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The conceptualization of teacher professional knowledge for enabling digital pedagogical transformation of content using animations for the topic of electromagnetism

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Supervisor: Prof. Elizabeth Mavhunga

Thesis Presented for the Degree
DOCTOR OF PHILOSOPHY
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1 November 2023

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Abstract

Electromagnetism as a topic in the Grade 11 Physical Sciences syllabus in South Africa appears to be a difficult topic to teach and understand. The abstract nature of the concepts and the two dimensional representations in textbooks have contributed to the difficulty in teaching the topic. The COVID-19 pandemic brought home the need to adapt teaching and learning at a faster rate than before, demanding that teaching and learning move onto online platforms at an exponential rate. Traditional theoretical constructs for teacher knowledge like TSPCK have been useful in traditional classrooms settings, however, are becoming insufficient to support the teacher effectively in digital classroom settings. Thus, this study explored the conceptualization and implementation of a refined conceptual framework that acknowledges the development of teacher digital competences and the cognitive load demand on learners who learn through multimedia. Firstly, a new construct was argued for which had its foundation in TSPCK but harnessed the technological knowledge required to digitally transform content and learning principles of multimedia learning. An iterative literature meta-synthesis enabled the amalgamation of three complementary frameworks to promote content transformation on a digital platform. Secondly, the new construct informed an intervention with practising Physical Sciences teachers with knowledge of using technology in the classroom. Results indicated that the participating teachers only possessed TSPCK, a requirement for the development of digital-TSPCK, before the intervention. The analysis of their animation planning, creation and reflections of the process indicated emerging levels of digital-TSPCK in each of the participating teachers. The nature of the component interactions of the amalgamated frameworks indicated that, not only did the components within each framework act together in the planning and creation of the animations, but

also there was visible interaction between the components of the different frameworks, which held potential for further investigation across other science topics. In conclusion, this new construct could empower teachers to become the creators of their own pedagogically reasoned online content in the form of animations. Furthermore, this study opens the floor for future studies in other science topics, and with pre-service teachers to enable them to enter the teaching profession armed with the knowledge to teach as content creators in the 4th Industrial revolution.

Key words: Topic Specific Pedagogical Content Knowledge, Digital-Topic Specific Pedagogical Content Knowledge, Electromagnetism, Digital science content.

Declaration

I declare that this thesis is my own unaided work and has not been copied from another source. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg.

I further declare that the text is my own, except where duly referenced and no part of it has been copied from another source (unless indicated as a quote). All phrases, sentences and paragraphs taken directly from other works have been cited and the reference recorded in full in the reference list.

I make this declaration on my honour as a postgraduate student at WITS University and recognise that by maintaining the declaration, I maintain both my own integrity and that of the University of which I am a member.

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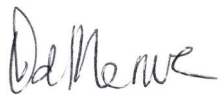
Denise van der Merwe



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List of Acronyms

B. Ed	Bachelor of Education
B. Sc	Bachelor of Sciences
B. Tech	Bachelor of Technology
CAPS	Curriculum and Assessment Policy Statement
CoRe	Content Representation
cPCK	Collective PCK
CS	Curricular Saliency
CTML	Cognitive Theory of Multimedia Learning
CTS	Conceptual Teaching Strategies
DBE	Department of Basic Education
ePCK	Enacted PCK
ICT	Information and Communication Technology
LPK	Learner Prior Knowledge
M. Sc	Masters in Science
PCK	Pedagogical Content Knowledge
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analysis
RBeLEs	Resource Based Learning Environments
RCM	Revised Consensus Model
RP	Representations
TPACK	Technological Pedagogical Content Knowledge
TPASK	Technological Pedagogical and Science Knowledge
TSPCK	Topic Specific Pedagogical Content Knowledge

SAMR	Substitution Augmentation Modification Redefinition model
STeLLA	Science Teachers Learning from Lesson Analysis
UNESCO	United Nations Educational, Scientific and Cultural Organization
WDT	What is Difficult to Teach and understand

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Addendum M Transcript of stimulated recall interviews

Chapter 1

1. Introduction

This chapter introduces and positions the study with the challenges of science teacher professional knowledge for remote teaching. It begins by describing the effects of digital globalization as experienced through the inception of the 4th industrial revolution and the consequential effect this may bring to teacher education programmes. An argument for a need to review and refine existing theoretical constructs commonly used in the development of teachers for traditional classroom teaching is forwarded. The rationale for a new theoretical construct entrenched in the theoretical framework of PCK, specifically Topic Specific TSPCK is posted. Included in this chapter are insights regarding the positionality of the researcher and the outline structