 2003). This was seen clearly in the study when the learners mapped the route the Bee-Bot would take on a piece of paper. They then had to code this using a Bee-Bot and get around the 3-dimensional structures they had created.

Table 4.4 depicts the differences and similarities between Cycle 1 and Cycle 2 in the action research strategy.

Table 4.4 Cycle 1 and Cycle 2 Pedagogical Knowledge

Cycle	Story	Objects
Cycle 1	Single story chosen by the researcher.	Bee-Bots and Lego
Cycle 2	Single story chosen by the learners.	Bee-Bots, Lego and paper

Both Cycle 1 and Cycle 2 made use of a story for the introduction to the lesson and with which to solve the problem. The problem was presented in the story and therefore the learners could choose the problem they wanted to solve in Cycle 2. Group A chose to help cousin Milo to surf 10 perfect waves and Group B chose to teach Fred the caterpillar to sing, sit and dance by following the correct sequence.

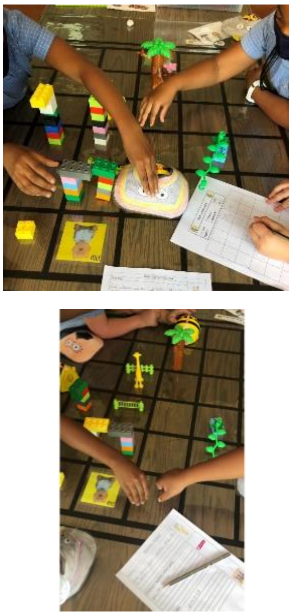
4.3.2 Technological Knowledge (TK)

Educational Technology Knowledge was explored in Table 4.5. In this study, the Technological Knowledge is coding and robotics. The learners used the Bee-Bots to create a string of code in each lesson. The complexity of the coding progressed in each consecutive lesson. This aligns with Chalmers (2018) and DBE (2021) as learners created sequences when coding. The learners sequenced a code to get the Bee-bot from the start card to the end card. They coded a route that solved the problem while making sure the Bee-Bot went around the obstacles. There was therefore progression in their coding skills in each lesson.

The technology they worked on was offline coding because the Bee-Bot did not require an internet connection to work. When learning to code, learners started by learning to sequence a simple set of instructions and then they could progress to more difficult coding such as loops of code or a longer sequence. The Bee-Bot mat consists of 15 cm x 15 cm blocks with a start and end card. The learner starts by placing the Bee-Bot on the start card and programs the movements so that the Bee-Bot will arrive at the end card while going past checkpoints and avoiding obstacles as per the story.

Table 4.5 Technological Knowledge

Technological Knowledge (TK): Coding and robotics	
Lesson 1	The first lesson was a straightforward start to finish coding sequence using the smallest number of steps on the Bee-Bot grid. Group A and B were both proficient in using the Bee-Bots.
Lesson 2	The second lesson had a sequence that needed to be followed for Grandpa Leo to find his glasses. He needed to go to each card in the correct order to find his glasses. The learners in Group B were proficient with coding. Group A showed more confidence when coding.
Lesson 3	The third lesson was a longer sequence of code that needed to be followed to complete the recipe successfully. Group A was more confident with using Bee-Bots; Participant 2 still wanted to be in charge. Group B were extremely confident with using Bee-Bots and enjoyed developing new skills of a longer sequence of code to follow.
Lesson 4	In the fourth lesson the learners could choose any scenario from the book to complete a set of code. For Lesson 4 the groups were given the opportunity to put all the skills that they had learnt to the test. They got to choose their own lesson that they wanted to complete after listening to the different stories from the book again. Group A chose to help Hazel's cousin Milo to surf 10 perfect waves. Group B chose to make Hazel teach her caterpillar to sing, dance and sit on command. Group A decided that for this lesson all group members needed to be given a fair chance to code and they decided that the lesson would be more fun if they worked together from the beginning.
Photographs	
 Picture 2: Lesson 1	Programming the Bee-Bot to move in the correct sequence.

Technological Knowledge (TK): Coding and robotics	
 Picture 3: Lesson 1	Explaining to the expert reviewer what they were doing and how they were going to code.
 Picture 4: Lesson 2	Bee-Bot wearing the glasses when it completed the sequence correctly and landed on the end card where the glasses had been placed.
 Picture 5: Lesson 1	Programming the Bee-Bot to move. Using their skills of teamwork and collaboration. Using their hands to represent the Bee-Bot to see how the Bee-Bot would turn and in what direction it needed to move.
 Picture 6: Lesson 3	Filling in the conclusion to the scientific method after coding the steps for a new recipe for Dad. The group incorporated all STEAM subjects. The scientific method was followed for Science. The Bee-Bots were used for technology. The group discovered how to use the backward button.

Technological Knowledge (TK): Coding and robotics	
 Picture 7: Lesson 3	Making sure the Bee-Bot went to the cards in the correct order to complete the recipe.
 Picture 8: Lesson 4	The three Bee-Bots follow one another to complete the 10 perfect waves. The waves were closer together to be completed in fewer than 40 steps.

As illustrated in Table 4.5, the learners expanded on their prior knowledge of coding. In cycle 1, coding and robotics manifested in the way the learners created their algorithms. They started off with a straightforward code of a single sequence to create a step-by-step code as seen in Picture 5: Lesson 1. This enabled the learners to use an algorithm (a set of steps) to get Aunty Matilda to work, using the quickest route.

In the second lesson, the learners had to sequence the cards to help Grandpa Leo to retrace his steps as seen in Picture 7: Lesson 3. The first stop was to go to the hammock, then to flowers that he watered, then to reading a book and lastly to the mushrooms where he left his class. This made sure that the learners first thought of the correct route that the Bee-Bot had to follow from the story. This meant that the learners had to make sure they visited all the stops to find the glasses in the end.

The third lesson taught the learners to create a function which is the method they needed to follow to create the recipe. They needed to create a group of tasks for Dad to follow a new recipe. They had to make sure that the Bee-Bot followed the steps correctly for the dish to be a success. Both groups were successful in coding a recipe for Dad to follow. They made sure that they followed the correct order of cards on the mat to ensure the recipe was correct. This meant that the code followed was a deliberate sequence of steps.

In Cycle 2 the learners used their knowledge from Cycle 1 to complete a coding task on their own. Each group made use of a different skill they had learnt. Group A created a repeat function for their Bee-Bot to surf the 10 perfect waves. Group B also created a repeat function in which Hazel taught Fred the caterpillar to sing, sit and dance. They then needed to be able to repeat the sequence again.

The guideline that emerged was that learners started with a simple sequence of code and then moved to more difficult coding skills, such as loops and repeat functions.

Technology was successfully added to the PCK in this study. Bee-Bots were incorporated into all the lessons and were at the centre of each. The lessons all revolved around the Bee-Bot and the learners' ability to code a correct sequence. The data showed that technology could be included successfully. This was evident in the learners using the Bee-Bots in all lessons. The lessons included Technology in the form of an electronic teaching device (Chalmers, 2018; Shulman, 1986).

When teaching coding and robotics, we made use of educational Technology to do this. The Technology used was the Bee-Bot.

4.3.3 Content Knowledge (CK)

Content Knowledge is outlined in Table 4.6. In this study, the Content Knowledge was STEAM. This ensured that all STEAM subjects were included in all the lessons. Table 4.6 shows each subject was studied in each lesson to see how the subject was included in the lesson. Pictures were added at the end of the table to show examples of how the subject was included using the Bee-Bots in the lessons. Braund (2020) posited that STEM is hard to implement; however, in this study, all STEAM subjects were successfully implemented in a single lesson. The data collected through observation and interviews, showed that STEAM can be successfully implemented in a single lesson.

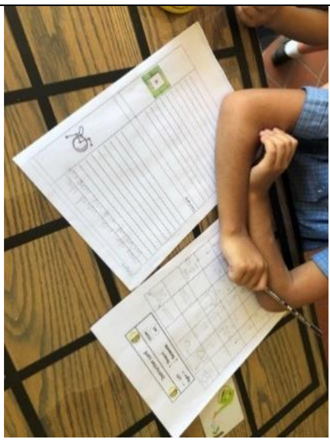
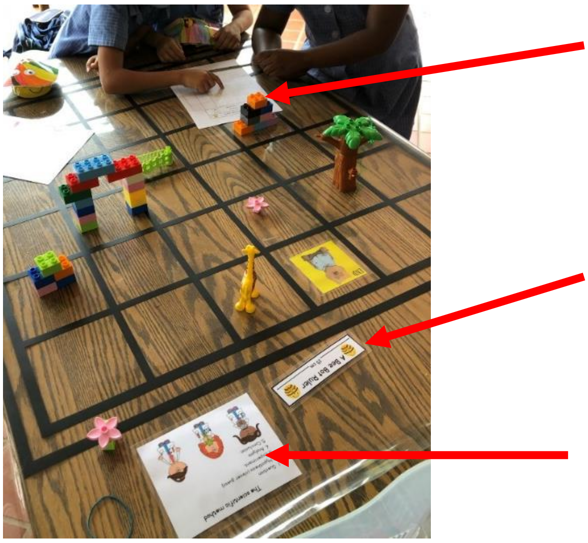
Table 4.6 Content Knowledge

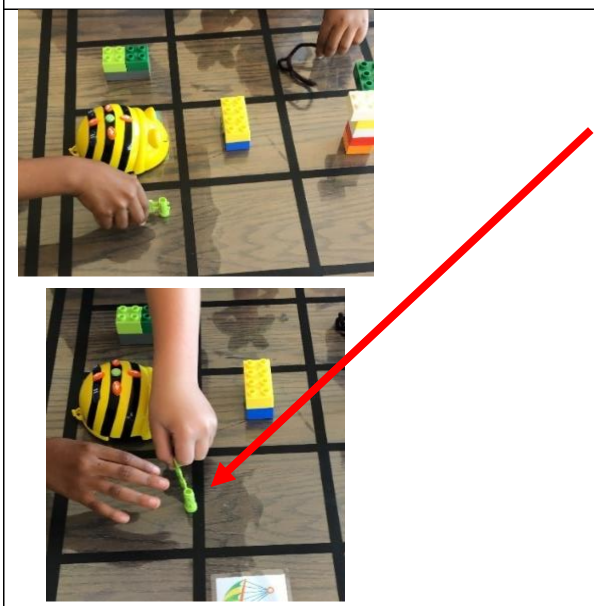
Content Knowledge (CK): STEAM	
Science	
Lesson 1	Learners documented their findings on the scientific method sheet and followed the scientific method when completing the lesson.
Lesson 2	Learners documented their findings and used the scientific method.
Lesson 3	Both groups used the scientific method and documented their findings.
Lesson 4	Both groups used the scientific method and documented their findings.
Technology	
Lesson 1	The electronic systems and control that was used were a Bee-Bot. The Bee-Bot was programmed to follow a step-by-step code effectively.
Lesson 2	The electronic systems and control that were used were Bee-Bots. Group A programmed the Bee-Bots with great confidence. Participant 3 often stood back and observed. Group B programmed Bee-Bots confidently. Participant 5 coded step-by-step. Participant 6 coded a complete string of code correctly to get the Bee-Bot from the start to the finish.
Lesson 3	The electronic systems and control that were used were Bee-Bots. Group A programmed the Bee-Bots with great confidence although it became apparent that this activity was more of a challenge for them. Participant 3 was an observer. Group B found the challenge of a specific challenge easier to overcome with teamwork.
Lesson 4	The electronic systems and control that were used were Bee-Bots. Both groups had Technology at the centre of their lessons as they both used Bee-Bots to solve a problem effectively.
Engineering	
Lesson 1	The learners used Lego to create structures to form the obstacles that the Bee-Bot needed to go around.
Lesson 2	Both groups made glasses for Grandpa Leo using pipe cleaners and made obstacles for the Bee-Bots to go around.
Lesson 3	Both groups added obstacles. Group A lost their blueberry card, so they made a new one.
Lesson 4	Group A made the waves, and the obstacles were eels that the Bee-Bot had to get around. Group B created Hazel out of Lego to teach Fred the caterpillar.
Art	
Lesson 1	The learners made Bee-Bot jackets for their Bee-Bots to make them look like a mouse. In the story the main character is Hazel who is a mouse. They also drew on an instruction card to show the direction the Bee-Bot would travel and the obstacles it needed to avoid.
Lesson 2	Both groups completed drawings on instruction cards to show the route the Bee-Bot would move.
Lesson 3	Both groups completed a drawing and planned on the instruction card. The instruction card was a template of blocks that was a visual representative of the same layout on the Bee-Bot mat. This allowed the learners to plan the layout of the mat sharing the obstacles and direct the Bee-Bot needed to move in. The drawings included arrows to show the direct the Bee-Bot needed to travel in.
Lesson 4	Group A drew patterns on cardboard to create the waves and they drew on the instruction card. Group B made the Bee-Bot look like a caterpillar after Participant 7 said she thought this would be a good idea.
Mathematics	
Lesson 1	The learners used mathematical vocabulary and discussed direction. The vocabulary included left, right, backward and forward. They also had to

Content Knowledge (CK): STEAM	
	problem solve to make sure they went the quickest route. This included their counting the number of blocks the Bee-Bot would need to move to complete the task. The Bee-Bot moved one block at a time when coded. This was to make sure the Bee-Bot did not use all 40 steps to complete the task. There was a huge amount of spatial awareness as they went from paper plan to concrete coding.
Lesson 2	Both groups made good use of mathematical vocabulary and of direction. They had good spatial awareness as the obstacles and direction arrows were transposed correctly onto the paper plans.
Lesson 3	Both groups faced the challenge of problem solving to complete a specific sequence. Mathematical language was present in their coding process. Both groups followed the recipe correctly. They used concrete objects to build and create obstacles for the Bee-Bots to navigate around.
Lesson 4	Group A used numerical order to number the waves in the order that the Bee-Bots needed to visit. The waves had to be measured to make sure they would fit under the mat in the block. Group B used much mathematical language in their discussions.

Photographs

Science

 Picture 8: Lesson 2	Completing the conclusion of the scientific method.
 Picture 10: Lesson 1	This picture shows the group working together to complete the instruction card when all the obstacles had been placed on the mat. In this picture, one can see the Bee-Bot ruler that shows how far the Bee-Bot moved in one step. The scientific method instruction card to aid the learners in remembering the steps is also visible.

Content Knowledge (CK): STEAM	
Technology	
 Picture 11: Lesson 4	Making the ten perfect waves for Cousin Milo to surf and seeing what objects they would use as the obstacles.
Engineering	
 Picture 12: Lesson 2	Making a bridge out of Lego.
 Picture 13: Lesson 2	The gate that opened and closed for the Bee-Bot to go through. This is a good presentation of Engineering and creativity skills. The green piece of Lego is used as the gate.

Content Knowledge (CK): STEAM	
Art	
 Picture 14: Lesson 1	Learners’ unique Bee-Bot jackets to make the Bee-Bot look like a mouse. These showed the learners’ creativity and their unique perspective on what they thought the mouse should be presented as.
Mathematics	
 Picture 15: Lesson 2	Drawing arrows and discussing the direction the Bee-Bot needed to go.

As illustrated in Table 4.6, all STEAM subjects were incorporated into each lesson. In Lesson 4 a good result was achieved when the learners included all STEAM subjects in the lesson when using a story of their choice.

Content Knowledge featured in the following ways in Cycle 1 and Cycle 2: The Science part of STEAM used the Bee-Bot to see if their hypothesis was correct by getting from the start to end card. Charlesworth and Lind (2010), Kok and Van Schoor, (2014) and Tsai (2006) all acknowledge the importance of using the scientific method. The lessons all included the scientific method as a guide to solve the problem. The scientific method and instruction card can be consulted in Appendix K. The learners used the format of posing a question, creating a hypothesis that learners interpreted as a clever guess, conducting the experiment, analysing the experiment and then concluding what they had discovered and whether their hypothesis was correct for their scientific method. They had a worksheet with the steps of the scientific method to help them complete every step.

The Bee-Bots were used as the coding device in each lesson. This ensured that Technology was present in each lesson as found in the context of electronic systems and controls. Engineering was demonstrated by creating structures that the Bee-Bot needed to get around without bumping into them. Art was explored by making the jackets for the Bee-Bots to turn them into the character of a mouse, as well as being able to move from the two-dimensional picture of the structures on the instruction card to the physical three-dimensional objects on the Bee-Bot mat. Mathematics was explored by using the mathematical vocabulary of direction to problem solve how to move the Bee-Bot from start to end following the correct sequence and direction. Overall, from the data collected, it was clear that the Bee-Bots worked well as a tool to integrate all STEAM subjects effectively. The interpretation above can differ due to the expected overlap of STEAM subjects when implemented in a single lesson.

The emerging guideline is the importance of the scientific method as this forms an important part of the structure of the lesson. The main Technology in the form of electronic systems and control is always the Bee-Bot, so it is important to keep the device the same. The learners need to be given the concrete materials they can use to build, such as Lego in these lessons. Art was visible in their creativity to solve problems. By having an instruction card for them to draw on it was ensured that Art would always be present in the lessons. Learners need to have prior knowledge of direction to distinguish between left and right.

4.3.4 Pedagogical Content Knowledge (PCK)

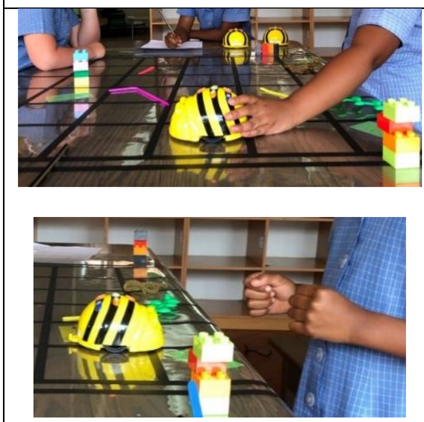
The Pedagogical Content Knowledge is outlined in Table 4.7. In this study, the Pedagogical Content Knowledge is how to teach STEAM to ensure the integration of all the subjects through the project-based approach. When using project-based learning, learners were able to express their creativity and imagination. They were able to create their own plans on the Bee-Bot mats and used any of the concrete objects they wished. Dewey realised the importance of project-based learning as a way for learners to collaborate (Parker & Thomsen, 2019; Pieratt, 2010). In this study, the learners needed to work as a team to solve the problem successfully.

They followed the steps of using project-based learning to teach STEAM. First, the learners had to communicate what the problem in the story was. Then they needed to plan, using the instruction card to decide the route the Bee-bot would follow to solve the problem. They then created the obstacles on the Bee-Bot mat and developed the route the Bee-bot would travel. The groups had to work collaboratively as a team to solve the problem effectively. They wrote down their observation as part of the scientific method and discussed their project with both the researcher and the expert reviewer (Ridwan et al., 2017).

Table 4.7 Pedagogical Content Knowledge

<table>
<tr><th colspan="2">Pedagogical Content Knowledge (PCK): How to teach STEAM using project-based learning</th></tr>
<tr><td>Lesson 1</td><td>The fact that a story about coding was used made it meaningful for the learners and the coding became the centre of the lesson while incorporating all of STEAM subjects. The problem they needed to solve was how to use the smallest number of blocks to get Aunty Matilda to work. Through their problem solving skills they completed the task and used their skills from their STEAM subjects to do this.</td></tr>
<tr><td>Lesson 2</td><td>The problem they needed to solve was how to help Grandpa Leo retrace his steps to find his glasses. They created the glasses and the layout on the Bee-Bot grid. The obstacles were randomly placed on the mat. They problem solved on their own, using their prior skills to solve the problem and complete the project on their own.</td></tr>
<tr><td>Lesson 3</td><td>The problem they needed to solve was how to help dad to follow a new recipe in the correct sequence. The groups were given cards to represent the fruits – these were placed anywhere on the mat. The groups then added obstacles to the mat as well. The groups used their skills of sequencing to code the correct sequence while avoiding the obstacles.</td></tr>
<tr><td>Lesson 4</td><td>Each group chose the problem they were going to solve when they chose the story they would use for the project. They used concrete objects to create their activity. Group A created the waves and eels. After a discussion on how they were going to know which square on the mat was sing, dance, and sit it was decided by Group B that they needed to make cards to go underneath the mat.</td></tr>
<tr><th colspan="2">Photographs</th></tr>
<tr><td>
Picture 16: Lesson 1</td><td>Programming the Bee-Bot step-by-step based on the instruction card.
The group completed STEAM subjects:
• They used the scientific method for Science.
• Technology was being able to program the Bee-Bots.
• Engineering was the obstacles they made using Lego blocks.
• Art was the instruction card and the Bee-Bot jackets.
• Mathematics was the mathematical vocabulary used and the direction to move the Bee-Bot correctly.</td></tr>
</table>

Pedagogical Content Knowledge (PCK): How to teach STEAM using project-based learning	
 Picture 17: Lesson 1	This group B lesson 1 incorporated all STEAM subjects; this is evident in this picture: • Science features in the scientific method that was followed and the group finding the problem and solution to the question, “Can you get Aunty Matilda to work?” • Technology is the Bee-Bots that were coded to complete the task. • Engineering is the Lego structures that they built and placed on the mat. • Art is the Bee-Bot jackets that they made and the instruction card they completed that showed the drawings of the obstacles and the way the Bee-Bot had to travel. • Mathematics is the direction that needed to be followed and knowing how to move the Bee-Bot left, right, forward and backward.
 Picture 18: Lesson 2	This group incorporated all STEAM subjects: • Science included completing the scientific method. • Technology features in their coding the Bee-Bot. • Engineering is the obstacles they created for the Bee-Bot to move around. • Art is the glasses they made and completing the instruction card. • Mathematics is the direction the Bee-Bot needed to move, based on the arrows drawn on the instruction card. This group allowed the Bee-Bots to follow one another after they had completed the correct sequence of code.
 Picture 19: Lesson 2	Retracing Grandpa Leo’s steps from start to finish. This group incorporated all STEAM subjects: • Science is included in completing the scientific method. • Technology is seen in their coding the Bee-Bot confidently. • Engineering features in the gate they created to open and close. They also made Grandpa Leo’s glasses. • Art is present in the instruction card that was completed with the directions the Bee-Bot needed to follow as well as drawings of the obstacles and place cards. • Mathematics features in the special awareness of moving from the instruction card to the concrete objects.

Pedagogical Content Knowledge (PCK): How to teach STEAM using project-based learning	
 Picture 20: Lesson 2	This group incorporated all STEAM subjects in their lessons: • For Science they completed the scientific method. • They programmed the Bee-Bots for Technology. • For Engineering they added obstacles that the Bee-Bot needed to get around. • For Art they drew and showed the directions the Bee-Bot needed to follow. • For Mathematics they used mathematical vocabulary and direction.
 Picture 21: Lesson 4	This group integrated all STEAM subjects in the lesson when they chose their own problem to solve: • For Science they completed the scientific method. Technology was at the centre of the lesson with their coding the Bee-Bots. • Engineering was present when making the waves out of cardboard and the eels out of straws and elastic bands. • Art was included in the patterns drawn on the waves and completing the instruction card. • Mathematics was included as they discussed numerical order as the Bee-Bot visited each wave. The waves had to be measured so that they could fit under the mat and then labelled so the Bee-Bot could go to each wave.
 Picture 22: Lesson 4	This group integrated all STEAM subjects in this lesson: • They used the scientific method for Science. • Technology was at the centre of the lesson with the use of Bee-Bots. • For Engineering they created Hazel characters using Lego blocks. • For Art they turned the Bee-Bot into a caterpillar and completed the instruction card. • For Mathematics they used mathematical language in their discussion. They had good spatial awareness as they moved from the paper plan to the mat plan.

When implementing the project-based approach it is important that the learners are able to solve the problems on their own. As seen in Table 4.7, the learners were able to solve the problems independently. The learners used concrete objects to create obstacles. They used many obstacles in each lesson for the Bee-Bot to move around. They had to plan the route the Bee-Bot would take as well as what they would create on the Bee-Bot mat. This allowed them to create their own lessons that were not teacher-guided regarding what they needed to create on the Bee-Bot mats. There were sufficient obstacles on the Bee-Bot mat to ensure that the learners could program multiple correct pathways without the problem being too arbitrary or restrictive.

The learners successfully incorporated all STEAM subjects. They did not focus on one subject at a time but rather on the problem they needed to solve. Through solving the problem, they were able to incorporate the subjects. When integrating all the subjects the learners learnt that they did not have to be in a Mathematics lesson when coding a Bee-Bot.

Table 4.8 Cycle 1 and Cycle 2 Project-based learning

Cycle	**Project-based learning**
Cycle 1	The problem was chosen by the researcher for the learners to solve. The problem the learners had to solve became increasingly difficult with each task. STEAM subjects were all integrated when they solved the problem using skills from each subject.
Cycle 2	The problem was chosen by the learners to solve in their project. STEAM subjects were all integrated without the guidance of the researcher.

The emerging guideline is the importance that teachers should have the knowledge of what STEAM integration is to teach the subjects effectively. When project-based learning is used to teach STEAM, it creates steps to follow to ensure the content is being taught (Ridwan et al., 2017). This is seen in Table 4.8 as the learners used project-based learning to solve the problem.

4.3.5 Technological Content Knowledge (TCK)

Technological Content Knowledge is outlined in Table 4.9. In this study, the Technological Content Knowledge is Technology in STEAM and how the subject was linked to coding and robotics. The Bee-Bots were at the heart of the lessons and STEAM subjects helped to create depth and enrich the lessons. The focus was on the specific content linked to the Bee-Bot educational toy.

Technology is the way to solve a problem using the design process. The learners first needed to investigate what the problem in the story was that they needed to solve. Then they needed to design the obstacles the Bee-Bot would need to get around. Then they needed to make the drawings on the instruction card to show the layout of the Bee-Bot mat. Then they evaluated their activity to see if they had solved the problem successfully. Lastly, they communicated their solutions to their peers, the researcher and the expert reviewer.

Table 4.9 Technological Content Knowledge

Technological Content Knowledge (TCK): Technology in this study	
Lesson 1	Investigated the problem of how to code the shortest route for Aunty Matilda to get to work. The learners drew the layout on the instruction card. Made the obstacles for the Bee-Bot to get around. Groups A and B used the Bee-Bots at the centre of the lesson. Group A's coding skills were good, but they did not put together a string of code. They moved the Bee-Bots and coded step-by-step. This falls under electronic systems and controls in the subject Technology. Evaluated the lesson and saw that they solved the problem when they considered whether they could go any other ways. Communicated their findings to one another, the researcher and the expert reviewer.
Lesson 2	Investigated the problem to see if they could retrace Grandpa Leo's steps to find his glasses. They used the Bee-Bots to retrace Grandpa Leo's steps to find his glasses. This falls under electronic systems and controls in the subject Technology. The learners drew the layout on the instruction card. Made the obstacles for the Bee-Bot to get around. They also made glasses for Grandpa Leo that the Bee-Bot could wear. Evaluated the lesson and saw that they could retrace Grandpa Leo's steps correctly to help him find his glasses. Communicated their findings to one another, the researcher and the expert reviewer.
Lesson 3	Investigated the problem to see if Hazel's dad could prepare a new meal by following the recipe. The learners drew the layout on the instruction card. Made both groups add obstacles to the fruit cards that they were given. Group A discovered the backward button, and this aided them in completing their step-by-step code around the obstacles. Group B completed a string of code using the activity plan to help them. Evaluated the lesson and saw that Dad could learn to follow a new recipe. Communicated their findings to one another, the researcher and the expert reviewer.
Lesson 4	Each group chose their own story. Group A Investigated the problem to see if they had coded the Bee-Bot to surf 10 waves in a numerical ordered sequence. The learners drew the layout on the instruction card. Made waves out of paper and eels the Bee-Bot had to get around. Evaluated the lesson and saw that they could not exceed the 40 steps that a Bee-Bot can complete. Communicated their findings to one another, the researcher and the expert reviewer.

Technological Content Knowledge (TCK): Technology in this study	
	Group B Investigated the problem to see if the Bee-Bot could help Hazel teach her caterpillar to sing, dance and sit in a sequence. The learners drew the layout on the instruction card. Made Hazel out of Lego to teach the caterpillar (the Bee-Bot dressed like a caterpillar) to sing, dance and sit. Communicated their findings to one another, the researcher and the expert reviewer.
Photographs	
 Picture 23: Lesson 2	Glasses made for Grandpa Leo to find if he had retraced his steps correctly. Instruction cards that were put down for the Bee-Bot to retrace Grandpa Leo's steps.

In Table 4.9 the Bee-Bots were important to implementing all STEAM subjects.

Both Cycle 1 and Cycle 2 incorporated the design process. They incorporated all five steps to complete the lesson successfully.

The emerging guideline is the importance of Technology in STEAM. The Technology in TPACK is the electronic devices and features as coding and robotics when using the design process as an educational technology tool to support the development of STEAM content.

4.3.6 Technological Pedagogical Knowledge (TPK)

The Technological Pedagogical Knowledge is summarised in Table 4.10. In this study, the Technological Pedagogical Knowledge included the 21st century and digital skills that were present in the lessons. The skills focused on were coding, innovation, collaboration, thinking creatively and problem solving. These skills are considered important 21st century skills that learners should be equipped with to be successful 21st century learners (DBE, 2019a; Geist, 2016).

Table 4.10 Technological Pedagogical Knowledge

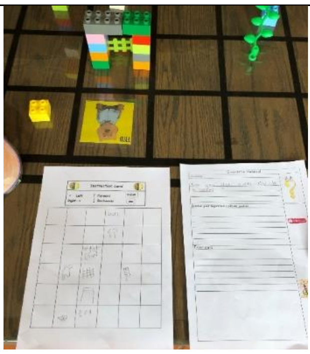
Technological Pedagogical Knowledge (TPK) 21st century /digital skills	
Coding	
Lesson 1	Both groups programmed and debugged the Bee-Bots. They coded one step at a time. Group A programmed and debugged the Bee-Bot. Coded one step at a time until they got it right. Group B coded the Bee-Bot efficiently.
Lesson 2	Group A: Participant 1 did not want to follow the paper plan to create a string of code. Participant 2 used her string of code, but it did not work. Participant 1 insisted on her way and coded step –by-step. This group wanted to use as many concrete objects as they could. Group A did not complete a whole sequence of code, but they tried a lot to debug but without success. They completed a string of code completely correctly without moving the Bee-Bot. Group B completed a sequence of code that correctly retraced Grandpa Leo's steps. Without using the Bee-Bot to guide them, they completed a full string of code.
Lesson 3	Both groups used digital skills they had learnt in previous lessons to help them code more effectively when faced with a more difficult sequence of code to complete. Group A coded separately from one another while group B helped one another. Both groups needed to code a specific pathway that needed to be followed as the order of fruits needed to be correct to complete the recipe.
Lesson 4	Group A had a set pathway to follow as they had numbered the waves so that they knew that each had been visited. As it was a long string of code, they discovered the limitations of the Bee-Bot and that they could only retain 40 steps of code. The code had to be adjusted as a shorter route had to be found.
Photographs	
 Picture 24: Lesson 4	The ten waves that the Bee-Bot had to get to and the straws that were the eels it had to go around. They had a set pathway to follow as they had numbered the waves so that they knew that each had been visited. As it was a long string of code, they discovered the limitations of the Bee-Bot. The Bee-Bot could retain only 40 steps of code. The code had to be adjusted as a shorter route had to be found. This was a big learning experience for the learners.
Innovation	
Lesson 1	Group A was innovative in the way they created the obstacles on the mat. Group B was innovative in the way they used their hands to aid them in coding the Bee-Bots to go in the correct direction. Their hands therefore acted like the Bee-Bot that they coded.
Lesson 2	They were quite innovative in what the structures became. Participant 3 observed closely and added ideas as problems arose. She became more assertive as the lesson went on. They asked good questions, like *Where do the glasses need to go?* After discussion they agreed on the end card. Group B placed a gate as an obstacle. This was opened for the Bee-Bot to go through and closed once it had moved through.
Lesson 3	Group A was innovative when they made their own blueberry when they lost this card. Group B was innovative as they placed fruit cards in a pattern to follow.
Lesson 4	Group A determined the green strips of paper for the caterpillar needed to be thinner so that they did not stop the Bee Bot's wheels from turning. Group B created their own waves out of paper and created eels that the Bee-Bot could not surf over.

Technological Pedagogical Knowledge (TPK) 21st century /digital skills	
Photographs	
 Picture 25: Lesson 1	This picture shows the Bee-Bot jackets being worn by the Bee-Bots. The learners were planning the layout of their obstacle course. The learners placed their start and end card and were working out the quickest route around the obstacles that they created out of Lego.
 Picture 26: Lesson 2	Participant 7 problem solved on how to turn the Bee-Bot into a caterpillar. At first the wheels would not move so she had to get help with some ideas. The end product was a thinner strip of green cardboard. The other way in which the Bee-Bot was turned into a caterpillar was by adding feelers.

Collaborate with peers	
Lesson 1	Group B collaborated better with one another than group A. In group A Participant 2 was keen to code on her own. Participant 1 did most of written parts and Participant 3 added good ideas verbally. In group B Participant 5 was a definite leader initially; she allocated tasks to everyone. She was allowed to take charge.
Lesson 2	Participant 5 allocated jobs as in lesson 1. Participant 7 objected, and they discussed their issues. The two compromised and were both happy to continue with the activity. They decided to put glasses on the Bee-Bot.
Lesson 3	Group A showed that they could work together but needed a conversation with the researcher to remind them of the skills needed. It was good to see the whole group adding to the success of this activity. Group B had an amazing group dynamic. All members were listened to and contributed something to the activity. They all displayed leadership qualities at different times without being forceful or overbearing.
Lesson 4	Group A collaborated the most during this lesson. Group B, after a discussion on how they were going to know which square on the mat was sing, dance and sit, decided that they needed to make cards to go underneath the mat.

Technological Pedagogical Knowledge (TPK) 21st century /digital skills

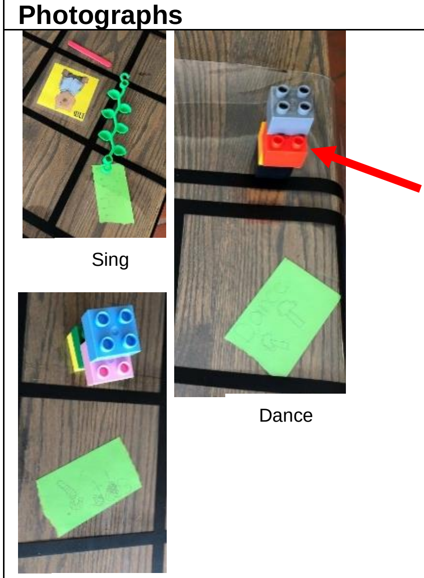
Photographs

 Picture 27: Lesson 1	One can see the instruction card where they drew and planned the route the Bee-Bot would take. The group collaborated well.

Thinking creatively

Lesson 1	Both groups thought creatively. Group A debugged the Bee-Bots to make sure they took the fastest route and group B spoke though all of their ideas as a group throughout the activity.
Lesson 2	In Group A the question was asked, *Where do the glasses need to go?* The group discussed this question and decided it needed to go on the end card. They thought creatively to make obstacles for the Bee-Bot to go around.
Lesson 3	Both groups thought creatively to come up with good questions to ask to solve the problem of creating a new recipe for Hazel's dad to follow.
Lesson 4	They helped one another with the problem solving and collaborated effectively.

Photographs

 Sing, Dance, Sit Picture 28: Lesson 4	This group opted for Hazel to teach her caterpillar how to sing (shown with music notes), dance (shown with hands in the air) and sit (shown with a caterpillar). Hazel was made out of Lego to give the instructions.

Problem solving

Lesson 1	Group A problem solved by debugging their code and finding out that they needed to remember that if they moved one block at a time, then each time they wanted to move they needed to clear the code. Group B used many problem solving skills. They debugged the code and started off with a step-by-step code that eventually led to the group creating a string of code using the coding sheet.
Lesson 2	Participant 1 and 3 showed good problem solving skills. Group B problem solved individually to solve the problem of debugging.
Lesson 3	This activity was more of a challenge as problems were encountered and solutions were discussed and found.

Technological Pedagogical Knowledge (TPK) 21st century /digital skills	
Lesson 4	Group A solved the problem when the Bee-Bot did not have enough steps to make it to the end. Group B solved how to turn the Bee-Bot into a caterpillar and still get the Bee-Bot to move using its wheels.
Photographs	
 Picture 29: Lesson 3	Learners explaining the steps the Bee-Bot needed to follow to complete the recipe correctly. The learners decided where the recipe pictures would be placed for the Bee-Bot to complete the recipe successfully. They explained their thinking to the expert reviewer. For Engineering they created a Lego bridge and obstacles for the Bee-Bot to go around. For Art they made a Blueberry when they could not find the Blueberry card. This showed how they solved another problem as they needed the blueberry to complete the sequence of the recipe. For Mathematics they did much problem solving and direction to make sure the Bee-Bot went in the correct direction.

As illustrated in Table 4.10 21st century and digital skills were present in each lesson. The learners used their prior knowledge of coding and what they had learnt in each lesson from Cycle 1 to complete the fourth lesson effectively on their own, forming Cycle 2. They learnt the importance of working together to help one another complete the objectives. They used the skills of thinking creatively to solve the problems presented. They had to collaborate with one another to ensure that their coding was successful. They had to be innovative to build and create different structures for the Bee-Bot to navigate around. The learners constantly had to problem solve and this lent itself well to their using their collaboration skills.

The nature of the problems, as well as the possible solutions to the problems were identified through the integration of STEAM. The problems were open-ended and ill-structured complex problems that Technology as a subject thrives to solve. This set the scene for the development of 21st century skills and digital skills in the classroom as well as STEAM integration possibilities. This led to the creation of the emerging guideline of problem solving.

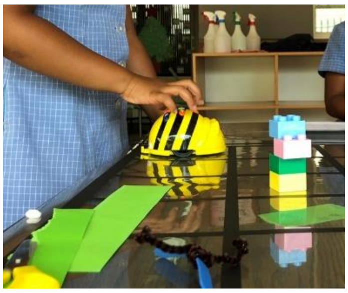
4.3.7 Technological Pedagogical Content Knowledge (TPACK)

Technological Pedagogical Content Knowledge is outlined in Table 4.11. In this study, Technological Pedagogical Content Knowledge features in the integration of the different TPACK elements in STEAM integrated coding and robotics activities to develop learners' computational thinking skills. Computational thinking is the learners' ability to solve problems in the same way a computer can (Chalmers, 2018; Chen et al., 2017). Computational thinking is what brought the Technology, Pedagogy and

Content knowledge together in this study. In each lesson the learners were given a problem that they needed to solve. They solved this problem by creating a project. Table 4.11 presents the success of the lessons as a whole with all the parts of TPACK included when the learners used their computational thinking skills.

Table 4.11 Technological Pedagogical Content Knowledge

Technological Pedagogical Content Knowledge (TPACK): Computational thinking	
Cycle 1	
Lesson 1	Technology: Using the Bee-Bot as a coding device to code a straightforward code to solve the problem of getting around the obstacles using the least number of steps.
	Pedagogy: The learners' ability to solve the problem using project-based learning to get Aunty Matilda to work, utilising the least amount of coding steps. The learners used their computational skills to complete a sequence of code effectively.
	Content: The learners' ability to include all STEAM subjects in a single lesson. The achieved this outcome as they included all STEAM subjects.
	Both groups used Lego as concrete objects to create an obstacle course for the Bee-Bots to get around.
Lesson 2	Technology: Using the Bee-Bot to follow a sequence of events accurately to help Grandpa Leo to find his glasses.
	Pedagogy: The learners' ability to solve the problem using project-based learning to help Grandpa Leo to retrace his steps to find his glasses. The learners used their computational skills to complete a sequence of code effectively.
	Content: The learners' ability to include all STEAM subjects into a single lesson. The learners achieved this outcome as thy included all STEAM subjects.
	Group B still worked more collaboratively than group A. They tried to debug their Bee-Bots to complete the sequence. Group B was happy to share resources and the ideas that they came up with. No-one dominated the activity. In group A, Participant 2 dominated the activity and Participant 1 and 3 collaborated mostly to complete the task. Participant 2 was keen to code on her own and her ideas were not always accepted by group A.
Lesson 3	Technology: Using Bee-Bots to solve the problem of a longer sequence of code to help Dad learn a new recipe.
	Pedagogy: The learners' ability to solve the problem using project-based learning to help Dad learn a new recipe by following a sequence correctly. The learners using their computational skills to complete a sequence of code effectively.
	Content: The learners' ability to include all S subjects into a single lesson. The learners achieved this outcome as they included all the STEAM subjects.
	Group B worked well together and had a good group dynamic. Group A participated much better as a team. Group A was competitive and wanted to get it right on their own rather than helping a friend.
Cycle 2	
Lesson 4	Technology: The learners' ability to use the Bee-Bot as an electronic tool to code a sequence. Incorporating both Technology as a subject in STEAM and Technology as an electronic device in TPACK effectively into a lesson on their own.
	Pedagogy: The learners' ability to solve the problem using a project-based activity when given the opportunity to choose their own story with a problem to solve. The learners used their computational skills to complete a sequence of code effectively.
	Content: The learners' ability to include all STEAM subjects into a single lesson even when they chose their own story and did not have the researcher as a facilitator of the lesson. The outcome of this was that the learners included all STEAM subjects even when the lesson was not guided by the researcher but rather was a lesson to see if they could use their knowledge from the previous three lessons to complete it on their own.
	In group A more collaboration was evident as the learners discussed what was needed to complete the activity.

<table>
<tr><th colspan="3">Technological Pedagogical Content Knowledge (TPACK): Computational thinking</th></tr>
<tr><td></td><td colspan="2">Group B discussed each step, and they were allowed to offer an idea of how to complete the activity effectively. They worked well as a team to make sure they all completed the correct code and sequence.</td></tr>
<tr><th colspan="3">Photographs</th></tr>
<tr><td colspan="2">
Picture 30: Lesson 4</td><td>Programming the Bee-Bot to move. From this angle one can see the Lego structure of Hazel who is teaching her caterpillar. The learners used their problem solving skills.</td></tr>
</table>

As illustrated in Table 4.11, the lessons integrated Bee-Bots into all STEAM subjects. It was observed how different the group dynamics were. Group A initially did not collaborate at all but learnt in the course of all the lessons how important it was for them to collaborate to complete the activities successfully. Group B worked well as a team and managed to maintain this throughout all the lessons. Both groups developed their problem solving skills and how to work collaboratively.

Computational thinking was present in both Cycle 1 and Cycle 2 when working with the TPACK framework as featured in Table 4.11.

As seen in Table 4.11, computational thinking skills were present in both cycles. Both cycles successfully incorporated all STEAM subjects. The learners used their knowledge from Cycle 1 to complete an independent task in Cycle 2.

The emerging guideline is the importance of having a problem for the learners that needs to be solved by using their computational thinking skills effectively. This is linked to the DBE draft curriculum Introducing Digital Skills to All into GET (DBE, 2019a). The fourth pillar is computational thinking skills and coding. Francis and Davis (2018) underscore the importance of teaching coding to propagate computational thinking; it can be taught with integration into other subjects.

4.3.8 Context

Consult Section 3.9 for details on the context of the study. The lessons were conducted on the Grade R veranda to allow for the natural flow of air.

4.4 Interviews

The interviews conducted by the researcher aimed to establish how the expert reviewer and the learners experienced the activities. The full answers of the learners appear in Appendix J. The answers from the expert reviewer are explored first.

4.4.1 Interview with expert reviewer

The expert reviewer gave insight into the lesson through observation notes discussed in Chapter 4.3 as well as an interview which is explored below. The interview questions were designed to link to the TPACK design tool.

Table 4.12 Interpreting the expert reviewer's interview

Questions	**Responses for expert reviewer**	**Link to TPACK**
1. How did you experience the learners' use of Bee-Bots?	The learners listened well to the introduction of each lesson and used this information well. Their coding skills and use of the Bee-Bots became progressively better as the activities were completed. This was pleasing to see as they had not had the usual exposure to technology due to online schooling.	Technological Knowledge (TK) (Coding and robotics) • They improved their skills. • Were exposed to technology
2. Did you see the integration of all STEAM subjects? Explain how you observed the subjects being used.	Science, technology, engineering and maths were the main components. The art component was evident but to a much lesser degree. The time available for each lesson could have been a contributing factor.	Content Knowledge (CK) (STEAM) • All STEAM subjects were included. • Longer lessons could provide more time for Art to be incorporated.
3. How did the learners work with concrete objects and what objects did they use?	The Bee-Bots were concrete – very easy to handle and manipulate; the buttons made coding manageable. There were several concrete objects for the learners to use to create the obstacle course – Lego blocks /pipe cleaners/straws/wooden sticks/paper strips and more.	Pedagogical Knowledge (PK) (Foundation Phase teaching, theories and strategies) • The concrete object of the Bee-Bot
4. Which 21st century skills did you see the learners use? Explain how they used or did not use each skill.	Application of skills The application of all previous knowledge and skills and the knowledge and skills acquired during the activities made the exercise a success. Coding This was at the heart of each lesson. Innovation As the activities progressed the learners were more comfortable about exploring how they could use the objects given to them to be innovative and create. Collaborate with peers	Technological Pedagogical Knowledge (TPK) 21st century /digital skills • The participants included 21st century and digital skills into their lessons.

Questions	Responses for expert reviewer	Link to TPACK
	This was a challenge, but some collaborative skills were learnt as time went on.	
	Think creatively There was creative thinking throughout the activities on many different levels.	
	Problem solving Problems occurred constantly. The learners didn't hesitate to look for a suitable solution.	
5. Did Bee-Bots aid in the integration of all the STEAM subjects? Explain your answer.	Yes. The Bee-Bots were the main component of the lesson. The other STEAM subjects were necessary to add depth and enrich the lessons and make them more meaningful for the learners.	Technological Content Knowledge (TCK) Technology in this study • The Bee-Bots were the main technology in the study in the form of a digital device.
6. Did the learners design and create the final product?	Yes. They were given certain concrete objects but the design and creating of the product was totally theirs.	Pedagogical Knowledge (PK) (Foundation Phase teaching, theories and strategies) • Project-based learning took place as the learners used concrete objects to create the layout on the Bee-Bot mat.
7. Do you think it is possible to integrate Bee-Bots into collaborative activities? Explain your answer.	Most definitely. The lessons that I saw were just one example of this.	Technological Pedagogical Content Knowledge (TPACK) (Computational thinking) • Including collaboration to solve problems.
8. How can Bee-Bot activities be designed towards STEAM integration?	In exactly the way that these lessons were designed. They were very successful.	Pedagogical Content Knowledge (PCK) (How to teach STEAM) • Having a lesson designed to integrate all the STEAM subjects helps to ensure they are all included.
9. How can collaborative skills be facilitated in Bee-Bot group activities?	By requiring the learners to share all of the resources and encouraging collaboration and sharing. For the educator to be there as a facilitator and observe the groups closely. To allow the learners the space and time to work collaboratively intervening only virtual	Technological Pedagogical Knowledge (TPK) 21st century /digital skills • This was an important 21st century skill that was found in the study.
10. How can utilising Bee-Bots facilitate TPACK	Using TPACK guidelines gives a clear indication of whether the activities were well planned and thought out. It also shows	Answering the RQ • The TPACK framework gives structure to the way

Questions	Responses for expert reviewer	Link to TPACK
designed STEAM activities in Grade 2?	whether the learners achieved specific outcomes and acquired new skills and knowledge.	the lessons are designed and planned. • It also enables to the teacher to see if the outcomes have been achieved.

The expert reviewer noted that for Pedagogical Knowledge, the learners used Bee-Bots that are concrete objects as well as other concrete objects, for example Lego and pipe cleaners to create the obstacle course.

The expert reviewer noted that Technological Knowledge was the learners' ability to code a sequence using the Bee-Bots. Due to COVID-19, the learners had not used Bee-Bots as frequently in the course of the year as they would have. Their skills progressed with each lesson as they grew in confidence.

Both 21st century and digital skills were successfully implemented. The digital skills featured in the learners' ability to code. They used their prior knowledge to help them solve the problems. The learners never hesitated to come up with a solution. They mostly collaborated and worked well together. They were creative and innovative in the completion of their lessons.

The expert reviewer noted that for Content Knowledge all STEAM subjects were included in the lessons. The Art component was least evident and this could be due to time limits. The lessons were designed to ensure that all the subjects would be included. The Bee-Bots aided in bringing all the subjects together. The expert reviewer noted that if more time was allocated for the activity, more aspects of subjects such as Art could be expanded on.

Collaboration was a skill that the learners needed to work on according to the expert reviewer. Group A had to work harder on cooperating and listening to the group's ideas. Group B collaborated well from the start.

The learners were facilitated by the researcher and were therefore able to complete the project on their own.

When investigating the RQ the expert reviewer's response was, "Using the TPACK guidelines gives a clear indication of whether the activities were well planned and thought out. It also shows whether the learners have achieved specific outcomes and acquired new skills and knowledge."

The expert reviewer helped to provide insight into what she had seen in the investigation process. The TPACK design tool helped to give the lessons structure and was a tool to use in order to observe the lessons effectively.

The three main themes that emerged from the expert reviewer have been written in red. They were the learners' ability to grow in confidence in their coding abilities, the way the learners solved problems with creativity and innovation and the collaboration that they need to work together in order to effectively complete the lessons.

4.4.2 Learner Interviews

The learner interviews explored SRQ 2, "How do learners experience these activities?" The value that the learners got from taking part in these activities was that they all had the opportunity to problem solve, expand their coding knowledge, work with Bee-Bots, build Lego structures and collaborate with their groups.

The learners all agreed that there was at least one problem that they solved. Participant 5 found problem solving interesting. They all learnt a new coding skill in the course of the lessons.

Table 4.13 Coding learners' answers to interviews

Colour Code of Learner Interviews	
Pedagogical Knowledge (PK) Foundation Phase teaching	Orange
Technological Knowledge (TK): Coding and robotics	Grey
Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Turquoise
Participant	Question
What problem did you solve?	
1	I solved that when we were doing waves, I did too many steps.
2	The giraffe - we had to move it because it was in the wrong place.
3	When I changed the instruction card so I could get to the end.
4	I remembered to make a course.
5	Retracing steps. Coding the right things.
6	I solved Hazel helping Dad.
7	To code. To make Dad do the recipe.
What new skills did you learn?	
1	Play with the Bee-Bots.
2	Coding in a year.
3	I learnt to code, and I learnt to work more as a team.

Colour Code of Learner Interviews	
4	I learnt to fix problems.
5	I code well.
6	I learnt you cannot turn with the Bee-Bot all the time.
7	I learnt to code the correct button.
What did you find interesting?	
1	I found it interesting that you have to press clear before you do more steps.
2	The Bee-Bots are cute.
3	That the Bee-Bots listened to instructions.
4	I found coding interesting.
5	Solving problems.
Colour code of learner interviews	
6	I found the story interesting.
7	That I had to think more than usually.
What would you like to do again?	
1	More lesson with Bee-Bots and Miss Ranger
2	Playing with Miss Ranger and the Bee-Bots.
3	I would like to code more.
4	I would like to do nothing again.
5	Coding.
6	I would love to play with the Bee-Bots next year.
7	To set the places and code.
What did you enjoy the most?	
1	Building Lego and playing with Bee-Bots.
2	Playing with the Bee-Bots.
3	I enjoyed doing the Bee-Bot dance.
4	I enjoyed coding the Bee-Bots.
5	Coding with my friends.
6	Playing with friends.
7	I enjoyed coding.
What would you change next time?	
1	If we can colour more.
2	Own coding not in the book.
3	I would not fight with others.
4	Nothing.
5	Nothing.
6	I would like to change the Bee-Bot so it can go diagonally.
7	To do it faster.

Three main themes emerged: coding using the Bee-Bots as a concrete object, developing coding skills, and developing 21st century and digital skills. The learners' interviews were too brief to get feedback of how they experienced the lessons. The learners' experiences were added to support the development of guidelines for teachers to create their own lessons.

The learners used the skills that they had learnt in each lesson to improve the outcomes of their next lessons. From the interviews with the learners, it was clear that they all really enjoyed coding and wanted to do more coding lessons.

The orange colour shows all the concrete objects the learners used, including the Bee-Bots and Lego. The grey shows all the coding skills the learners practised and how they experienced coding. The turquoise shows the problem solving skills the learners practised as well as the collaboration they had with their friends.

Participant 6 found the stories very interesting and wished that the Bee-Bot could move diagonally. Participant 3 saw the value of not fighting and rather working together to complete the task.

The insight from the learners' interviews helped to see how they experienced the lessons. This helped to answer the secondary research question. Through these interviews it was clear that the learners enjoyed learning through play. Johnston et al. (2018) also underscore the value of learning through play and scaffolding the activity.

4.5 Conclusion

As the researcher, I was privileged to enlist the help of such a knowledgeable expert reviewer. She really presented insightful ideas and was always willing to go over notes and observations. She had excellent ideas, like including making a Bee-Bot jacket for it to look like a mouse. It was good to have someone else to observe the lessons so that while I was taking pictures and making notes, she was also making notes. This helped to ensure that no important information was missed. It meant that both groups always had someone to observe them and make sure that each learner was always feeling safe.

I really enjoyed being hands-on and involved in the data collection as I felt it was a way to experience what the learners were experiencing. It helped me to be a part of the action research cycle as I was able to plan, act and observe, and reflect on the outcomes of the lessons. Photographs are a wonderful way to capture a moment and to show evidence of what took place during the lessons.

The TPACK framework was an important tool to see whether the lesson that was presented had been successful. This helped to create consistency and allowed the researcher and the expert reviewer to have a guideline to work from. The core concepts from the results are labelled in Figure 4.2.

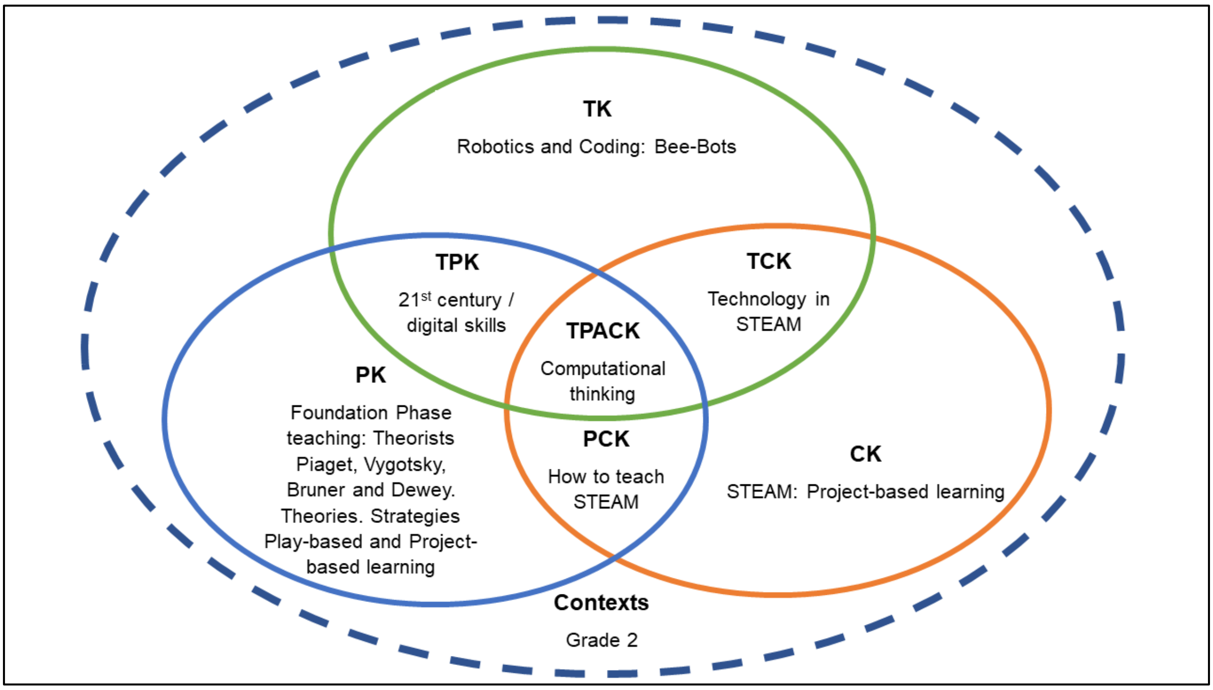


Figure 4.2 TPACK conclusion

Adapted from Koehler, Mishra and Cain (2013)

The two action research cycles come together with the key components in Figure 4.2. When looking at Figure 4.2 it is important to see that the results were backed up by the literature in purple.

The concluding chapter looks at the investigation of the research questions as well as emerging guidelines that were discussed in the results chapter in green. When creating the guidelines, it was important to incorporate the key components found in Figure 4.2.

Regarding the two research cycles, it is important to note that both cycles included the action research process and are discussed according to the research design. Using the TPACK conceptual framework enabled all the lessons to have the same base structure that was then changed per lesson. This enabled the learners to become familiar with how the lessons would take place. This boosted the learners' confidence and they coded more confidently as the lessons progressed. The lessons were then conducted and the learners were able to add their prior knowledge as well as the new knowledge. When the lessons were observed by the researcher and the expert reviewer, the observation sheet ensured that there was a document to go back to and see whether the lessons had been successful. It also made the discussion between the researcher and the expert reviewer about the observations meaningful as they had both completed the same observation sheets. Reflection enabled the research questions to be investigated based on what had been observed. The guidelines provided should aid teachers in creating their own lessons based on the study conducted.

Chapter 5: Findings and conclusions

5.1 Introduction

The results of the investigations into the RQ, “How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?” and the secondary research questions SRQ 1, “How can TPACK be utilised to design coding activities?” as well as SRQ 2, “How do learners experience these activities?” were presented in Chapter 4. Chapter 4 showed that the TPACK framework created a meaningful tool for a lesson plan and an observation sheet. It made it easier for the expert reviewer and the researcher to use as a guide to ensure that all aspects were present in the lesson; it aided in comparing the groups and in observing the similarities and differences. TPACK was used to ensure that STEAM subjects, digital and 21st century skills were effectively included and present in all the lessons. Ridwan et al. (2017) found that project-based learning helps to incorporate STEAM subjects, as was also evident in this study.

Bell (2010) and Eguchi (2014) underscore the importance of problem solving through a project-based approach. The interviews with the learners provided meaningful insight into how they experienced the activities and what they gained from completing the lessons. The learners all practised their skills of problem solving and working collaboratively in their groups. Learners’ coding skills improved from each lesson as their confidence grew.

Using the TPACK framework made it easy to understand the similarities in the lessons and how their skills developed from the one lesson to the next when looking at the observation sheets. In the course of the study, the learners went from coding a single string of code to being able to code a whole sequence of code correctly.

Reflection took place continuously in the form of observation notes and discussions between the researcher and the expert reviewer. At the end of each lesson the researcher and expert reviewer discussed what they had observed in the lesson. At the end of all the lessons they revisited all four lessons and the answers to the interview questions. The aim of this reflection was to see if the research questions were being answered and if the guidelines could be improved. The answers to the research questions based on the observations are explained below.

5.2 Revisiting the research questions

The research questions are explored in Table 5.1. The table depicts where one can find the investigation to the questions.

Table 5.1 Research questions addressed

Research question	Chapter in which the research question is addressed
RQ	
“How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?”	Table 3.4 shows the research process summary that includes the questions investigated and what data gathering instruments were used.
	The plan stage in action research was used to investigate the main research question as seen in Figure 3.6 and Figure 3.7.
	In Section 4.4.1 the RQ was answered in the interview by the expert reviewer.
SRQ 1 AND SRQ 2	
SRQ 1 “How can TPACK be utilised to design coding activities?” **SRQ 2 “How do learners experience these activities?”**	Table 3.4 shows the research process summary that includes the questions investigated and the data instrument used.
	The process to act, observe and reflect in action research was used to investigate the secondary research questions as seen in Figure 3.6 and Figure 3.7.
	Section 4.3 unpacked SRQ 1 and Section 4.4.2 indicates how SRQ 2 featured in the learners’ interviews.

These questions are explored in greater detail in this chapter. When looking at the two secondary research questions, SRQ 1, “How can TPACK be utilised to design coding activities?” and SRQ 2, “How do learners experience these activities?” it is important to look at each question individually first.

5.2.1 Secondary research question 1

SRQ 1. How can TPACK be utilised to design coding activities?

The TPACK conceptual framework is the golden thread in the study that needs to be included in the guidelines. It was used in creating and observing the lessons and is an important aspect as it created a set of control questions when observing a lesson. When using TPACK as a tool, it creates guidelines for an educator to follow to create their own lesson. TPACK was used to create coding activities by linking each part of the TPACK framework to its use in a coding activity. This is shown in Figure 5.1 where the TPACK conceptual framework is unpacked for this study.

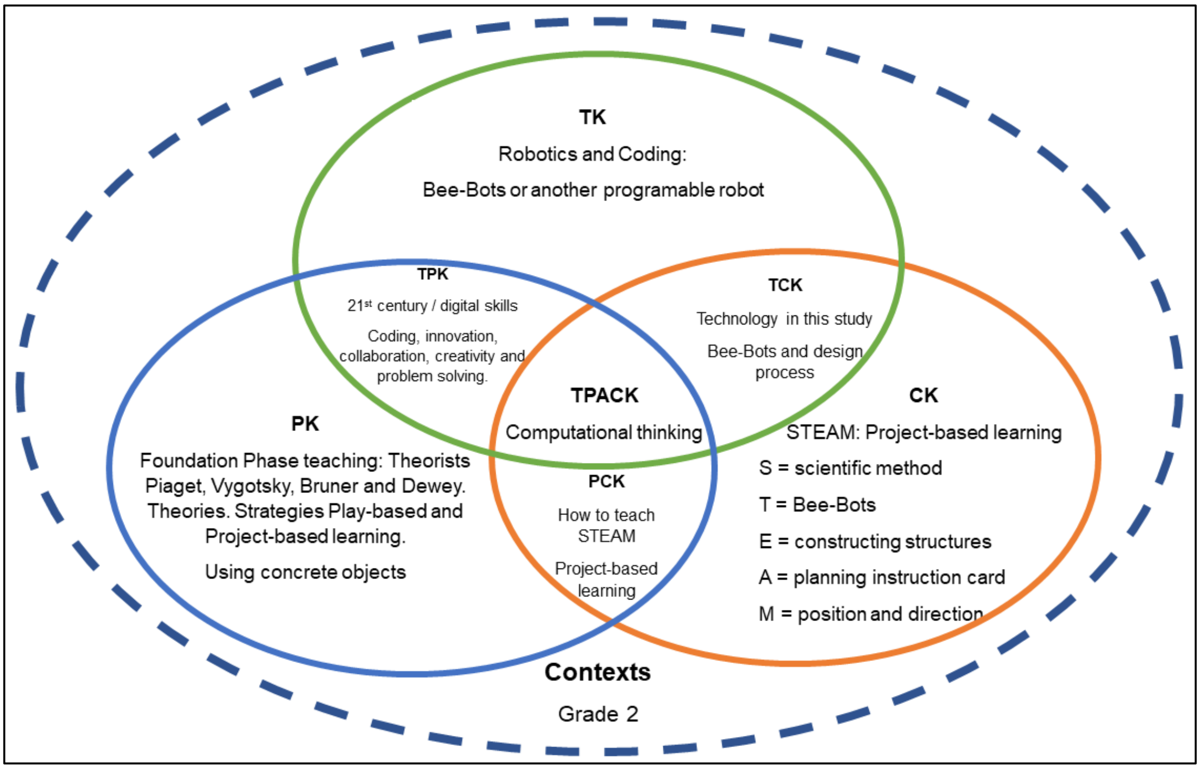


Figure 5.1 TPACK in this study

In Figure 5.1 the researcher has unpacked the TPACK framework as it appeared in this study. These are the core components that helped to integrate all STEAM subjects into a TPACK designed lesson. In the same way Angeli et al. (2016) and Bers et al. (2013) adapted the TPACK framework for a desired outcome; this study also adapted the TPACK framework to be used as a design tool. The design tool was helpful in creating the guidelines and it is important that all aspects are present in the planned lesson. The lesson plans are found in Appendix G and give insight into the lessons presented in Cycle 1.

The TPACK conceptual framework was used throughout the study and further information can be found in Appendix C, Appendix D and Appendix E. Appendix C shows what needs to be included for each section of the TPACK framework and gives examples from this study as to what can be included. Appendix D is a review sheet to make notes on to see if all TPACK aspects are present in the lesson plan created. Appendix E is an observation sheet with a column to tick whether the aspect is present in the lesson and a space to make notes on what actions are observed. In this study these three steps were included for each of the lessons presented.

In reflecting it would have been difficult to see whether the lesson had been successful without the aid of the TPACK conceptual framework. With the Covid-19 protocols at school the learners had not used Bee-Bots that year. This was anticipated to be a challenge; however, the learners remembered what they had done in Grade R and helped one another to complete a sequence of code successfully.

5.2.2 Secondary research question 2

SRQ 2. How do learners experience these activities?

The learners all enjoyed coding and working with the Bee-Bots. They became more familiar and able to code as the lessons progressed. They learnt new coding skills and at the end of the lessons the groups realised that it was important to work as a team and to help one another. The lessons provided the learners with structure in the form of the scientific method that they needed to follow. This helped to keep them on track so that they knew what they needed to have done by the end of the lesson. The stories added meaning to the lesson and something the learners could discuss and make relevant to what they were coding. They were free to make and create the Bee-Bot mat as they pleased. The only input they received from the researcher was the story, sheets to fill in and a box with all the objects they could use in the lesson. This allowed them the freedom to be creative and not be restricted to what they had to make but rather what they wanted to make.

When conducting the interviews with the learners the aim was to investigate SRQ 2, "How do learners experience these activities?" The learners all answered that they used Bee-Bots and could make a prediction before solving a problem. They built structures, made characters and took turns to code the Bee-Bots to move. They all knew the correct direction when using the arrows on the instruction card and how to move from a two-dimensional drawing to a concrete three-dimensional Bee-Bot mat with obstacles. This showed that they had good spatial awareness skills. This relates to Table 2.5 which outlines the mathematical concepts for Grade 2 learners (DBE, 2011a). They all enjoyed playing with their friends, using the Bee-Bots, making obstacles and making a Bee-Bot jacket; they enjoyed coding and solving the problems that came with each lesson. They all wanted to share what they had learnt with their friends.

As seen in Piaget's four stages of a learner's development, the learners were working in the concrete operations stage as they were learning through play (Charlesworth & Lind, 2010; Huitt & Hummel, 2003). The learners learnt through play and the environment around them as they gained confidence and used what they had learnt in the previous lessons to complete Lesson 4 (Murris & Verbeek, 2014). This allowed the learners to learn from their friends, which relates to Vygotsky's cognitive development theory of learning through play (Meier & Marais, 2014). The learners were able to visualise the route the Bee-Bot was going to take; this relates to Bruner's iconic stage of development (Charlesworth & Lind, 2010). The lessons were learner-centred and followed a project-based approach that relates to Dewey's theory of project-based learning (Parker & Thomsen, 2019; Pieratt, 2010).

They all concluded that they had to solve at least one problem when coding. Learners 2, 3, 5 and 7 said that they had learnt a new skill of coding. Learner 1 learnt how to play with the Bee-Bot and learner 4 learnt to debug problems. Learners 1, 2, 3, 4 and 7 all enjoyed playing with the Bee-Bots and learner 5 and 6 enjoyed playing and coding with friends.

It was interesting that Learners 4 and 5 did not want to change anything if they completed the activities again, whereas Learner 6 wanted to make a Bee-Bot that could move diagonally. When observing the interviews, it was clear that each learner had learnt a new skill and enjoyed coding. The learners had positive responses to the activities and all enjoyed working with the Bee-Bots and coding. When doing the activities, they incorporated their digital and 21st century skills to complete all the lessons effectively.

This study helped to address the phenomenon of 21st century and digital skills. The learners developed their skills of collaborating with peers, thinking creatively and solving problems which is also outlined as important skills in the DBE framework (DBE, 2019a). This was evident in observing each lesson and seeing which of the skills were present. The learners developed their coding skills through practice and remembering what they had learnt from the previous lessons. They were innovative in the way they decided to make and create the obstacles for the Bee-Bot to move around.

The student-teacher ratio as featured in the work of Vale et al. (2020) was not a challenge in this study as there were seven learners to 2 teachers (one teacher and one retired teacher). It worked well with each learner having their own Bee-Bot as they all got a turn to practise programming the code into the Bee-Bot.

5.2.3 Research question

RQ. How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?

When reflecting on the RQ it is important to break the question up into sections to reflect on all aspects. The following is reflected on: Bee-Bots, TPACK, STEAM and Grade 2 as is seen in Figure 5.2.

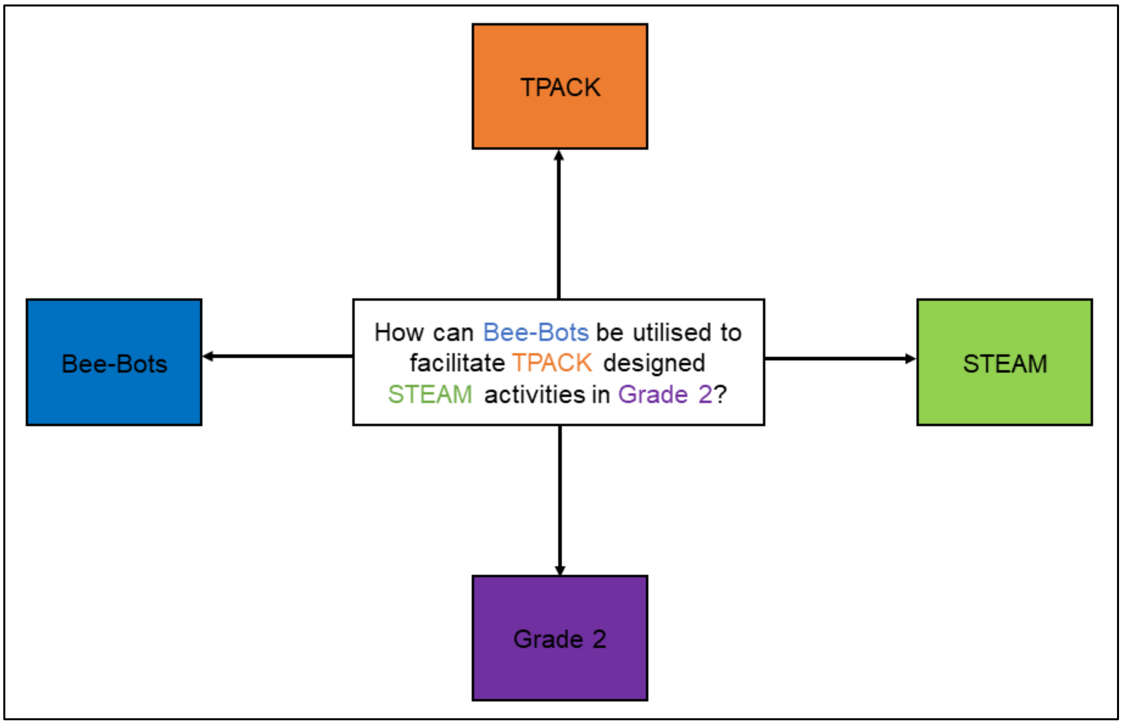


Figure 5.2 RQ breakdown

Figure 5.2 is unpacked into Bee-Bots, TPACK, STEAM and Grade 2. These four focus areas are then explored based on the study and the literature explored.

5.2.3.1 Bee-Bots

Bee-Bots were utilised in all the lessons and they were the centre of all of them. The Bee-Bot was used to solve the problem by coding a sequence of code on the Bee-Bot mat, while navigating around the obstacles. The Bee-Bot was the concrete object used to code the solution to the problem. Unlike Koehler et al. (2011) who saw the problem of technology not being made with the classroom in mind, this study used Bee-Bots that were created with young children in mind to help them learn to code. Bee-Bots helped to strengthen the learners' skills and this is also underscored by Janka (2008) and Johnston et al. (2018).

5.2.3.2 TPACK

The lessons were all planned based on the TPACK conceptual framework and observed using TPACK as a tool to ensure the lesson was observed with a standardised observation sheet (Consult Appendix E). This meant that each lesson was designed and observed using the TPACK conceptual framework. As seen in the work of Rahman et al. (2017) who point out that TPACK enriches learners' understanding, this study shows that the conceptual framework enriched learners' understanding of coding and robotics as they successfully completed each problem.

5.2.3.3 STEAM

Lesson 1 to 3 were designed to include all STEAM subjects as a part of Cycle 1 and Lesson 4 was designed to see if the learners would incorporate all STEAM subjects when completing a lesson on their own as seen in Cycle 2. It was important to take from Cycle 1's observations and see whether the learners could incorporate all STEAM subjects into a lesson where they chose the problem. Both groups were successful in achieving this. When they worked on their own in Lesson 4, all STEAM subjects were present; this validated that all STEAM subjects can be included even if the lesson is more flexible. STEAM subjects were integrated successfully in all the lessons. The activities were completed by Grade 2 learners. According to DBE (2019a) and Harper (2017), teachers need to be empowered to integrate subjects; this study gives teachers a guideline to be empowered to do so.

The researcher found that STEAM subjects could be successfully integrated. Bagiati et al. (2010) found that engineering helps to incorporate STEM subjects. Yakman and Lee (2012) underscored the importance of incorporating Art as well into STEAM; this was also relevant in this study as Art was incorporated in the lesson through the instruction card and the learners' creativity.

5.2.3.4 Grade 2

The context of Grade 2 helped to focus the study on the skills that a Grade 2 learner is expected to achieve. The work given was all grade appropriate and acknowledged the DBE curriculums.

The study shows that when putting the four elements together, utilising Bee-Bots helped to integrate all STEAM subjects in a TPACK designed lesson presented in Grade 2.

5.3 Guidelines developed

This section shares the emerging guidelines that stemmed from the study, as indicated in the green sections in Chapter 4. These are based on the reflections of the researcher and expert reviewer and are found in Table 5.2.

Table 5.2 Emerging guidelines

Emerging Guidelines (Green)	Core Guideline
Having a story to follow helps the learners to create a picture of the problem they are going to solve.	**Story** A story either from the book, *If I were a wizard* by Paul Hamilton or from the stories the researcher created.
Start with a simple sequence of code and then move to harder coding skills such as loops and repeat functions.	**Coding and robotics** Developing learners' skills from lesson to lesson.
Use the scientific method to give the lesson structure. Electronic systems and control are the Bee-Bot. Concrete materials are the materials they could use to build and create obstacles. Having an instruction card for them to draw and plan the route. Prior knowledge of direction to correctly distinguish between their left and right.	**STEAM** Incorporating STEAM subjects by using the scientific method, Bee-Bots, concrete objects to build structures with, instruction card and direction. The teacher needs to have knowledge of all STEAM subjects to be able to implement them.
Technology in STEAM is the subject. Technology and how Bee-Bots fall under the content of electronic systems and controls. The Technology in TPACK is the electronic devices and is coding and robotics when using the design process as an educational technology tool to support the development of STEAM content.	**Technology in this study** There needs to be differentiation between the subject Technology and the technology used to aid the lesson.
The emerging guideline is the importance of having a problem for the learners that needs to be solved by using their computational thinking skills effectively. This sets the scene for the development of 21st century skills and digital skills in the classroom as well as STEAM integration possibilities.	**Problem solving** There needs to be a suitable problem that the learners need to solve to develop their 21st century, digital and computational thinking skills.
The TPACK from the design process is used as a tool to create, observe and reflect on all the lessons created.	**TPACK design tool** Teachers need to use Figure 4.2 as a tool when creating, observing and reflecting on the lesson.

The emerging guidelines are summarised in Table 5.2 and are used to create the guidelines of using stories, coding and robotics, STEAM, technology in STEAM, problem solving and the TPACK design tool. These guidelines show how the TPACK tool is a tested structure and works when integrating STEAM subjects into a single lesson. Six core guidelines are needed to teach an integrated lesson successfully as seen in Figure 5.3.

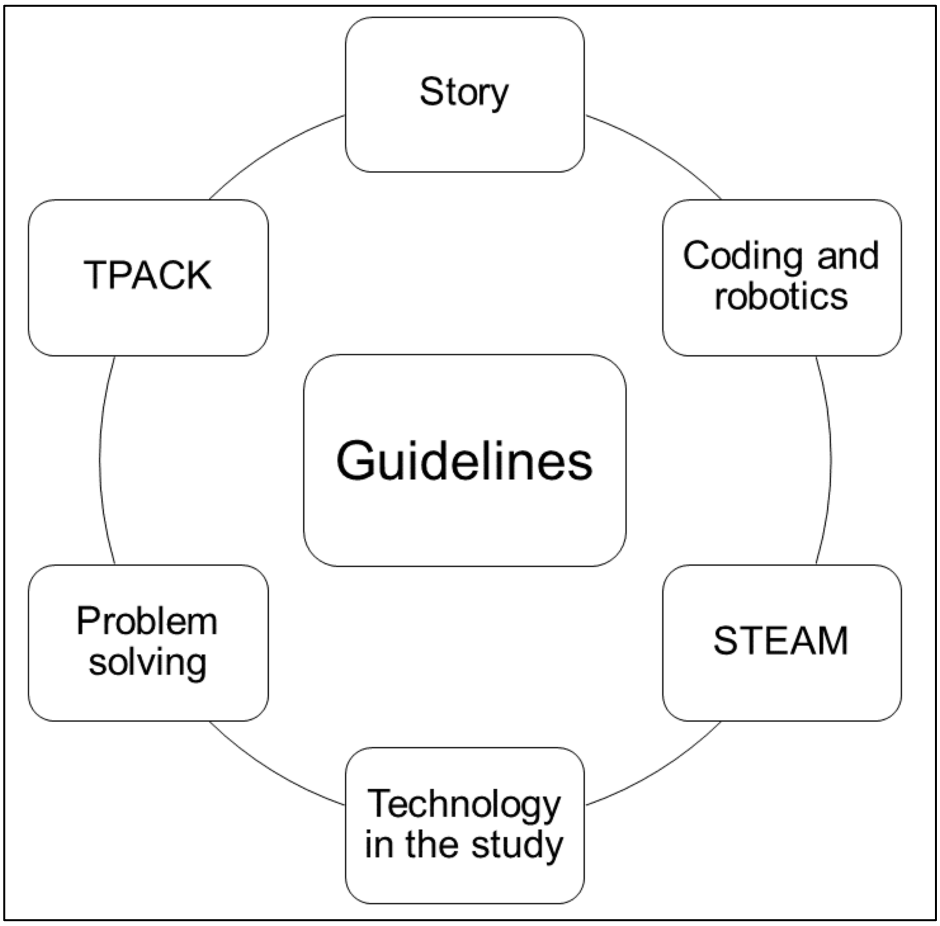


Figure 5.3 Core guidelines

How to implement Figure 5.3 is explained in detail below. The story is a good guideline to use as it creates something for the learners to use to solve the problem. For coding and robotics, one must start with a simple sequence of code and then move to more difficult coding skills, such as loops and repeat functions.

When integrating STEAM: The scientific method gives structure to the lesson and incorporates scientific inquiry. The main Technology in the form of electronic systems and controls is always the Bee-Bot, so it is important to keep the device the same. The learners need to be given concrete materials they can use for building, such as Lego and other apparatus for the Engineering. Art is visible in learners' having an instruction card to draw objects on and ensures that Art is always present in the lessons. Learners need to have prior knowledge of direction to distinguish between their left and right to incorporate Mathematics. The teacher needs to have the knowledge of what STEAM integration is to teach the subjects effectively in a single lesson.

The Technology in this study was the subject Technology and how Bee-Bots fall under the content of electronic systems and controls. The Technology in TPACK is the electronic devices and features as coding and robotics when using the design process as an educational technology tool to support the development of STEAM content.

Problem solving must be incorporated through open-ended and ill-structured complex problems that Technology as a subject thrives to solve. This sets the scene for the development of 21st century skills and digital skills in the classroom as well as STEAM integration possibilities. The lessons present a problem for the learners that needs to be solved by using their computational thinking skills effectively.

The teacher needs to have a knowledge of the Technology needed for a coding and robotics lesson, the Pedagogy behind what they are going to teach and the Content of the subjects they are going to teach. When the teacher has prepared the lesson to include the TPACK guidelines they need to ensure that they have knowledge of STEAM subjects' content. The combination of the TPACK conceptual framework and all STEAM subjects results in an integrated lesson.

This study has shown that the most important guideline for a teacher to follow to create their own lesson is to have a knowledge of the TPACK framework as well as how it has been adapted in this study to be used as a tool to create and observe lessons. This allows for the structure needed to create a STEAM integrated lesson as well as to observe it effectively.

Harper (2017), Johnston et al. (2018) and Martin-Hansen (2018) underscore the importance of giving teachers the tools to integrate subjects. These guidelines should help teachers to incorporate STEAM subjects into a lesson using the TPACK framework as a guide.

These guidelines should empower teachers to integrate STEAM subjects backed up by DBE (2019a) and Harper (2017) who focus the importance of empowering teachers.

The guidelines are further presented as practical guidelines in Appendix L; these include ideas and examples and can be implemented by a teacher. When designing lessons, teachers can refer to Appendix G where lessons to use as a guide have been included. The Bee-Bot instruction card and scientific method are included in Appendix K.

While reflecting, the researcher and the expert reviewer felt that not all teachers will have access to the book, *If I were a wizard* by Paul Hamilton. Therefore, the researcher has created stories that can be used if there is no access to the book and can be found in Appendix L.

5.4 Limitations of the study

During the study it was not easy to distinguish between Technology as a subject and educational technology. There is a blurred line between the two and how to use them in the classroom. The researcher had to go back through the chapters to ensure that the correct distinction between the two had been made. Another limitation was that in the Foundation Phase there is not always a clear distinction between the different subjects as much integration already takes place when teaching.

Covid-19 regulations during the time of data collection in 2020 resulted in a limitation in the interaction between the participants and researcher. Collaboration was limited to verbal communication as no sharing was allowed. Communication could have been inhibited due to masks as participants could not see the formation of words being said. Bee-Bots would normally have been introduced to the learners in the course of their Grade 2 year; however, only some of the learners had prior knowledge of working with Bee-Bots in previous years.

Due to Covid-19 the following measures were adhered to: the participants always wore masks; no gloves could be worn. All apparatus was sanitised before and after the lessons; the lessons did not take place on a carpet but rather on a sanitised desk; participants did not share apparatus.

Conducting this study at a private school meant that the school already had access to Bee-Bots. Other schools might not all have access to Bee-Bots.

The time constraint of 45 minutes could be a limitation, depending on the lesson times allocated in a particular school. Less than 45 minutes could result in learners not being able to complete the problem effectively in the given time.

The short responses by the learners in the interviews could be a limitation to the amount of data collected. This could be addressed in a return study by having interviews after each lesson and not just at the end of the study.

5.5 Value and contribution

This study provides guidelines for teachers to create their own lessons incorporating STEAM subjects using the TPACK framework as a tool. It made use of offline coding without having to rely on internet access. The Bee-Bots are physical devices and therefore helped the learners in the concrete stage of learning with respect to coding; learners were able to move the device physically.

In Table 5.3 the researcher explores the differences between what the DBE expects Grade 2 learners to code and what they achieved in this study. This table indicates aspects of the study as it shows what learners are capable of achieving according to the DBE (2021) as well as what they achieved in this study. Table 5.3 is colour-coded to show what was included in this study (blue) and what was not present (orange).

Table 5.3 DBE framework versus this study
(DBE, 2021)

Topic	DBE content requirement for Grade 2	This study
Pattern recognition and Problem Solving	• Creating patterns • Introduction to Algorithmic thinking • Following instructions to make a pattern according to numbers. • Encoding and decoding	Learners were able to create their own patterns in the code; for example, the learners placed the fruit in the order the Bee-bot needed to follow to create a new recipe. Learners were exposed to algorithmic thinking when they explored coding the Bee-Bots. When creating the 10 perfect waves they followed a pattern of numbers. When finding the quickest route for Aunty Matilda they counted the steps in their coding.
Algorithms and Coding	Introducing the basic features of programming interface: • Create a project • Move blocks into the scripting area • Select a block category • Select character/agent or objects. • Use blocks in scripting area as buttons • Changing the size of the characters/agent or object. • Save a project • Close the Application	The learners were able to design the layout on the Bee-Bot mat including multiple objects for the Bee-Bot to move around. The learners were able to continue a sequence and create a string of code. They looked at different ways to find the solution to the same problem. They used only a single character of a Bee-Bot to complete the code. They used multiple Bee-Bots so that each learner had their own and was able to contribute to the code.

Topic	DBE content requirement for Grade 2	This study
	• Continue with sequences • Introduce that more than one sequence of programming can take place at once in a single program. • Introduce more than one character/agent or object.	The orange aspects are all covered in Scratch programming that is a form of block code.
Robotics	Introduction of mechanical components • Basic chassis, basic fasteners, axles and wheels. • Propulsion through an elastic band and a fan • Continue with building a chassis. • Continue with electric fan using a basic circuit and using a fan for propulsion.	The learners were exposed to the robotic toy of a Bee-Bot that has two wheels at the base of the robot. The Bee-Bot has wheels that help it to move forwards and backwards, and turns is left and right. The learners used this to code a sequence to solve a problem. They learnt to program the Bee-Bot in a single sequence of code while moving around obstacles. In this study the learners were not exposed to creating their own robot but rather only programming the already made robotic toy of a Bee-Bot. It is for this reason that the chassis, fasteners, and axles were not introduced.
Internet and E-Communications	• Digital Communication: Different methods of communication. • Digital Communication: Text, Voice and Video.	The learners used different methods to communicate effectively with their group, however no digital communication was used. They used written text on the instruction card to show how the Bee-Bot would move around the objects. They used voice in their verbal discussions and when solving the problems. The Bee-Bots were offline so the learners did not use text, voice and video aspects of communication as found on a computer. All communication between the learners and the Bee-Bots was through physical programmable buttons on the Bee-Bots.
Application Skills	Physical/Virtual keyboards: • Directional Keys (up, down, left and right) • Introduction to pointing devices. Introduction to a text editor application. • Using and identifying the following keys on a (Physical/virtual) keyboard: Enter key, Space bar, Shift key, Backspace key, Delete key, Full stop, Question mark, Comma, Exclamation mark and Numeric Keys	The learners used the directional arrows on the Bee-Bot to make it move forwards, backwards, and turn left and right. The learners did not use the QWERTY keyboard as found with a personal computer to apply their skills but rather used the Bee-Bot button interface to apply the coding skills that they had learnt. The buttons included directional arrows, pause, clear (Delete), and go (Enter) buttons.

Table 5.3 shows DBE content requirements for Grade 2 and what the study included in the lesson in blue. The DBE uses Scratch Junior which is a block-based form of coding and is done online and using a personal computer or similar device. Even though the Bee-Bots do not require a block-based code the study still included aspects from the Grade 2 requirements for coding as highlighted in blue in Table 5.3. This study used Bee-Bots that are offline devices but still enable learners to complete some of the desired outcomes of the curriculum and they ensure that learners can learn to code with a concrete device. Bee-Bots allow learners to watch the concrete movement of their coding steps (Highfield, 2010). Learners can manipulate the objects, which helps them to deepen their understanding (Mayesky, 2012). The learners did not code an online device which could be a solution to any school that does not have access to the internet.

5.6 Recommended research

For future studies, it is recommended that the Bee-Bot be substituted for a different programmable electronic toy to see if the same results are achievable. A future study could also have a third action research lesson to see whether a different teacher could incorporate all STEAM subjects into a TPACK designed lesson using Bee-Bots.

Future studies could look at the learners' experiences and Keller's ARCS. ARCS was designed to understand what motivates learners to learn (Keller, 1987). ARCS is an acronym refers to Attention, Relevance, Competence and Satisfaction.

Questions that could be posed for future research:

How can other devices be utilised to facilitate TPACK designed STEAM activities in Grade 2?

How can different Grades use Bee-Bots to facilitate TPACK designed STEAM activities?

How do learners experience Project-Based learning through Keller's ARCS?

5.7 Researcher's experiences while conducting the research

It was very rewarding to see the lessons in action and all STEAM subjects being integrated. The learners really enjoyed the coding aspect as they had not been able to do this with Covid-19 protocols at school. As the researcher I really enjoyed working with the expert reviewer and sharing observations with her.

The reflection journal enabled the researcher to ensure that important observations were not lost. The journal was used in correlation with the notes made on the observation sheets.

5.8 Conclusion

The RQ. “How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?” has been revisited. The research questions were broken up into the focus areas of Bee-Bots, TPACK, STEAM and Grade 2. Bee-Bots are designed specifically for young children and this gave the Grade 2 learners a better ability to grasp the STEAM subjects effectively as they had a concrete object to manipulate. This study shows that the conceptual framework enriched learners’ understanding of coding and robotics as they successfully completed each problem. This study shows that STEAM subjects could be successfully integrated into a single lesson whether it is well or ill structured. The study shows that when putting the four elements together, utilising Bee-Bots helped to integrate all STEAM subjects in a TPACK designed lesson presented in Grade 2.

This study resulted in the development of six guidelines on how to make a STEAM integrated lesson using the TPACK design tool. These guidelines include the use of a story, use of coding and robotics, knowledge of STEAM subjects and their integration, differentiation between technology as a teaching aid and Technology as a subject, appropriate problems to solve, and the use of the TPACK design tool itself. This study has shown that the most important guideline for a teacher to follow to create their own lesson is to have a knowledge of the TPACK framework as well as how it has been adapted in this study to be used as a tool to create and observe lessons.

The value and contribution of this study has been shown by comparison of this study with the DBEs expectation for coding and robotics for Grade 2 learners. This study had a high overlap in the topic of pattern recognition and problem solving, as well as physical input using buttons. There was also a good introduction into learners being able to continue and complete a sequence of code.

References

Altrichter, H., Kemmis, S., McTaggart, R., & Zuber-Skerritt, O. (2002). The concept of action. *The Learning Organization, 9*(3), 125–131. doi:10.1108/09696470210428840

Angeli, C., Voogt, J., Fluck, A., Webb, M., Cox, M., Malyn-Smith, J., & Zagami, J. (2016). A K-6 Computational Thinking Curriculum Framework: Implications for Teacher Knowledge. *Educational Technology & Society, 19*(3), 47–57.

Bagiati, A., Yoon Yoon, S., Evangelou, D., & Ngambeki, I. (2010). Engineering Curricula in Early Education: Describing the Landscape of Open Resources. *Early Childhood Research and Practice, 12*(2), 1-15.

Baran, E., Chuang, H.-H., & Thompson, A. D. (2011). TPACK: An emerging research and development tool for teacher educators. *Turkish Online Journal of Educational Technology, 10*(4), 370-377.

Baum, F., MacDougall, C., & Smith, D. (2006). Participatory action research. *Journal Epidemiol Community Health, 60*, 854–857. doi:10.1136/jech.2004.028662

Bell, S. (2010). Project-Based Learning for the 21st Century: Skills for the Future. *The Clearing House, 83*, 39–43. doi:10.1080/00098650903505415

Beni, S., Stears, M., & James, A. (2017). Foundation phase teachers' interpretation of the life skills programme with regard to the teaching of natural science. *South African Journal of Childhood Education, 7*(1), 1-14. doi:https://doi.org/10.4102/sajce.v7i1.440

Bennison, A., & Goos, M. (2010). Learning to teach mathematics with technology: A survey of professional development needs, experiences and impacts. *Mathematics Education Research Journal, 22*(1), 31-56.

Bergen , D., & Fromberg, D. P. (2008). Play and Social Interaction in Middle Childhood. *Phi Delta Kappan, 90*(6), 426-430.

Bers, M. U., Seddighin, S., & Sullivan, A. (2013). Ready for robotics: Bringing together the T and E of STEM in early childhood teacher education. *Journal of Technology and Teacher Education, 29*(3), 355-377.

Blackley, S., & Howell, J. (2019). The Next Chapter in the STEM Education Narrative: Using Robotics to Support Programming and Coding. *Australian Journal of Teacher Education, 44*(4), 51-64. doi:10.14221/ajte.2018v44n4.4

Boddy, C. R. (2016). Sample size for qualitative research. *Qualitative Market Research: An International Journal, 19*(4), 426-432. doi:10.1108/QMR-06-2016-0053

Braund, M. (2020). Beyond Stem Silos: A Case for Transdisciplinarity. In P. Vale, L. Westaway, Z. Nhase, & I. Schudel, *Proceedings of the 28th Annual Conference of the Southern African Association for Research in Mathematics,* *Science and Technology Education* (p. SAARMSTE). Eastern Cape: SAARMSTE.

Burghardt, D., & Hacker, M. (2004). Informed Design: A Contemporary Approach to Design Pedagogy as the Core Process in Technology. *The Technology Teacher*, 6-8.

Cakir , N. K., & Guven, G. (2019). Arduino-Assisted robotic and coding applications in science teaching: Pulsimeter activity in compliance with the 5E learning model. *Science Activities, 56*(2), 42–51. doi:https://doi.org/10.1080/00368121.2019.1675574

Can-Yaşar, M., Inal, G., Özgün, U., & Kandir, A. (2012). Using technology in pre-school education. *US-China Education Review, 3*(4), 375-383.

Chalmers, C. (2018). Robotics and computational thinking in primary school. *International Journal of Child-Computer Interaction, 17*, 93-100. doi:https://doi.org/10.1016/j.ijcci.2018.06.005

Chalufour, I., Hoisington, C., Moriarty, R., Winokur, J., & Worth, K. (2004). The science and mathematics of building structures. *Science and Children, 41*(4), 31-34.

Charlesworth, R., & Lind, K. K. (2010). *Math and Science for Young Children.* (7th, Ed.) Canada: WADSWORTH CENGAGE Learning.

Chen, G., Shen, J., Barth-Cohen, L., Jiang, S., Huang, X., & Eltoukhy, M. (2017). Assessing elementary students' computational thinking in everyday reasoning and robotics programming. *Computers & Education, 109*, 162-175. doi:http://dx.doi.org/10.1016/j.compedu.2017.03.001

Coghlan, D., & Brydon-Miller, M. (2014). Technical Action Research. In D. Coghlan, & M. Brydon-Miller, *The SAGE Encyclopedia of Action Research* (pp. 771-772). London : SAGE Publications Ltd. doi:https://dx.doi.org/10.4135/9781446294406

Copple, C., & Bredekamp, S. (2009). *Developmentally appropriate practice in early childhood programs. Serving children from birth through age 8.* (Third, Ed.) Washington: NAEYC Books.

Costello, P. J. (2007). *Action Research.* London : Continuum.

Creswell, J. W. (2007). *Qualitative Inquiry and Research Design Choosing Among Five Approaches* (2nd ed.). Thousand Oaks, California: SAGE.

Creswell, J. W. (2009). *Research Design Qualitative, Quantitative and Mixed Methods Approaches* (3rd ed.). Thousand Oaks, California: SAGE.

Dell'Erba, M. (2019). *Preparing Students for Learning, Work and Life Through STEAM Education - Policy Brief*. (A. E. Partnership, Producer, & Education Commission of the States) Retrieved from ERIC: https://eric.ed.gov/?id=ED598088

Dennis, L. (1940). Play in Dewey's Theory of Education. *Young Children, 25*(4), 230-235.

Denscombe, M. (2014). *The Good Research Guide : For Small-scale Research Projects.* (5th, Ed.) Maidenhead: McGraw-Hill Education - Open University Press. doi:9780335264711

Department of Basic Education. (2003). *Revised national curriculum statement grades R-9 (Schools): Technology: Teachers' guide for the development of learning programmes.* Pretoria: The Department of Education of South Africa.

Department of Basic Education. (2011a). *Curriculum and Assessment Policy Statement GRADES 1-3 Mathematics.* Pretoria: Department of Basic Education.

Department of Basic Education. (2011b). *Curriculum and Assessment Policy Statement Grades R-3 Life Skills.* Pretoria: Department of Basic Education.

Department of Basic Education. (2018). *Curriculum and Assessment Policy Statement Information Technology.* Pretoria: Department of Basic Education.

Department of Basic Education. (2019a). *Introducing Digital Skills for all into GET Curriculum Framework Grade R-9. Draft.* DBE. Pretoria: DBE.

Department of Basic Education. (2019b). *Professional Development Framework for Digital Learning*. Retrieved from Business Process Enabling South Africa: https://www.bpesa.org.za/index.php/local-skills-development-research/department-of-basic-education-dbe-professional-development-framework-for-digital-learning.html

Department of Basic Education. (2021). *Proposed Amendments to the Curriculum and Assessment Policy Statement (CAPS) to Make Provision for Coding and Robotics Grades R-9.* Pretoria: Department of Basic Education.

DiFrancesca, D., Lee, C., & McIntyre, E. (2014). Where Is the "E" in STEM for Young Children? *Teacher Education, 23*(1), 49-64.

Dixon, K., Janks, H., Botha, D., Earle, K., Poo, M., Oldacre, F., . . . Schneider, K.-L. (2018). A critical analysis of CAPS for Life Skills in the Foundation Phase (Grades R–3). *Journal of Education, 71*, 6-23. doi:http://dx.doi.org/10.17159/2520-9868/i71a01

Ebersöhn, L., Eloff, I., & Ferreira, R. (2016). First steps in action research. In K. Maree, & 2nd (Ed.), *First steps in research* (pp. 134-159). Pretoria, South Africa: Van Schaik Publishers.

Eguchi, A. (2014). Robotics as a Learning Tool for Educational Transformation. *Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education*, (pp. 27-34). Padova.

Eilks, I., & Markic, S. (2011). Effects of a Long-Term Participatory Action Research Project on Science Teachers' Professional Development. *Eurasia Journal of Mathematics, Science and Technology Education, 7*(3), 149-160. doi:10.12973/ejmste/75196

Finlay, L., & Ballinger, C. (2006). *Qualitative Research for Allied Health Professionals: Challenging Choices.* Chichester, West Sussex: John Wiley & Sons, Ltd.

Fran, B., MacDougall, C., & Smith, D. (2006). Participatory action research. *J Epidemiol Community Health, 60*, 854–857. doi:10.1136/jech.2004.028662

Francis, K., & Davis, B. (2018). Coding Robots as a Source of Instantiations for Arithmetic. *Digital Experiences in Mathematics Education, 4*, 71–86. doi:10.1007/s40751-018-0042-7

García-Carrillo, C., Greca, I. M., & Fernández-Hawrylak, M. (2021). Teacher Perspectives on Teaching the STEM Approach to Educational Coding and Robotics in Primary Education. *Education Sciences, 11*(64), 1-16. doi:https://doi.org/10.3390/educsci11020064

Geist, E. (2016). Robots, Programming and Coding, Oh My! *Childhood Education, 92*(4), 298-304. doi:10.1080/00094056.2016.1208008

Greca Dufranc, I. M., García Terceño, E. M., Fridberg, M., Cronquist, B., & Redfors, A. (2020). Robotics and Early-years STEM Education: The botSTEM Framework and Activities. *European Journal of STEM Education, 5*(1), 1-13. doi:10.20897/ejsteme/7948

Guba, E. G. (1981). Criteria for Assessing the Trustworthines of Naturalistic Inquirie. *Educational Communication and Technology, 21*(2), 75-91.

Hamilton, P. (2017). If I Were a Wizard. *Access, 31*(2), 46-47.

Hannaway, D. M., & Steyn, M. G. (2017). Teachers' experiences of technology-based teaching and learning in the Foundation Phase. *Early Child Development and Care, 187*(11), 1745-1759. doi:10.1080/03004430.2016.1186669

Harper, C. (2017). *The STEAM powered classroom*. Retrieved from http://68.77.48.18/RandD/Educational%20Leadership/The%20STEAM-Powered%20Classroom%20-%20Harper.pdf

Hatch, J. A. (2007). *Early Childhood Qualitative Research.* New York, USA: Routledge Taylor & Francis Group.

Highfield, K. (2010). Robotic Toys as a Catalyst for Mathematical Problem Solving. *Australian Primary Mathematics Classroom, 15*(2), 22-27.

Huitt, W., & Hummel, J. (2003). Piaget's Theory of Cognitive Development. *Educational Psychology Interactive: Cognitive Development*, 1-5.

Jamil, F. M., Linder, S. M., & Stegelin, D. A. (2018). Early Childhood Teacher Beliefs About STEAM Education After a Professional Development Conference. *Early Childhood Educ J, 46*, 409–417. doi:10.1007/s10643-017-0875-5

Jang, H. (2016). Identifying 21st century STEM competencies using workplace data. *Journal of Science Education and Technology, 25*(2), 284–301. doi:10.1007/s10956-015-9593-1

Janka, P. (2008). Using a Programmable Toy at Preschool Age: Why and How? *SIMPAR 2008 Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots* (pp. 112-121). Venice (Italy): Dept. of Informatics Education, Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovakia.

Jansen, J. D. (2016). Introduction to language of research. In K. Maree, & 2nd (Ed.), *First Steps in Research* (pp. 16-24). Pretoria, South Africa : Van Schaik Publishers.

Jara, I., Claro , M., Enri, J., San Martín, E., Rodríguez , P., Cabello, T., . . . Labbé, C. (2015). Understanding factors related to Chilean students' digital skills: A mixed methods analysis. *Computers & Education, 88*, 387e398. doi:https://doi.org/10.1016/j.compedu.2015.07.016.

Johnston, K., Highfield, K., & Hadley, F. (2018). Supporting young children as digital citizens: The importance of shared understandings of technology to support integration in play-based learning. *British Journal of Educational Technology, 49*(5), 896–910. doi:10.1111/bjet.12664

Jones, A., Buntting, C., & de Vries, M. J. (2013). The developing field of technology education: a review to look forward. *International Journal of Technology and Design Education, 23*, 191–212. doi:10.1007/s10798-011-9174-4

Kanbul, S., & Uzunboylu, H. (2017). Importance of Coding Education and Robotic Applications for Achieving 21st-Century Skills in North Cyprus. *International Journal of Emerging Technologies in Learning (iJET), 12*(1), 130-140. doi:https://doi.org/10.3991/ijet.v12i01.6097

Katzenmeyer , C., & Lawrenz, F. (2006). National Science Foundation. *New Directions for Evaluation, 109*, 7-18. doi:10.1002/ev.175

Keller, J. M. (1987). Development and Use of the ARCS Model of Instructional Design. *Journal of Instructional Development, 10*(3), 1-10.

Kemmis, S. (2009). Action research as a practice-based practice. *Educational Action Research, 17*(3), 463-474. doi:10.1080/09650790903093284

Knight, V., Wright, J., & DeFreese, A. (2019). Teaching Robotics Coding to a Student with ASD and Severe Problem Behavior. *Autism and Developmental Disorders, 49*, 2632–2636. doi:https://doi.org/10.1007/s10803-019-03888-3

Koehler, M. J., & Mishra, P. (2005). What Happens when Teachers Design Educational Technology? The Development of Technological Pedagogical Content Knowledge. *Educational Computing Research, 32*(2), 131-152.

Koehler, M. J., & Mishra, P. (2009). What Is Technological Pedagogical Content. *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70.

Koehler, M. J., Mishra, P., & Cain, W. (2013). What Is Technological Pedagogical Content Knowledge (TPACK)? *Journal of Education, 193*(3), 13-19.

Koehler, M. J., Mishra, P., Bouck, E. C., DeSchryver, M., Kereluik, K., Shin, T. S., & Wolf, L. G. (2011). Deep-play: Developing TPACK for 21st century teachers. *Int. J. Learning Technology, 6*(2), 147-163. doi:10.1504/IJLT.2011.042646

Kok , L., & Van Schoor, R. (2014). A science-technology-society approach to teacher education for the foundation phase: Students' empiricist views. *South African Journal of Childhood Education, 4*(1), 95-110.

Kopelke, K. (2015). *ICT Learning Innovation Centre* . (Queensland Government) Retrieved from Making your classroom buzz with Bee-Bots: Ideas and Activities for the Early Phase: https://codigo21.educacion.navarra.es/wp-content/uploads/2015/09/BeebotguideA4v2.pdf

Land, M. H. (2013). Full STEAM Ahead: The Benefits of Integrating the Arts Into STEM. *Procedia Computer Science, 20*, 547–552. doi:10.1016/j.procs.2013.09.317

Maree, K. (2016). *First Steps In Research* (Second ed.). Pretoria, South Africa: Van Schaik Publishers.

Martin-Hansen, L. (2018). Examining ways to meaningfully support students in STEM. *International Journal of STEM Education, 5*(53), 1-6. doi:https://doi.org/10.1186/s40594-018-0150-3

Mavhunga, E., & Rollnick, M. (2013). Improving PCK of Chemical Equilibrium in Pre-service Teachers. *African Journal of Research in Mathematics, Science and Technology Education, 17*(1-2), 113-125. doi:http://dx.doi.org/10.1080/10288457.2013.828406

Mawson, B. (2003). Beyond 'The Design Process': An Alternative Pedagogy for Technology Education. *International Journal of Technology and Design Education, 13*, 117–128.

Maxwell, J. A. (2012). *Qualitative Research Design : An Interactive Approach.* Thousand Oaks, California: SAGE.

Mayesky, M. (2012). *Creative Activities for Young Children.* (10th, Ed.) Belmont, California: WADSWORTH CENGAGE Learning.

McKernan, J. (1988). The Countenance of Curriculum Action Research: Traditional, Collaborative and Emancipatory-Critical Conceptions. *Journal of Curriculum and Supervision, 3*(3), 173-200.

McNiff, J. (2014). *Writing and doing action research .* London: SAGE.

Meier, C., & Marais, P. (2014). *Education Management in Early Childhood Development.* (2nd, Ed.) Pretoria, South Africa: Van Schaik.

Melnikovas, A. (2018). Towards an Explicit Research Methodology: Adapting Research Onion Model for Futures Studies. *Journal of Futures Studies, 23*(2), 29–44. doi:10.6531/JFS.201812_23(2).0003

Mouton, J. (2001). *How to succeed in your Master's and Doctoral Studies.* Pretoria: Van Schaik Publishers.

Murris, K., & Verbeek, C. (2014). A foundation for foundation phase teacher education: Making wise educational judgements. *South African Journal of Childhood Education, 4*(2), 1-17.

Naudé, M., & Davin, R. (2017). *Assessment in the Foundation Phase.* Pretoria, South Africa: Van Schaiks.

Nieuwenhuis, J. (2016a). Analysing qualitative data. In K. Maree, & 2nd (Ed.), *First steps in Research* (pp. 103-127). Pretoria, South Africa: Van Schaik Publishers.

Nieuwenhuis, J. (2016b). Introducing Qualitative Research. In K. Maree, & 2nd (Ed.), *First Steps in Research* (pp. 49-70). Pretoria, South Africa: Van Schaik Publishers.

Nieuwenhuis, J. (2016c). Qualitative research design and data-gathering techniques. In K. Maree, & 2nd (Ed.), *First Steps in Research* (pp. 71 -102). Pretoria, South Africa: Van Schaik Publishers.

Olsen, S. J., Azziz-Baumgartner, E., Budd, A. P., Brammer, L., Sullivan, S., Pineda, R. F., . . . Fry, A. M. (2020). Decreased Influenza Activity During the COVID-19 Pandemic — United States, ustralia, Chile, and South Africa, 2020. *Morbidity and Mortality Weekly Report, 69*(37), 1305-1309.

Papert, S. (1972). Teaching Children Thinking. *Programmed Learning and Educational Technology, 9*(5), 245-255. doi:10.1080/1355800720090503

Parker, R., & Thomsen, B. (2019). *Playful integrated pedagogies that foster children's holistic skills development in the primary school classroom.* Højmarksvej : Lego foundation.

Pénzes, I., van Hooren, S., Dokter, D., & Hutschemaekers, G. (2018). How Art Therapists Observe Mental Health Using Formal Elements in Art Products: Structure and Variation as Indicators for Balance and Adaptability. *Frontiers in Psychology, 9*(1611), 1-13. doi:10.3389/fpsyg.2018.01611

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity, 31*, 31-43. doi:https://doi.org/10.1016/j.tsc.2018.10.002

Pieratt, J. R. (2010). Advancing the ideas of John Dewey: A look at the high tech schools. *Education and Culture, 26*(2), 52-64.

Platz, J. (2007). *Ohio Alliance for Arts Education*. Retrieved from How do you turn STEM into STEAM? Add the Arts! : http://www.ikzadvisors.com/wp-content/uploads/2009/09/STEM-+-ARTS-STEAM.pdf

Ponticorvo, M., Rubinacci, F., Marocco, D., Truglio, F., & Miglino, O. (2020). Educational Robotics to Foster and Assess Social Relations in Students' Groups. *Frontiers in Robotics and AI, 7*(78), 1-14. doi:10.3389/frobt.2020.00078

Pool, J., Reitsma, G., & Mentz, E. (2011). An evaluation of Technology teacher training in South Africa: Shortcomings and recommendations. *International Journal of Technology and Design Education, 23*, 455–472. doi:10.1007/s10798-011-9198-9

Queirós, A., Faria, D., & Almeida, F. (2017). Strengths and limitations of qualitative and quantitative research methods. *European Journal of Education Studies, 3*(9), 369-387. doi:10.5281/zenodo.887089

Quieng, M. C., Lim, P. P., & Lucas, M. R. (2015). 21st Century-based Soft Skills: Spotlight on Non-cognitive Skills in a Cognitive-laden Dentistry Program. *European Journal of Contemporary Education, 11*(1), 72-81. doi:10.13187/ejced.2015.11.72

Rahman, M., Krishnan, V. J., & Kapila, V. (2017). *ASEE*. Retrieved from Exploring the Dynamic Nature of TPACK Framework in Teaching STEM: https://www.asee.org/public/conferences/78/papers/18463/view

Resnick, M., Maloney, J., Monroy-Hernandez, A., Rusk, N., Eastmond, E., Brennan, K., . . . Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60-67. doi:10.1145/1592761.1592779

Ridwan, A., Rahmawati, Y., & Hadinugrahaningsih, T. (2017). STEAM Integration in Chemistry Learning for Developing 21st Century Skills. *MIER Journal of Educational Studies, Trends & Practices, 7*(2), 184 - 194.

Saunders, M. N., Lewis, P., & Thornhill, A. (2019). *Research Methods for Business Students.* (Eighth, Ed.) Harlow, England: Pearson.

Saunders, M., & Tosey, P. (2012/2013). The Layers of Research Design. *Academia*, 58-59.

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological Pedagogical Content Knowledge (TPACK): The Development and Validation of an Assessment Instruction for Preservice Teachers. *Journal of Research on Technology in Education, 42*(2), 123-149.

Schooner, P., Nordlöf, C., Klasander, C., & Hallström, J. (2017). Design, system, value: The role of problem-solving and critical thinking capabilities in technology education, as perceived by teachers. *Design and Technology Education: An International Journal, 22*(2), 60-75.

Shulman, L. (1986). Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher, 14*, 4-14.

Shulman, L. S. (1981). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Snowman, J., & McCown, R. (2013). *ED Psych* (Student ed.). Belmont: Wadsworth Cengage learning.

Stainton, H. (2019). *The research onion for beginners*. Retrieved from Life as a Butterfly: https://www.lifeasabutterfly.com/research-onion-beginners/

Tomlinson, S. (1997). Edward Lee Thorndike and John Dewey on the science of education. *Oxford Review of Education, 23*(3), 365-383.

Tsai, C. (2006). Reinterpreting and reconstructing science: Teachers' view changes toward the nature of science by courses of science education. *Teaching and Teacher Education, 22*(1), 363–375.

Turan , S., & Aydoğdu, F. (2020). Effect of coding and robotic education on pre-school children's skills of scientific process. *Education and Information Technologies, 25*, pages4353–4363. doi:https://doi.org/10.1007/s10639-020-10178-4

UNESCO. (2017). *Working Group on Education: Digital skills for life and work.* Paris, France: UNESCO.

Vale, P., Westaway, L., Nhase, Z., & Schudel, I. (2020). Conference Theme: Fostering Delight in Mathematics, Science and Technology Education. *Book of Proceedings of the 28th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education* (pp. 1-390). Eastern Cape: SAARMSTE.

Van Deursen, A. J., & Van Dijk, J. A. (2009). Improving digital skills for the use of online public information and services. *Government Information Quarterly, 26*, 33–340. doi:0.1016/j.giq.2008.11.002

Van Heerden, J. (2014). *Science and Technology in Foundation Phase (Grade R - 3).* Centurion: Biblaridion.

Van Laar, E., Van Deursen, A. J., Van Dijk, J. A., & De Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior, 72*, 577-588. doi:http://dx.doi.org/10.1016/j.chb.2017.03.010

Varkey Foundation's Atlantis Group. (2019). *System Failure Why EdTech policy needs a critical update.* London: Atlantis Group Varkey Foundation.

Venketsamy, R., & Wilson, C. (2020). Voices from the Classrooms: Early Grade Teachers' Experience in the use of Digital Technology in Mathematics

Teaching. In P. Vale, L. Westaway, Z. Nhase, & I. Schudel, *Book of Proceedings of the 28 th Annual Conference of the Southern African Association for Research in Mathematics, Science and Technology Education* (pp. 169-181). Eastern Cape: SAARMSTE.

Vygotsky, L. S. (1978). *Mind in Society.* Cambridge: Harvard University Press.

White, G. W., Suchowierska, M., & Campbell, M. (2004). Developing and systematically implementing participatory action research. *Arch Phys Med Rehabil, 85*(2), 3-12.

Willis, J. W. (2012). Approaches to Data Analysis and Interpretation. In: Foundations of Qualitative Research: Interpretive and Critical Approaches. *SAGE Research Methods*, 287-320. doi:https://dx.doi.org/10.4135/9781452230108

Wing, J. (2008). Computational thinking and thinking about computing. *Philosophical transactions of the royal society., 366*(1881), 3717-3725. doi:10.1098/rsta.2008.0118

Woods, P. (2006). *Successful Writing for Qualitative Researchers* (2nd ed.). Abingdon Oxon, England: Routledge Taylor & Francis Group.

World Economic Forum. (2020). *Schools of the Future Defining New Models of Education for the Fourth Industrial Revolution.* Geneva: World Economic Forum.

Yakman, G., & Hyonyong, L. (2012). Exploring the Exemplary STEAM Education in the U.S. *Journal of the Korean association for science education, 32*(6), 1072-1086. doi:https://doi.org/10.14697/jkase.2012.32.6.1072

Yin, R. K. (2011). *Qualitative Research from Start to Finish.* New York: The Guilford Press.

Appendix A

Timeline

2020	
Proposal	July
Ethics	July
Chapter 2 – Literature Review	July
Chapter 3 – Methodology	August
Design activities	August
Data collection	November
Data analysis	December
2021	
Chapter 4: Action	January
Chapter 6: Conclusion	June
Language editing	July
Changes made	August
Dissertation handed in	August

Appendix B

Letters of consent

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

14 October 2020

REQUEST FOR PARTICIPATION AND INFORMED CONSENT

Dear Sir/Madam

I, Ms. Megan Ranger, am currently completing a MEd (master's) study in Computer Integrated Technology at the University of Pretoria on the following topic: "Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2". In my study I will aim to gain insight into how to integrate Science, Technology, Engineering, Art, and Mathematics (STEAM) in a Grade 2 classroom by using Bee-Bots.

For the purposes of my study, you are requested to give permission for your daughter to participate in six sessions of 45 minutes each. These sessions will take place during the school day. Your daughter may need to stay at school until 14:00. These sessions will take place during lessons not dedicated to any subject and thus your daughter's compulsory lessons will not be disturbed by this study. Your daughter will participate in coding and robotics play activities using Bee-Bots. At the end of the activities there was an interview to find out how your daughter experienced the activities. The expert reviewer (Mrs Cathy Tansell) and I will observe your daughter during the activities, focusing on the STEAM integration, and will take photos to capture participation. Mrs Cathy Tansell is a retired IT teacher from our school with 30 years of teaching experience, she was recruited as an expert reviewer for the purpose of eliminating any bias introduced to the study by myself.

The safety of your daughter is my top priority. Mrs Tansell and I will be present throughout the study. Your daughter will not be left alone or unsupervised during the study. Due to Covid-19 the following measures will be adhered to; your daughter will always wear a mask and no gloves can be worn. All apparatus will be sanitised before and after the lessons. The lessons will not take place on a carpet but rather on a sanitised desk. Your daughter will not share apparatus. Your daughter will take part in verbal collaboration with her peers while maintaining safe social distancing. After your daughter has completed the lesson, she will be taken directly

to the school's aftercare by myself and Mrs Tansell until they are signed out and collected by yourselves from school. The aftercare facility is provided by the school on the school property. Mrs Tansell and I are not involved in the aftercare run by the aftercare staff of the school.
Your daughter's participation is voluntary, and you have the right to withdraw her from the study at any time you wish. If during the study your daughter or yourselves wish to withdraw from the study during a lesson, your daughter will be taken to the aftercare facility as mentioned above. All information that she provides will be treated as confidential and her name will be kept anonymous and will not be made public to anyone. This will be achieved by replacing her name with a pseudonym. During the study, your daughter will be assigned a letter or number to identify her. For example, student A or student 1. Furthermore, your daughter will not be asked to provide any information that could result in her identity being made public. I will always respect your daughter's dignity, ensure she is protected from harm and she will not be placed at risk while participating in the study. The generated data will be stored securely by the University of Pretoria for 15 years.
We also would like to request your permission to use your data, confidentially and anonymously, for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis and using the data for teaching purposes. The confidentiality and privacy applicable to this study is binding on future research studies.

If you are willing to allow your daughter to participate in the study, kindly sign this letter to indicate your consent. This will mean that you agree to your daughter participating voluntarily and that you understand that you may withdraw her from the study at any time. Under no circumstances will her identity be published. Where photographs of your child are published for purposes of this study, her face will be blocked out to protect her privacy and safety.
In addition to your consent, your daughter will also need to give her assent to participate in this study. If you consent to photographs being taken of your daughter, you will be asked to approve the photograph before it is included in the study.

Kind regards

_______________________________ _______________________________

Ms. Megan Ranger (Researcher)
Email: mranger@stmarys.pta.school.za
Telephone number: 076 120 7442

Prof. Ronel Callaghan (Supervisor)
Email: ronel.callaghan@up.ac.za

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

REQUEST FOR PARTICIPATION AND INFORMED CONSENT

I, ____ hereby give permission that my daughter ____ may participate in the M.Ed. study in Computer Integrated Technology at the University of Pretoria on the following topic: "Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2". The study will be conducted by Miss Megan Ranger.

Please tick the applicable boxes:

I consent to my daughter participating in six 45-minute sessions and answering interview questions. ☐

I consent to my daughter having her photo taken and published with her face blocked out. ☐

I do not consent to any photographs to be taken of my daughter. ☐

Signed on this ……… day of …………………….2020

____
Signature of Parent/Guardian

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

14 October 2020

REQUEST FOR PARTICIPATION AND INFORMED CONSENT

Dear ___________________________________

I am currently completing a MEd study in Computer Integrated Technology at the University of Pretoria on the following topic: "Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2". In my study I will aim to gain insight into how integrating Science, Technology, Engineering, Art, and Mathematics (STEAM) in a Grade 2 classroom can be done by using Bee-Bots.

Your parents have given permission for you to participate in my research. Please indicate your consent by colouring in the blocks when answering the questions below.

Kind regards

_____________________________ _____________________________

Ms. Megan Ranger (Researcher)
Email: mranger@stmarys.pta.school.za
Cellular number: 0761207442

Prof. Ronel Callaghan (Supervisor)
email: ronel.callaghan@up.ac.za

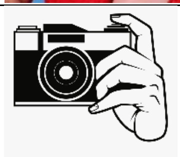
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

REQUEST FOR PARTICIPATION AND INFORMED CONSENT

Reply slip

My name is ____________________________________

I am in Grade 2.	Yes	No
I agree to go to six lessons after school with Miss Ranger using Bee-Bots.  	Yes	No
I agree that my photograph can be taken. 	Yes	No
I understand that no photos of my face will be shown. 	Yes	No
I understand that Miss Ranger is studying at the University of Pretoria. UNIVERSITEIT VAN PRETORIA UNIVERSITY OF PRETORIA YUNIBESITHI YA PRETORIA	Yes	No
I understand that if I am unhappy, I can leave. 	Yes	No

Date: ______________________

14 October 2020

INFORMED CONSENT

Expert reviewer

Dear Sir/Madam

I am currently completing a M.Ed. (Masters) study in Computer Integrated Technology at the University of Pretoria on the following topic: "Utilising Bee-Bots to facilitate TPACK designed STEAM activities in Grade 2". In my study I will aim to gain insight into how to integrate Science, Technology, Engineering, Art, and Mathematics (STEAM), in a Grade 2 classroom, by using Bee-Bots.

For the purposes of my study, you are requested to evaluate the activities, observe, and analyse the activities and be interviewed after the activities have taken place. You are requested to participate in six sessions of 45 minutes each. These sessions will take place during the school day. These sessions will take place during lessons not dedicated to any particular subject. You will be requested to help design, evaluate, observe and analyse the activities using the TPACK framework as a design tool.

You are requested to give permission to be a part of my study. Your participation is voluntary, and you have the right to withdraw her from the study at any time if you so wish. All information which you provide will be treated as confidential and your name will be kept anonymous and not made public to anyone. This will be achieved by replacing your name with a pseudonym. For example, Expert Reviewer A. Furthermore, you will not be asked to provide any information that could result in your identity being made public. You will have full access to the data generated during your involvement as well as the final results of the project. The generated data will be stored securely by the University of Pretoria for 15 years.

We also would like to request your permission to use your data, confidentially and anonymously, for further research purposes, as the data sets are the intellectual property of the University of Pretoria. Further research may include secondary data analysis and using the data for teaching purposes. The confidentiality and privacy applicable to this study is binding on future research studies.

Due to Covid-19 the following measures will be adhered to. You and all the participants will always wear a mask and no gloves can be worn. All apparatus will be sanitised before and after the lessons. The sessions will not take place on a carpet but rather on a sanitised desk. No apparatus will be shared. Verbal collaboration will take place while maintaining safe social distancing.

If you are willing to participate in the study, kindly sign this letter to indicate your consent. This will mean that you agree voluntarily and that you understand that you may withdraw from the study at any time. Under no circumstances will your identity be made known to others.

Kind regards

______________________________ ______________________________

Ms. Megan Ranger (Researcher)
Email: mranger@stmarys.pta.school.za
Cellular number: 0761207442

Prof. Ronel Callaghan (Supervisor)
email: ronel.callaghan@up.ac.za

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

INFORMED CONSENT

Expert reviewer

Title of research project: Integrating STEAM in a Grade 2 classroom using Bee-Bots

I, ____ the undersigned, in my capacity as expert reviewer hereby agree to participate in the above-mentioned research. I understand that my contribution will be treated as anonymous and confidential, and that I have the right to withdraw from the study at any time, if I wish to do so.

Kind regards

__________________________ __________________________

Ms. Megan Ranger (Researcher) Prof. Ronel Callaghan (Supervisor)
Email: mranger@stmarys.pta.school.za email: ronel.callaghan@up.ac.za
Cellular number: 0761207442

Signed at ____________________ on ___________________________________2020.

__________________________ __________________________

Expert reviewer Researcher

____

Witness

6 October 2020

Dear Grade 2 Parents

Miss Ranger has discussed her project with me and I have approved her request to conduct this research at our school. I thank you in advance for allowing your daughter to participate. I am confident that she will have a lot of fun and learn so much through these lessons. I wish Miss Ranger every success in her research project and the completion of her Med.

Kind regards

Alison Jennings

Appendix C

TPACK guidelines sheet

Lessons		
1	Technological Knowledge (TK) (Coding and robotics)	The Technological Knowledge that is focused on is Bee-Bots. These are mechanical robots that move on a grid. The participant will need to code the Bee-Bots to move from the start card to the finish card.
2	Content Knowledge (CK) (STEAM)	The Content Knowledge is the subjects of STEAM and will need to be integrated.
		Scientific skills are incorporated. The scientific skill of observation as the participants will observe to see if their code works. They will communicate with one another to share their ideas and thoughts. They will predict which way is the quickest and then conduct their experiment. They use the scientific method as a guide to follow.
		Technology: Using the Bee-Bots to create an algorithm, a set of steps, to get the character Hazel from the start to the finish. This falls under electronic systems and controls in the subject Technology.
		Engineering: They will create and build suitable structures.
		Art: Creating the characters and completing the instruction card.
		Mathematics: Position and direction, which way will she need to travel. The Bee-Bots can move forward, backward, left and right. Problem solving: what is the quickest route to take?
3	Pedagogical Knowledge (PK) (Foundation Phase teaching, theories and strategies)	The Pedagogical Knowledge in the Foundation Phase is that learners learn with concrete objects.
4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Technological Pedagogical Knowledge focuses on the 21st century and digital skills and the following skills are observed:
		Application of skills
		Coding
		Innovation
		Collaborate with peers
		Think creatively
		Problem solving
5	Technological Content Knowledge (TCK) Technology in this study	Technological Content Knowledge is technology in STEAM subjects and Technology as an educational device.
6	Pedagogical Content Knowledge (PCK) (How to teach STEAM)	Pedagogical Content Knowledge is how to teach STEAM using project-based learning so that the participants will design and create a final product.
7	Technological Pedagogical Content Knowledge (TPACK) (Computational thinking)	Technological Pedagogical Content Knowledge is computational thinking.
8	Context: Grade 2 class	The participants are all from a Grade 2 classroom.

Appendix D

Review sheet based on TPACK

	Lessons		Notes
1	Technological Knowledge (TK) (Coding and robotics)	The Technological Knowledge focused on is Bee-Bots. These are mechanical robots that move on a grid. The participant needs to code the Bee-Bots to move from the start card to the finish card.	
2	Content Knowledge (CK) (STEAM)	The Content Knowledge is the subjects of STEAM and need to be integrated.	
		Scientific skills are incorporated. The scientific skill of observation as the participants observe to see if their code works. They will communicate with one another to share their ideas and thoughts. They predict which way is the quickest and then conduct their experiment.	
		Technology: Using the Bee-Bots to create an algorithm, a set of steps to get the character Hazel from the start to the finish. This falls under electronic systems and controls in the subject Technology.	
		Engineering: They create and build suitable structures.	
		Art: Creating the characters.	
		Mathematics: Position and direction, which way will she need to travel. The Bee-Bots can move forward, backward, left and right. Problem solving: what is the quickest route to take?	
3	Pedagogical Knowledge (PK) (Foundation Phase teaching, theories and strategies)	The Pedagogical Knowledge in the Foundation Phase is that learners learn with concrete objects.	
4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Technological Pedagogical Knowledge focuses on the 21st century and digital skills and the following skills are observed:	
		Application of skills	
		Coding	
		Innovation	
		Collaborate with peers	
		Think creatively	
		Problem solving	
5	Technological Content Knowledge (TCK) Technology in this study	Technological Content Knowledge is technology in STEAM subjects and Technology as an educational device.	
6	Pedagogical Content Knowledge (PCK) (How to teach STEAM)	Pedagogical Content Knowledge is how to teach STEAM using project-based learning; the participants design and create a final product.	
7	Technological Pedagogical Content Knowledge (TPACK) (Computational thinking)	Technological Pedagogical Content Knowledge establishes whether it is possible for learners to use their computational thinking skills.	
8	Context: Grade 2 class	The participants are all from a Grade 2 classroom.	

Appendix E

Observation sheet based on TPACK

Make columns bigger when printing.

Lessons			Tick if present in the lesson	Description or illustration
1	Technological Knowledge (TK) (Coding and robotics)	How the participants used the Bee-Bots		
2	Content Knowledge (CK) (STEAM)	How the participants incorporated the Content Knowledge of integrating all the subjects in STEAM. Give a description of how the subject was incorporated.		
		Science		
		Technology		
		Engineering		
		Art		
		Mathematics		
3	Pedagogical Knowledge (PK) (Foundation Phase teaching, theories and strategies)	How the participants used concrete objects.		
4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Which 21st century and digital skills did the participants use? How did they use the skill?		
		Application of skills		
		Coding		
		Innovation		
		Collaborate with peers		
		Think creatively		
		Problem solving		
5	Technological Content Knowledge (TCK) Technology in this study	How the participants made use of technology in STEAM in their lesson.		
6	Pedagogical Content Knowledge (PCK) (How to teach STEAM)	How the participants designed and created the final products using project-based learning.		
7	Technological Pedagogical Content Knowledge (TPACK) (Computational thinking)	How the participants used their computational thinking skills.		
8	Context Grade 2 class	The participants are all from a Grade 2 classroom.		

Appendix F

Reflection journal

Date	Notes
30 October 2020	Ideas from expert reviewer: Leaners can make a Bee-Bot jacket for the Bee-Bot. You also can include a ruler to show how far the Bee-Bot will move with each step.
16 November 2020	Lesson 1 Group A Group started to make the Lego structures on the Lego base and then moved to placing it on the Bee-Bot grid. Worked well to choose who would write, all wanted to build with the Lego. All helped with instruction cards to plan the quickest route. Pointed out the steps of the quickest route. Planned the steps well and did a lot of trial and error before they could complete a full sequence. Became better at giving one another turns. Once all had gotten the correct sequence, they made the Bee-Bot follow each other. Didn’t use the Bee-Bot cover for long. Not as keen to write the reflection and conclusion as just wanted to code more. No preplanning was more impulsive where they placed work. Lesson 1 Group B Group worked very well as a team overall. They are a very calm group that help each other. Participant 4 led them well with all having a turn and helping one another. They used their hands to plan out the steps and see how the Bee-Bot would move. Participant 7 used the Bee-Bot when making the sequence e.g., move forward and then turn right. Group needed to make sure used the correct directions as participant 6 was not always sure.
	Lesson 2 Group A: This group had a very complicated obstacle course around the sequenced steps the Bee-Bot needed to retrace to find Grandpa Leo’s glasses. They didn’t work well together. They commented that the Bee-Bots must be broken as they believed they had coded correctly.
Interview	Lessons were successful – methodology used to structure the lessons worked well. Covering everything The TPACK tool helped to make sure you have something to go back to and refer to that the lesson was a success as had something to go back and compare it to.
Data collection	When taking part in the data collection it was wonderful to be able to present the lesson as well as to observe the lesson.

Appendix G

Lesson Plans

PACK guidelines sheet

Lesson 1: Can you get Aunty Matilda to work using the fastest route.

Introduction

Read the passage from *If I were a wizard* by Paul Hamilton. The passage explains how Aunty Matilda needs to get to work on her bicycle even if a fallen tree is blocking her way.

This will encourage the learners to create an algorithm. It involves creating a step-by-step account of the instructions she will need to follow to get to work. The most effective algorithm is the one that gets her to work the fastest.

The group is provided with the following objects that they can use:

- Lego
- Cardboard
- Scissors
- Glue
- Ruler
- Pencil
- Own pencil boxes
- Bee-Bot
- Bee-Bot grid
- Bee-Bot ruler
- Bee-Bot jacket template

Body

Learners are given all the apparatus to conduct their experiment to determine the fastest route to get Aunty Matilda to work.

Conclusion

Learners pack up and sanitise.

Lessons		
1	Technological Knowledge (TK) (Coding and robotics)	The Technological Knowledge focused on Bee-Bots. These are mechanical robots that move on a grid. The participants need to code the Bee-Bots to move from the start card to the finish card.
The learners are provided with a Bee-Bot each and a grid sheet. They use these to code Aunty Matilda's route to work.		
2	Content Knowledge (CK) (STEAM)	The Content Knowledge is the subjects of STEAM and needs to be integrated.
		Scientific skills are incorporated. The scientific skill of observation as the participants observe to see if their code works. They communicate with one another to share their ideas and thoughts. They predict which way is the quickest and then conduct their experiment.

		Technology: Using the Bee-Bots to create an algorithm, a set of steps, to get the character Hazel from the start to the finish.
		Engineering: They create and build suitable structures.
		Art: Creating the characters.
		Mathematics: Position and direction, which way she needs to travel. The Bee-Bots can move forward, backward, left and right. Problem solving: what the quickest route to take is.
Science: Follow the scientific method. Question: How will Aunty Matilda get to work? Hypothesis: Make a clever guess as to the fastest route. Experiment: Use the Bee-Bots to get her to work. Observation: Watch the route the Bee-Bot takes. Conclusion: Was my hypothesis correct. Technology: Using the Bee-Bots to create an algorithm, a set of steps. Engineering: Use cardboard and or Lego to create structure that the Bee-Bot must get around, including the fallen tree. Art: Create a Bee-Bot jacket for Aunty Matilda. Mathematics: Position and direction (left, right, forward and backward), problem solving, measurement 15 cm per step the Bee-Bot makes.		
3	Pedagogical Knowledge (PK) (Foundation Phase teaching)	The Pedagogical Knowledge in the Foundation Phase is that learners learn with concrete objects.
Learners learn using the concrete objects of Lego and Bee-Bots.		
4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Technological Pedagogical Knowledge focuses on the 21st century and digital skills and the following skills are observed:
		Application of skills
		Coding
		Innovation
		Collaboration with peers
		Thinking creatively
		Problem solving
The teacher and the expert reviewer observe which of the 21st century and digital skills are used.		
5	Technological Content	Technological Content Knowledge is to establish whether Bee-Bots aid in the integration of all the STEAM subjects when using technology.

<table>
<tr><td></td><td>Knowledge (TCK) coding and robotics in STEAM</td><td></td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe how the learners make use of technology.</td></tr>
<tr><td>6</td><td>Pedagogical Content Knowledge (PCK) (Project-based learning)</td><td>Pedagogical Content Knowledge is project-based learning; the participants design and create a final product.</td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe how the learners work together to achieve the final outcomes.</td></tr>
<tr><td>7</td><td>Technological Pedagogical Content Knowledge (TPACK) (Integrated Bee-Bots collaborative activities)</td><td>Technological Pedagogical Content Knowledge to establish whether it is possible to integrate Bee-Bots in collaborative activities.</td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe the integration and collaboration of the Bee-Bots within the activity.</td></tr>
<tr><td>8</td><td>Context: Grade 2 class</td><td>The participants are all from a Grade 2 classroom.</td></tr>
</table>

Lesson 2: Can you help Grandpa Leo to retrace his steps?

Introduction

Read the passage from *If I were a wizard* by Paul Hamilton. The passage explains how Grandpa Leo needs to retrace his steps so that he can find his glasses. The learners need to sequence and order. They have to help Grandpa Leo to retrace his steps.

The groups are provided with the following objects that they can use.

- Lego
- Cardboard
- Scissors
- Glue
- Ruler
- Pencil
- Own pencil boxes
- Pipe cleaner
- Picture cards of Grandpa's Leo steps
- Bee-Bot
- Bee-Bot grid
- Bee-Bot ruler
- Bee-Bot jacket template

Body

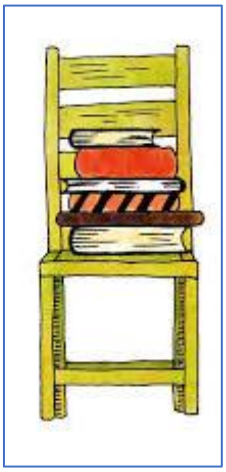
Learners are given all the apparatus to conduct their experiment to help Grandpa Leo retrace his steps.

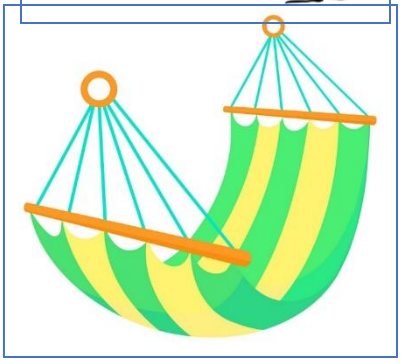
Conclusion

Learners pack up and sanitise.

<table>
<tr><th colspan="3">Lessons</th></tr>
<tr><td>1</td><td>Technological Knowledge (TK) (Coding and robotics)</td><td>The Technological Knowledge is focused on Bee-Bots. These are mechanical robots that move on a grid. The participants need to code the Bee-Bots to move from the start to the finish card.</td></tr>
<tr><td colspan="3">The learners are each provided with a Bee-Bot and a grid sheet. They use these to code Grandpa Leo to retrace his steps.</td></tr>
<tr><td rowspan="6">2</td><td rowspan="6">Content Knowledge (CK) (STEAM)</td><td>The Content Knowledge is the subjects of STEAM and need to be integrated.</td></tr>
<tr><td>Scientific skills are incorporated. The scientific skill of observation as the participants observe to see whether their code works. They communicate with one another to share their ideas and thoughts. They predict which way is the quickest and then conduct their experiment.</td></tr>
<tr><td>Technology: Using the Bee-Bots to create an algorithm, a set of steps to get the character Grandpa Leo from the start to the finish.</td></tr>
<tr><td>Engineering: They create and build suitable structures.</td></tr>
<tr><td>Art: Creating the characters.</td></tr>
<tr><td>Mathematics: Position and direction; which way she needs to travel. The Bee-Bots can move forward, backward, left and right. Problem solving; what is the quickest route to take?</td></tr>
<tr><td colspan="3">Science: Follow the scientific method.
Question: How Grandpa Leo retraces his steps.
Hypothesis: Make a clever guess as to what steps to follow.
Experiment: Use the Bee-Bots to follow the steps he has remembered.
Observations: Watch the route the Bee-Bot takes.</td></tr>
</table>

Conclusion: Was my hypothesis correct? Technology: Using the Bee-Bots to create an algorithm, a set of steps. Engineering: Use cardboard and/or Lego to create a structure that the Bee-Bot must get around including the fallen tree. Use pipe cleaners to create his glasses. Art: Create a Bee-Bot jacket for Grandpa Leo. Mathematics: Position and direction (left, right, forward and backward), problem solving, measurement of 15 cm per step the Bee-Bot makes.		
3	Pedagogical Knowledge (PK) (Foundation Phase teaching)	The Pedagogical Knowledge in the Foundation Phase is that learners learn with concrete objects.
Learners learn using the concrete objects of Lego and Bee-Bots.		
4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Technological Pedagogical Knowledge focuses on the 21st century and digital skills and the following skills are observed:
		Application of skills
		Coding
		Innovation
		Collaboration with peers
		Thinking creatively
		Problem solving
The teacher and the expert reviewer observe which of the 21st century and digital skills are used.		
5	Technological Content Knowledge (TCK) coding and robotics in STEAM	Technological Content Knowledge is to establish whether Bee-Bots aid in the integration of all the STEAM subjects when using technology.
The teacher and the expert reviewer observe how the learners make use of technology.		
6	Pedagogical Content Knowledge (PCK) (Project-based learning)	Pedagogical Content Knowledge is project-based learning; the participants design and create a final product.
The teacher and the expert reviewer observe how the learners work together to achieve the final outcomes.		
7	Technological Pedagogical Content Knowledge (TPACK) (Integrated Bee-Bots collaborative activities)	Technological Pedagogical Content Knowledge is to establish whether it is possible to integrate Bee-Bots into collaborative activities.
The teacher and the expert reviewer observe the integration and collaboration of the Bee-Bots within the activity.		
8	Context: Grade 2 class	The participants are all from a Grade 2 classroom.



Lesson 3: Can you help Dad create a new dish for supper.

Introduction

Read the passage from *If I were a wizard* by Paul Hamilton. The passage explains how Hazel's Dad makes only Bug Bolognese. Learners can choose from the given ingredients to create a new recipe. They need to think about what a mouse eats. They listen to a fact card about what mice eat.

This encourages the learners to create an algorithm. This is a step-by-step process of the instructions Dad will need to create a new dish. The Bee-Bot then has to travel in the correct sequence to create the new meal.

The group is provided with the following objects.

- Lego
- Cardboard
- Scissors
- Glue
- Ruler
- Pencil
- Own pencil boxes
- Fact card on mice
- Ingredients
- Bee-Bot
- Bee-Bot grid
- Bee-Bot ruler
- Bee-Bot jacket

Body

Learner are given all the apparatus to conduct their experiment to create a new meal for Dad.

Conclusion

Learners pack up and sanitise.

<table>
<tr><td colspan="3">Lessons</td></tr>
<tr><td>1</td><td>Technological Knowledge (TK)
(Coding and robotics)</td><td>The Technological Knowledge focused on is Bee-Bots. These are mechanical robots that move on a grid. The participants need to code the Bee-Bots to move from the start to the finish card.</td></tr>
<tr><td colspan="3">The learners are each provided with a Bee-Bot and a grid sheet. They use these to code a new recipe for Dad.</td></tr>
<tr><td rowspan="6">2</td><td rowspan="6">Content Knowledge (CK)
(STEAM)</td><td>The Content Knowledge is the subjects of STEAM and need to be integrated.</td></tr>
<tr><td>Scientific skills are incorporated. The scientific skill of observation as the participants observe to see whether their code works. They communicate with one another to share their ideas and thoughts. They predict which way is the quickest and then conduct their experiment.</td></tr>
<tr><td>Technology: Using the Bee-Bots to create an algorithm, a set of steps to get the character Hazel's dad from the start to the finish.</td></tr>
<tr><td>Engineering: They create and build suitable structures.</td></tr>
<tr><td>Art: Creating the characters.</td></tr>
<tr><td>Mathematics: Position and direction; which way will Dad needs to move to make a new recipe. The Bee-Bots can move forward, backward, left and right. Problem solving: what is the quickest route to take?</td></tr>
<tr><td colspan="3">Science: Follow the scientific method.
Question: How to make a dish for Dad.</td></tr>
</table>

<table>
<tr><td colspan="3">Hypothesis: Make a clever guess.
Experiment: Use the Bee-Bots to create the steps needed for a new recipe.
Observation: Watch the route the Bee-Bot makes.
Conclusion: Was my hypothesis correct?

Technology: Using the Bee-Bots to create an algorithm, a set of steps.

Engineering: Use cardboard and or Lego to create ingredients the Bee-Bots must use to create a new meal.

Art: Create a Bee-Bot jacket for Dad. Creating a new recipe to follow.

Mathematics: Position and direction (left, right, forward, and backward), problem solving; measurement of 15 cm per step the Bee-Bot takes.</td></tr>
<tr><td>3</td><td>Pedagogical Knowledge (PK) (Foundation Phase teaching)</td><td>The Pedagogical Knowledge in the Foundation Phase is that learners learn with concrete objects.</td></tr>
<tr><td colspan="3">Learners learn using the concrete objects of Lego and Bee-Bots.</td></tr>
<tr><td rowspan="7">4</td><td rowspan="7">Technological Pedagogical Knowledge (TPK) 21st century /digital skills</td><td>Technological Pedagogical Knowledge focuses on the 21st century and digital skills and the following skills are observed:</td></tr>
<tr><td>Application of skills</td></tr>
<tr><td>Coding</td></tr>
<tr><td>Innovation</td></tr>
<tr><td>Collaboration with peers</td></tr>
<tr><td>Thinking creatively</td></tr>
<tr><td>Problem solving</td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe which of the 21st century and digital skills are used.</td></tr>
<tr><td>5</td><td>Technological Content Knowledge (TCK) coding and robotics in STEAM</td><td>Technological Content Knowledge is to establish whether Bee-Bots aid in the integration of all the STEAM subjects when using technology.</td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe how the learners make use of technology.</td></tr>
<tr><td>6</td><td>Pedagogical Content Knowledge (PCK) (Project-based learning)</td><td>Pedagogical Content Knowledge Project-based learning; the participants design and create a final product.</td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe how the learners work together to create the final outcome.</td></tr>
<tr><td>7</td><td>Technological Pedagogical Content Knowledge (TPACK) (Integrated Bee-Bots collaborative activities)</td><td>Technological Pedagogical Content Knowledge to establish whether it is possible to integrated Bee-Bots into collaborative activities.</td></tr>
<tr><td colspan="3">The teacher and the expert reviewer observe the integration and collaboration of the Bee-Bots within the activity.</td></tr>
<tr><td>8</td><td>Context: Grade 2 class</td><td>The participants are all from a Grade 2 classroom.</td></tr>
</table>

Fruit Salad Recipe for Dad

Step 1: Get a bowl, chopping board and knife.		 
Step 2: Cut the strawberries in half and add them to the bowl.		
Step 3: Add the blueberries.		
Step 4: Peel and chop the bananas and add them to the bowl.		
Step 5: Chop the apple into quarters and add them to the bowl.		
Step 6: Add the raspberries to the bowl.		
Step 7: Dish up and enjoy your fruit salad.		

Appendix H

Interview questions

Expert reviewer

1. How did you experience the learners' use of Bee-Bots?	
2. Did you see the integration of all STEAM subjects? Explain how you observed the objects being used.	
3. How did the learners work with concrete objects and what objects did they use?	
4. Which 21st century skills did	Application of skills

you see the learners using? Explain how they used or did not use each skill.	
	Coding
	Innovation
	Collaboration with peers
	Thinking creatively
	Problem solving
5. Did Bee-Bot's aid in the integration of all the STEAM subjects? Justify your answer.	
6. Did the learners design and create the final product?	

7. Do you think it is possible to integrate Bee-Bots into collaborative activities? Justify your answer.	
8. How can Bee-Bot activities be designed for STEAM integration?	
9. How can collaborative skills be facilitated in Bee-Bot group activities?	
10. How can Bee-Bots be utilised to facilitate TPACK designed STEAM activities in Grade 2?	

Learners

Questions	Answers. Circle the pictures to answer the questions.		
Are you in Grade 2?	Yes	No	
Are you a girl?	Yes	No	
Did you use a Bee-bot?	 I have used Bee-Bots	 I have used Bee-Bots a little bit	 I have not used Bee-Bots
Did you predict what was going to happen?	 Yes	 A little bit	 No
Did you program the Bee-Bot to move?	 Yes	 A little bit	 No
Did you build a structure?	 Yes	 A little bit	 No

Did you create a character?	 Yes	 A little bit	 No
Draw an arrow to show the directions indicated.	Left up Right down		
Did you enjoy playing with the Bee-Bots?	 Yes	 A little bit	 No
Did you enjoy making structures?	 Yes	 A little bit	 No
Did you enjoy making the characters?	 Yes	 A little bit	 No

Do you like to work with your friends?	 Yes	 A little bit	 No
Did you solve any problems?	 Yes	 A little bit	 No
Did you enjoy learning to code?	 Yes	 A little bit	 No
Would you tell a friend about what you created?	 Yes	 A little bit	 No
What problem did you solve?	__________		
What new skills did you learn?	__________		

What did you find interesting?	
What would you like to do again?	
What did you enjoy the most?	
What would you change next time?	

Appendix I

Observation notes

Table summary of all observation notes

Lesson			Expert reviewer	Researcher	Similarities
Lesson 1	Group A	TK coding and robotics	Quite proficient with Bee-Bots	Learners coded Bee-Bots one step at a time.	Used Bee-Bots
		CK STEAM	Integrated all STEAM subjects. S: Scientific method and documented findings. T: Programmed Bee-Bots. E: Built and placed obstacles. A: Made Bee-Bot jacket. M: Good mathematical vocabulary.	Integrated all STEAM subjects. S: Scientific method. T: Programmed Bee-Bots. E: Lego to build structures. A: Made Bee-Bot. jacket and drew a map on instruction card. M: Direction and problem solving.	Integrated all steam subjects. Used the scientific method. Programmed the Bee-Bots. Built and created obstacles. Made a Bee-Bot jacket. Used good mathematical vocabulary. Observed different skills being used for Art and Mathematics.
		PK Foundation Phase	Built obstacle using concrete objects. The Bee-Bots are concrete objects.	Used Lego to build obstacles as well as the Bee-Bots.	Bee-Bots and concrete objects to make obstacles.
		TPK 21st century /digital skills	Application of skills: skills applied: Coding: Programmed and debugged the Bee-Bot. Coded one step at a time. Innovation: Using concrete objects to build obstacles on mat. Collaboration: Not too good. Participant 2 keen to code only. Participant 1 did most of written parts. Participant 3 added good ideas verbally. Think creatively using concrete objects to build obstacles on mat.	Application of skills: Used digital skills Coding: Coded steps and recoded until they got it right. Innovation: Designed an interesting layout for Aunty Matilda to get around. Collaboration: Could work more on this skill. Two worked well together. Thinking creatively: How to debug and to find the quickest route. Problem solving: Lots of this was seen. Started by doing one step at a time and had to remember they needed to clear and	They used digital and 21st skills effectively.

			Problem solving: Debugging programme.	finally move to one full sequence.	
		TCK coding and robotics in STEAM	The Bee-Bots were at the centre of the lesson. Their coding skills were good. Didn't put together a string of code – moved Bee-Bots and coded step-by-step.	They made use of Bee-Bots to incorporate all STEAM subjects.	Bee-Bots to incorporate all STEAM subjects.
		PCK Project-based learning	The learners used the concrete objects available. The obstacles were randomly placed on the mat.	They designed the problem and created the layout for the obstacle course.	Created own layout and obstacles.
		TPACK Integrated Bee-Bots collaborative activities	There was some collaboration between Participant 1 and Participant 3 to create paper coding sheet.	They had to work together to make the obstacle course and find the quickest route.	The group worked on their collaboration skills.
		Context: Grade 2 class	Same for expert reviewer and researcher.		
	Group B	TK coding and robotics	The children were very comfortable and proficient using the Bee-Bots.	They were confident to use the Bee-Bots.	Confident to use the Bee-Bots.
		CK STEAM	S: Were introduced to the scientific method. Documented their finding on the given sheet: T: Programmed Bee-Bots confidently. E: Built obstacles for the mat using Lego blocks and other concrete objects. A: Created jackets for the Bee-Bots. M: Used mathematical language throughout the lesson	S: Used the scientific method. T: Used the Bee-Bots. E: Built structures of the coding mat. A: Drew the directions and obstacles present on the instruction card. M: Mathematical language and directionality. From the paper plan to the map, it was a huge amount of special awareness to get right.	Used the scientific method effectively. Programmed the Bee-Bots confidently. Created Bee-Bot jacket and drew directions on instruction card. Used mathematical language.
		PK Foundation Phase	To build and create obstacles for the	Bee-Bots and Lego using concrete objects.	Used concrete objects to build and create.

			Bee-Bots to navigate.		
		TPK 21st century /digital skills	Application of skills. All skills applied. Coding: The Bee-Bots were programmed efficiently. Innovation: Made hands into a Bee Bot to calculate the amount of steps /direction before coding Bee Bot. Collaboration: Mostly; Participant 5 was a definite leader initially. Allocated tasks to everyone. She was allowed to take charge. Thinking creatively: There was chatter most of the time as the learners worked through the activity. Different ideas /ways to perform the task. Problem solving: Lots of problem solving evident. Debugging code /step-by-step coding that eventually led to the group creating a string of code using the coding sheet.	Application of skills. Used own knowledge of digital skills and prior knowledge and shared this with the group. Coding: Used Bee-Bots to create code. Innovation: Very creative with what they made the Bee-Bots go around. Collaboration: Excellent group work and all had a role to play. Worked well together and helped one another. Thinking creatively: Used hands to plan out the Bee-Bots' movements. Problem solving: Excellent collaboration to solve problems and go back and debug the code. Found the quickest route and the longest route to make sure they had chosen the correct route.	They used digital and 21st skills effectively.
		TCK coding and robotics in STEAM	The fact that a story was used about coding made it meaningful for the learners and the coding became the centre of the lesson while incorporating all of the STEAM elements.	The students coded the Bee-Bot to get Aunty Mathilda to work, using the quickest route.	The story helped to make the coding meaningful to the participants.
		PCK Project-based learning	Used available materials to create final product.	The students created the obstacles.	Participants created the final product.

		TPACK Integrated Bee-Bots collaborative activities	There was a certain amount of collaboration although Participant 5 was the real leader of the group.	Excellent collaboration	Collaborated well as a group.
		Context: Grade 2 class	Same for expert reviewer and researcher.		
Lesson 2	Group A	TK coding and robotics	Children displaying great confidence when manipulating the Bee-Bots.	Coding the Bee-Bots.	Both coded Bee-Bots.
		CK STEAM	S: Documented findings on sheet – scientific method used. T: Programmed the Bee-Bots with great confidence. Participant 3 often stood back and observed. E: Had built and placed obstacles on mat. Made glasses using pipe cleaners. A: Completed the paper coding sheet. M: Mathematical vocabulary /directionality evident throughout lesson. Good spatial awareness as the obstacles /direction arrows are transposed onto the paper plan.	S: Scientific method. T: Sequencing the Bee-Bot. E: Created obstacles for the Bee-Bot. A: Made glasses for Grandpa Leo and drew on the instruction card. M: Direction and problem solving.	Integrated all steam subjects. Used scientific method. Sequenced the Bee-Bots. Drew on instruction card. Used good mathematical vocabulary.
		PK Foundation Phase	Built obstacles to place on mat using concrete objects. Made Grandpa's glasses.	Used Lego to make towers and used pipe cleaner to make glasses.	Made glasses using pipe cleaners.
		TPK 21st century /digital skills	Application of skills: All skills applied. Coding: Participant 1 didn't want to follow paper plan to create a string of code. Participant 2 insisted	Application of skills: Used the skills they knew about coding and expanded on these skills. Coding: Did not complete whole	They used digital and 21st skills effectively.

			but it didn't work. Participant 1 insisted on her way and coded step-by-step. Innovation: This group wanted to use as many of concrete objects as they could. They were quite innovative in what the structures became. Collaboration: Participant 3 observed closely and added ideas as problems arise. Becoming more assertive. Thinking creatively: The question was where do the glasses need to go? Afterthought: On the end card. Problem solving: Participant 1 and 3 showed good problem solving skills.	sequence of code but they tried a lot to debug but not all successful. Innovation: Had a very busy obstacle course. Collaboration: Did not collaborate well as all very competitive and wanted to finish first. Thinking creatively: Though creatively to make obstacles for the Bee-Bot to go around. Problem solving: Problem solved individually to solve of problems with debugging.	
		TCK coding and robotics in STEAM	The Bee-Bots were at the centre of the lesson. Their coding skills developing. Still preferred to code step-by-step.	Used the Bee-Bot to retrace Grandpa Leo's steps to find his glasses.	Coding skills are developing.
		PCK Project-based learning	The children used the concrete objects available. The obstacles placed randomly on the mat.	They created the glasses and the layout on the Bee-Bot grid.	Used Lego to create obstacles.
		TPACK Integrated Bee-Bots collaborati ve activities	Participant 3 insisted that her obstacle was left on the mat – became more assertive. Participant 1 and 3 collaborated mostly to complete the task. Participant 2 keen to code only.	They tried to debug their Bee-Bots to complete the sequence.	Participant 1 and 3 collaborated well together.

			Participant 2's ideas not always accepted by group.		
		Context: Grade 2 class	Same for expert reviewer and researcher.		
	Group B	TK coding and robotics	The learners were very proficient coding the Bee-Bots.	Coding the Bee-Bots.	Used Bee-Bots effectively.
		CK STEAM	S: Documented their finding on the given sheet using the scientific method headings. T: Programmed Bee-Bots confidently. Participant 5 coded step-by-step. Participant 6 coded a complete string of code correctly to get Bee Bot from start to finish. E: Created obstacles using concrete objects. Made Grandpa's glasses. A: The paper coding plan was completed. The obstacles were drawn. M: Transposing drawings of obstacles from mat onto paper plan; illustrating spatial awareness.	S: Scientific method T: Sequencing the Bee-Bot. E: Created obstacles for the Bee-Bot. A: Made glasses for Grandpa Leo and drew on the instruction card. M: Direction and problem solving.	Integrated all STEAM subjects.
		PK Foundation Phase	To build and create obstacles for the Bee-Bots to navigate.	Used Lego to make towers and used pipe cleaner to make glasses.	Built and created obstacles course using different concrete objects.
		TPK 21st century /digital skills	Application of skills: All skills applied. Coding: The first time a complete string of code completed correctly without moving the Bee Bot. Innovation: The group placed a gate as an obstacle. This	Application of skills: Used the skills they knew about coding and expanded on these skills. Coding: Completed a sequence of code that correctly retraced Grandpa Leo's steps.	They used digital and 21st skills effectively.

			was opened for the Bee Bot to go through and closed once it had moved through. Collaboration: Participant 5 allocated jobs as in lesson 1. Participant 7 objected, and they discussed their issues. The two compromised and were both happy to continue with the activity. Thinking creatively: Decided to put glasses on the Bee Bot. Devising code on paper plan. Problem solving: Constantly throughout the lesson. Discussions were constant. Participant 7's problem solving skills coming to the fore.	Without using the Bee-Bot to guide them. Innovation: Create an innovative grid in order for Grandpa Leo to retrace his steps. Collaboration: Worked well together and did not let anyone in the group tell them what to do. All got a turn to code, and they helped each other. Thinking creatively: Created glasses that could fit the Bee-Bots. Problem solving: Problem solved the correct way to sequence the Bee-Bot.	
		TCK coding and robotics in STEAM	Coding and robotics became the centre of the lesson while incorporating all of the STEAM elements as documented previously.	Use the Bee-Bot to retrace Grandpa Leo's steps to find his glasses.	Used Bee-Bot to code while incorporating all STEAM subjects.
		PCK Project-based learning	Used available materials to create final product.	They created the glasses and the layout on the Bee-Bot grid.	Created all the obstacles and code.
		TPACK Integrated Bee-Bots collaborati ve activities	The resources were shared quite happily as were the ideas that came up. No one dominated the activity.	They tried to debug their Bee-Bots to complete the sequence.	Worked well as a group and all ideas were heard and discussed.
		Context: Grade 2 class	Same for expert reviewer and researcher.		

Lesson 3	Group A	TK coding and robotics	Again, the group was confident about using the Bee-Bots. Participant 2 liked to be in charge.	Coded but not in one sequence but rather individual steps.	Coding more in sequences.
		CK STEAM	S: Documented findings on sheet; scientific method used. T: Programmed the Bee-Bots with great confidence although it became apparent that this activity was more of a challenge. Participant 3 an observer. E: Decided to add obstacles even though it wasn't altogether necessary. Had lost the blueberry card so they made blueberries using pipe cleaners. A: The paper planning sheet was completed. M: This challenge included a specific sequence. Mathematical language evident as coding progressed.	S: Scientific method that they are becoming more familiar with. T: Bee-Bots E: Built a bridge and used Lego to make obstacles. A: Drawing on the instruction card. M: Direction and problem solving.	Integrated all STEAM subjects.
		PK Foundation Phase	Although obstacles weren't necessary this group automatically added using the concrete objects. Also made the lost blueberries.	Lego and Bee-Bots	Group planned good obstacles.
		TPK 21st century /digital skills	Application of skills: All applied. Coding: Coding was done step-by-step as there was a specific pathway that needed to be followed; the order of fruits needed to be correct.	Application of skills: Used digital skills they had learnt from previous two lessons to help them code more effectively. Coding: Coded the Bee-Bot effectively. Started to use the	They used digital and 21st skills effectively.

			The group members coded separately. Participant 1 discovered the backward button and used it to good effect. Innovation: Creating the lost blueberries. The group didn't hesitate to replace the lost card. Collaboration: This group found collaboration a challenge. The teacher had to mediate and initiate a conversation about including all group members. The activity proceeded well. Thinking creatively: Answers to questions during introduction to lesson were well thought out. Much conversation when trying to draw the paper plan. Participant 3 wanted to know what the problem was. She had an immediate solution. Problem solving: This activity was more of a challenge but once the group worked as a team the challenges were solved. Participant 1 and 3 problem solving skills good. Logical thinking.	backward button to code. Innovation: Created an innovate route that the Bee-Bot had to follow. Collaboration: Worked better as a group after I had to intervene as they were not kind to one member of the group. They then all agreed that they needed to give each other a turn and help one another. Thinking creatively: Helped one another to make a raspberry when they could not find the Raspberry card. Problem solving: Did not make as many obstacles as they said they had learnt from the day before that this makes it harder to code the Bee-Bot.	
		TCK coding and robotics in STEAM	The Bee-Bots were at the centre of the lesson. Their coding skills developing. The backward button was	Coded the Bee-Bot to follow a new recipe for Dad to make.	Discovered the backward button.

			discovered. Resorted to coding step-by-step as the given sequence had to be followed.		
		PCK Project-based learning	The groups were given cards to represent the fruits – these were placed randomly under the mat. This group added obstacles too.	Designed the obstacle course and the sequence the Bee-Bot needed to follow.	Created and designed own mat.
		TPACK Integrated Bee-Bots collaborative activities	The group showed that they could work together but needed a conversation with the teacher to remind them of the skills needed. It was good to see the whole group adding to the success of this activity.	Participated much better as a team today. Group was very competitive and wanted to get it right on their own rather than helping a friend.	Best group had collaborated so far.
		Context: Grade 2 class	Same for expert reviewer and researcher.		
	Group B	TK coding and robotics	This group had become extremely confident about using the Bee-Bots. Enjoyment combined with developing new skills.	Coding in one sequence.	Both groups had gained confidence.
		CK STEAM	S: Documented findings on sheet; scientific method used. T: Programmed the Bee-Bots with great confidence. This activity was more of a challenge as there was a specific sequence involved. E: This group built and added obstacles towards the latter part of the activity. A: Planning sheet completed.	S: Scientific method that they were becoming more familiar with. T: Bee-Bots E: Did not build anything at the beginning and then they added obstacles that the Bee-Bot had to go around. A: Drawing on the instruction card. M: Direction and very good problem solving.	Integrated all STEAM subjects.

			M: This challenge included a specific sequence that needed to be followed according to the recipe. Mathematical language evident as the paper plan was drawn and as coding progressed.		
		PK Foundation Phase	Built obstacles for the Bee Bot to navigate.	Lego and Bee-Bots.	Both used Bee-Bots and made obstacle courses.
		TPK 21st century /digital skills	Application of skills: All applied. Coding: More care was taken when coding as now a specific pathway had to be followed; the order of fruits needed to be correct. The group members supported one another to get Bee Bot on the correct path. Innovation: Appeared to place fruit cards in a pattern under the mat. Collaboration: The group were happy to listen to and discuss everyone's ideas, whether it was part of writing/planning or a practical part of the activity. Thinking creatively: Thinking skills good as questions were asked during the introduction to the activity. Paper plan appeared more of a challenge, but team worked together to complete. Problem solving: This activity was	Application of skills: Used digital skills they had learnt from previous two lesson to help them code more effectively. Coding: Coded really well using their visual skills to code a complete sequence of code. Innovation: Sequenced a recipe in an innovative order on the grid. Looked as if they had planned the layout of the fruit. Collaboration: Very good collaboration and always helped one another. Think creatively: Creative in drawing instruction card. Problem solving: Helped one another and shared ideas.	They used digital and 21st skills effectively.

			more of a challenge but as problems were encountered solutions were discussed and found.		
		TCK coding and robotics in STEAM	The Bee-Bots were at the centre of the lesson. Learners' coding skills developed so well, from step-by-step, moving the Bee-Bot as each step was coded to coding a string of code from a paper plan.	Coded the Bee-Bot to follow a new recipe for Dad to make.	Using a string of code effectively.
		PCK Project-based learning	This group initially decided to use the fruit cards and code the Bee Bot to get from start to finish. They made obstacles and added them once they had mastered the activity.	Created an obstacle course that the Bee-Bot had to avoid to get to the correct recipe cards.	Made own obstacle course.
		TPACK Integrated Bee-Bots collaborative activities	The group dynamics were amazing. All members were listened to and offered something to the activity. They all showed leadership qualities at different times without being forceful or overbearing.	Very good collaboration. They were calm and work together.	Both groups had good collaboration.
		Context: Grade 2 class	Same for expert reviewer and researcher.		
Lesson 4	Group A	TK coding and robotics	The group was confident about using the Bee-Bots. It was decided before the activity was started that all group members would have a fair chance to code.	Made the Bee-Bot help Cousin Milo surf 10 perfect waves.	Both coded confidently.
		CK STEAM	S: Documented findings on sheet;	S: Scientific method. T: Bee-Bots	Integrated all STEAM subjects.

			scientific method used. T: Technology is at the centre of the lesson. E: Made the waves and obstacles which were eels. A: Patterns were drawn on the waves. Planning sheet completed. M: Numerical order was discussed as the Bee Bot visited each wave. The waves had to be measured so that they could fit under the mat. Mathematical vocabulary evident throughout the activity.	E: Created eels that the Bee-Bot had to get around. A: Drew the 10 waves and filled in the instruction card. Patterned waves. M: Direction and problem solving. Numerical order.	
		PK Foundation Phase	To create the waves and the eels.	They used Bee-Bots and wooden sticks.	Used concrete objects.
		TPK 21st century /digital skills	Application of skills: All skills applied. Coding: They had a set pathway to follow as they had numbered the waves so that they knew that each had been visited. As it was a long string of code, they discovered the limitations of the Bee Bot – it could retain only 40 steps of code. The code had to be adjusted as a shorter route had to be found. Innovation: The learners decided to number the waves to track the Bee-Bots' progress.	Application of skills: Used all the skills they had learnt to create their own lesson. Coding: When coding realised that they had used all the Bee-Bot's memory and hadn't reached the end card. They then needed to redesign the course to make the waves closer together so the Bee-Bot could complete the sequence and reach all 10 waves. They labelled the waves to make sure the Bee-Bot went to them all. Retained only 40 steps of code. Innovation: Creating their own waves out of paper and creating	They used digital and 21st skills effectively.

			Collaboration: The learners decided to number the waves to track the Bee-Bots' progress. Thinking creatively: Had to adjust the number of steps the Bee Bot used, i.e., find a shorter route. Obstacles became eels – appropriate for underwater activity. Problem solving: Numbered the waves. Adjusted the route. Waves were too long and needed to be measured and adjusted to fit the mat.	eels that the Bee-Bot couldn't surf over. Collaboration: They worked really well as a group and helped one another. Thinking creatively: Created a new layout when the sequenced code need to be made closer together. Number of steps. Problem solving: Solved the problem when the Bee-Bot didn't have enough steps to make it to the end.	
		TCK coding and robotics in STEAM	They used the Bee-Bots to tell their story.	They coded the Bee-Bot to surf 10 waves in a numerical ordered sequence.	The used the story to help them code.
		PCK Project-based learning	They used the concrete objects to create and complete the activity.	They created the waves and eels.	Used concrete objects.
		TPACK Integrated Bee-Bots collaborative activities	More collaboration was evident as the learners discussed what was needed to complete the activity.	They worked really well together, even when they needed to make changes so that the Bee-Bot didn't run out of steps.	Collaborated well.
		Context: Grade 2 class	Same for expert reviewer and researcher.		
	Group B	TK coding and robotics	The learners coded the Bee-Bots to tell their story of how the caterpillar could sing /dance/sit with one command.	They used the Bee-Bot to teach Fred the caterpillar to sing, dance and sit in a sequence.	Both coded confidently.
		CK STEAM	S: Documented findings on sheet; scientific method used. T: Technology is at the centre of the lesson.	S: Scientific method T: Bee-Bots E: Created Lego Hazel characters to teach Fred the Caterpillar. A: Turned the Bee-Bot into a caterpillar. Drew	Integrated all STEAM subjects.

			E: They created Hazel characters using Lego blocks. A: Participant 7 decided that the Bee Bot needed to look like a caterpillar – used green paper to create caterpillar Bee Bot. M: Mathematical language evident during the group discussions. Spatial awareness as the paper plan and the mat plan were compared.	on the instruction card to show the sequence. M: Direction and problem solving.	
		PK Foundation Phase	Hazel characters were created using Lego blocks. Straws were used as obstacles.	They used Lego and Bee-Bots.	Used concrete objects.
		TPK 21st century /digital skills	Application of skills: All skills applied Coding: Coded the caterpillar Bee Bot to visit the squares on the mat that had been labelled sing/dance/sit. Participant 6 discovered that instead of the Bee Bot turning around to proceed, it could go backward. Innovation: The green strips of paper for the caterpillar needed to be thinner so that they didn't stop the Bee Bot's wheels from turning. Collaboration: The learners worked well together – respecting one another's ideas. At different times during the activity, they all showed	Application of skills: Used all the skills they had learnt to create their own lesson. Coding: Coded the Bee-Bot to take Fred the caterpillar in the correct sequence. Innovation: Tried to use paper to make the Bee-Bot into a caterpillar. At first the paper covered the wheels so they needed to see how they could still have use of the wheels and turn the Bee-Bot into a caterpillar. This took a lot of trial and error and in the end they succeeded. Collaboration: They all did their jobs and then came together at the end. They helped one another to all get the correct sequence.	They used digital and 21st skills effectively.

			leadership qualities that were developing. Think creatively: Creating a caterpillar Bee Bot. Creating cards for sing /dance/sit. Problem solving: How to determine which square on the mat was sing /dance/sit.	Think creatively: They made cards to show the caterpillar singing, dancing and sitting and drew pictures to describe the word. Problem solving: Problem solved how to turn the Bee-Bot into a caterpillar and how to get it to complete the correct sequence.	
		TCK coding and robotics in STEAM	They used the Bee-Bots to tell their story.	They used the Bee-Bot to help Hazel teach her caterpillar to sing, dance and sit.	The used the story to help them code.
		PCK Project-based learning	After a discussion of how they were going to know which square on the mat was sing /dance/sit, it was decided that they needed to make cards to go underneath the mat.	They created the card for the grid and turned the Bee-Bot into a caterpillar.	Used concrete objects.
		TPACK Integrated Bee-Bots collaborati ve activities	The learners discussed each step, and they were all allowed to offer an idea of how to complete the activity effectively.	They worked well as a team to make sure they all completed the correct code and sequence.	Collaborated well.
		Context: Grade 2 class	Same for expert reviewer and researcher.		

Appendix J

Interview question answers

Expert reviewer

1. How did you experience the learners' use of Bee-Bots?	The learners listened well to the introduction of each lesson and used this information well. Their coding skills and use of the Bee-Bots became progressively better as the activities were completed. This was pleasing to see as they had not had the usual exposure to technology due to online schooling.
2. Did you see the integration of all STEAM subjects? Explain how you observed the subjects being used.	Science, technology, engineering and maths were the main components. The art component was evident but to a much lesser degree. The time available for each lesson could have been a contributing factor.
3. How did the learners work with concrete objects and what objects did they use?	The Bee-Bots were concrete – very easy to handle and manipulate; the buttons made coding manageable. There were several concrete objects for the learners to use to create the obstacle course – Lego blocks /pipe cleaners/straws/wooden sticks/paper strips and more.
4. Which 21st century skills did you see the learners use? Explain how they used or did not use each skill.	Application of skills The application of all previous knowledge and skills and the knowledge and skills acquired during the activities made the exercise a success.
	Coding This was at the heart of each lesson.
	Innovation As the activities progressed the learners were more comfortable about exploring how they could use the objects given to them to be innovative and create.
	Collaborate with peers This was a challenge, but some collaborative skills were learnt as time went on.
	Think creatively There was creative thinking throughout the activities on many different levels.
	Problem solving Problems occurred constantly. The learners didn't hesitate to look for a suitable solution.
5. Did Bee-Bots aid in the integration of all the STEAM subjects? Explain your answer.	Yes. The Bee-Bots were the main component of the lesson. The other STEAM subjects were necessary to add depth and enrich the lessons and make them more meaningful for the learners.

6. Did the learners design and create the final product?	Yes. They were given certain concrete objects but the design and creating of the product was totally theirs.
7. Do you think it is possible to integrate Bee-Bots into collaborative activities? Explain your answer.	Most definitely. The lessons that I saw were just one example of this.
8. How can Bee-Bot activities be designed towards STEAM integration?	In exactly the way that these lessons were designed. They were very successful.
9. How can collaborative skills be facilitated in Bee-Bot group activities?	By requiring the learners to share all of the resources and encouraging collaboration and sharing. For the educator to be there as a facilitator and observe the groups closely. To allow the learners the space and time to work collaboratively intervening only if vital.
10. How can utilising Bee-Bots facilitate TPACK designed STEAM activities in Grade 2?	Using TPACK guidelines gives a clear indication of whether the activities were well planned and thought out. It also shows whether the learners achieved specific outcomes and acquired new skills and knowledge.

Learners

Question	Participant						
	1	2	3	4	5	6	7
Are you in Grade 2?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Are you a girl?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you use a Bee-bot?	I used Bee-Bots	I used Bee-Bots	I used Bee-Bots	I used Bee-Bots	I used Bee-Bots	I used Bee-Bots	I used Bee-Bots
Did you predict what was going to happen?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you program the Bee-Bot to move?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you build a structure?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you create a character?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Draw an arrow to show the following directions.	Correct	Correct	Correct	Correct	Correct	Correct	Correct
Did you enjoy playing with the Bee-Bots?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you enjoy making structures?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you enjoy making the characters?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do you like to work with your friends?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you solve any problems?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Did you enjoy learning to code?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Would you tell a friend about what you created?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Participant	Question
What problem did you solve?	
1	I solved that when we were doing waves, I did too many steps.
2	The giraffe - we had to move it because it was in the wrong place.
3	When I changed the instruction card so I could get to the end.
4	I remembered to make a course.
5	Retracing steps. Coding the right things.
6	I solved Hazel helping Dad.
7	To code. To make Dad do the recipe.
What new skills did you learn?	
1	Play with the Bee-Bots
2	Coding in a year.
3	I learnt to code, and I learnt to work more as a team.
4	I learnt to fix problems.
5	I code well.
6	I learnt not all the time you can turn with the Bee-Bot.
7	I learnt to code the correct button.

What did you find interesting?	
1	I found interesting that you have to press Clear before you do more steps.
2	The Bee-Bots are cute.
3	That the Bee-Bots listened to instructions.
4	I found coding interesting.
5	Solving problems.
6	I found the story interesting.
7	That I had to think more than usually.
What would you like to do again?	
1	More lesson with Bee-Bots and Miss Ranger.
2	Playing with Miss Ranger and the Bee-Bots.
3	I would like to code more.
4	I would like to do nothing again.
5	Coding.
6	I would love to play with the Bee-Bots next year.
7	To set the places and code.
What did you enjoy the most?	
1	Building Lego and playing with Bee-Bots.
2	Playing with the Bee-Bots.
3	I enjoyed doing the Bee-Bot dance.
4	I enjoyed coding the Bee-Bots.
5	Coding with my friends.
6	Playing with friends.
7	I enjoyed coding.
What would you change next time?	
1	If we can colour more.
2	Own coding not in the book.
3	I would not fight with others.
4	Nothing.
5	Nothing.
6	I would like to change the Bee-Bot so it can go diagonal.
7	To do it faster.

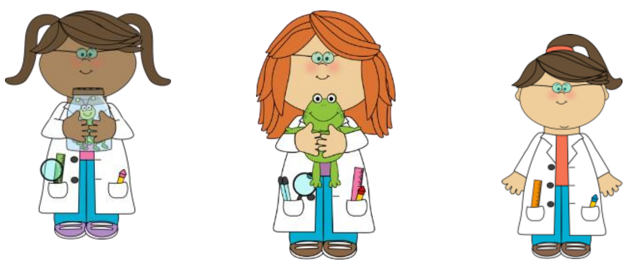
Appendix K

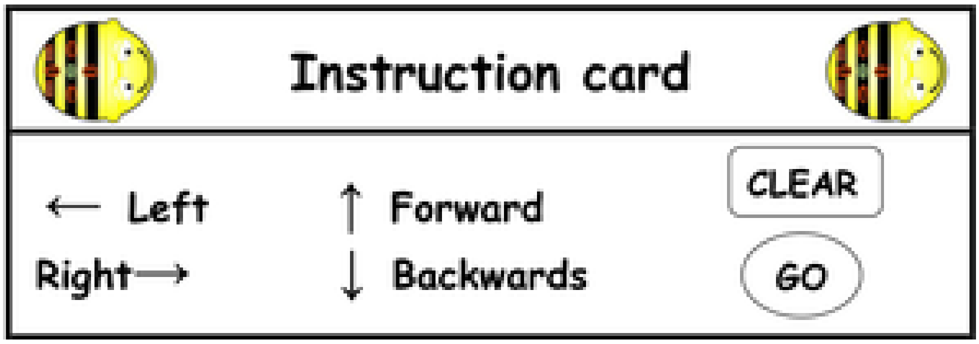
Scientific method sheets and Bee-Bot instruction card

Question
____
____
Create your hypothesis (Clever guessing)
____
____
____
____
Experiment
____
____
____
____
Analysis
____
____
____
____
Conclusion
____
____
____

The Scientific Method

1. Question
2. Hypothesis (Clever guessing)
3. Experiment
4. Analysis
5. Conclusion




Instruction card
← Left
Right →
↑ Forward
↓ Backwards
CLEAR
GO

Appendix L

Practical guidelines

Suggested guideline to use for creating your own STEAM integrated lesson.

Make sure you have the apparatus needed. You will need the following:

Knowledge of TPACK conceptual framework found in Figure 2.5

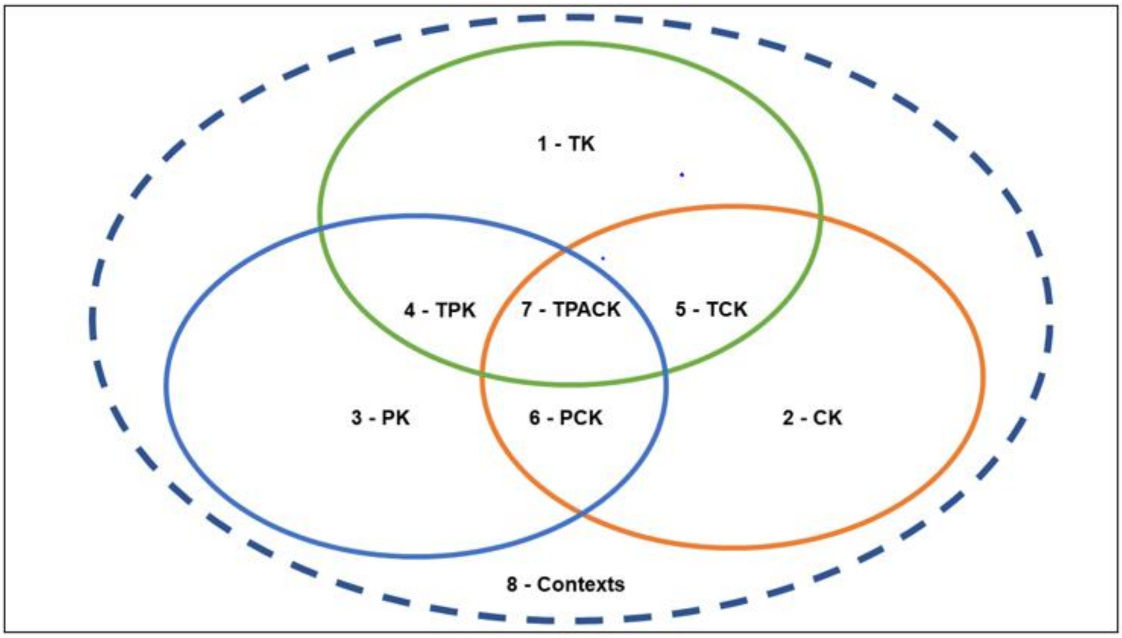


Figure 2.5 TPACK framework and its knowledge components

Adapted from Koehler, Mishra and Cain (2013)

Bee-Bots and chargers.

- Bee-Bot mat or a flat surface to work on.
- Story book *If I were a wizard* by Paul Hamilton or you can use a story below. Or the stories as templates in point 5.
- Box with concrete objects for the learners to use; these can include:
    - HB and coloured pencils
    - Blue, white board markers
    - Glue
    - Cardboard
    - Straws
    - Pipe cleaners
    - Ice cream sticks

  - Elastic bands
  - Lego blocks
- Instruction card and scientific method.
- Any printed resource cards the learners will need.

1. Use the TPACK guideline sheet to assist you in creating your lessons. This sheet explains what you can include in your lesson for each TPACK step. The lesson plans were created based on including 1 to 8 from the guideline sheet.

Lessons		
1	Technological Knowledge (TK) (Coding and robotics)	The Technological Knowledge focused on Bee-Bots. These were mechanical robots that moved on a grid. The participant needs to code the Bee-Bots to move from the start card to the finish card.
2	Content Knowledge (CK) (STEAM)	The Content Knowledge is the subjects of STEAM and need to be integrated.
		Science: Scientific skills were incorporated. The scientific skill of observation as the participants observed to see if the code worked. They communicated with one another to share their ideas and thoughts. They predicted which way was the quickest and then conducted their experiment. They used the scientific method as a guide to follow.
		Technology: Using the Bee-Bots to create an algorithm, a set of steps to get the character Hazel from the start to the finish. This falls under electronic systems and controls in the subject Technology.
		Engineering: They created and built suitable structures.
		Art: Creating the characters and completing the instruction card.
		Mathematics: Position and direction, which way she needed to travel. The Bee-Bots can move forward, backward, left and right. Problem solving: What was the quickest route to take?
3	Pedagogical Knowledge (PK) (Foundation Phase teaching)	The Pedagogical Knowledge in the Foundation Phase is that learners learn with concrete objects.
4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Technological Pedagogical Knowledge focused on the 21st century and digital skills and the following skills was observed:
		Application of skills
		Coding
		Innovation
		Collaborate with peers
		Thinking creatively
		Problem solving
5	Technological Content Knowledge (TCK) coding and robotics in STEAM	Technological Content Knowledge was technology in STEAM subjects.
6	Pedagogical Content Knowledge (PCK) (Project-based learning)	Pedagogical Content Knowledge was how to teach STEAM using project-based learning so that the participants were going to design and create a final product.

7	Technological Pedagogical Content Knowledge (TPACK) (Integrated Bee-Bots collaborative activities)	Technological Pedagogical Content Knowledge is computational thinking.
8	Context Grade: 2 class	The participants were all from a Grade 2 classroom.

2. The lessons followed the structure of having an introduction, body and conclusion.
    - The introduction is to read a short story that posed a problem that needs to be solved.
    - The body is to use the Bee-Bots to code a solution to a problem from the story.
    - The conclusion is to reflect on what learners have done in the lesson by completing the scientific method steps. They also need to pack away everything they used.
3. The lessons can then be observed using the observation sheet to see if the learners incorporated all the aspects when they completed the lessons.

Lessons			Tick if present in the lesson	Description or illustration
1	Technological Knowledge (TK) (Coding and robotics)	How the participants used the Bee-Bots		
2	Content Knowledge (CK) (STEAM)	How the participants incorporated the Content Knowledge of integrating all the subjects in STEAM. Give a description of how the subject was incorporated.		
		Science		
		Technology		
		Engineering		
		Art		
		Mathematics		
3	Pedagogical Knowledge (PK) (Foundation Phase teaching)	How the participants used concrete objects.		

4	Technological Pedagogical Knowledge (TPK) 21st century /digital skills	Which 21st century and digital skills did the participants use? How did they use the skill?		
		Application of skills		
		Coding		
		Innovation		
		Collaborate with peers		
		Thinking creatively		
		Problem solving		
5	Technological Content Knowledge (TCK) coding and robotics in STEAM	How the participants made use of technology in STEAM in their lesson.		
6	Pedagogical Content Knowledge (PCK) (Project-based learning)	How the participants designed and created the final products using project-based learning.		
7	Technological Pedagogical Content Knowledge (TPACK) (Integrated Bee-Bots collaborative activities)	How the participants used their computational thinking skills.		
8	Context: Grade 2 class			

4. Some ideas for stories

- Code start to finish.

Once upon a time there was an elephant called Ellie. She needed to get to the waterhole to drink some water. She wanted to make sure she took the correct route to get to the waterhole as she was very thirsty. She needed to get their quickly, so she decided to take a shortcut. She needed to remember to start at the big thorn tree and end at the waterhole. The obstacles she had to get around were the big rocks that had fallen into the road. Can you help Ellie get to the waterhole without getting stuck at the big rocks?

- Short sequence to follow.

Ellie the elephant lost her yellow bow. She tried to remember when she had it last. She needed to retrace her steps to find it. First, she walked past the thorn tree, then she walked past the big rocks, then she walked past the ant hill and then she arrived at the waterhole before coming home. She retraced her steps and found her bow at home as she had not put it on. Can you help Ellie retrace her steps to find her bow?

- Longer sequence to follow.

It was Ellie the elephant's first day of school. She needed to make sure she got dressed in the correct uniform as she was no longer able to wear what she wanted to like in preschool. First, she got out of bed. Then she had her breakfast. Then she brushed her teeth. Then she got dressed; she needed first to put on her dress, then her socks and lastly her shoes. Now she was ready for her first day of school. Can you help Ellie to get ready for school?

Turnitin Report

MEd Dissertation
Turnitin Summary
Prof P Callaghan
Supervisor
28/09/2021

MEd Dissertation
Turnitin Summary
Miss MJ Ranger
Researcher
28/09/2021

MEd Dissertation Body

by Megan Ranger

Submission date: 28-Sep-2021 12:23AM (UTC+0200)

Submission ID: 1659174385

File name: Ranger_Dissertation_body_for_Turnitin.docx (8.59M)

Word count: 30953

Character count: 160338

MEd Dissertation Body

ORIGINALITY REPORT

4%	3%	1%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

1%

★ repository.up.ac.za

Internet Source

Exclude quotes	On	Exclude matches	< 10 words
Exclude bibliography	On		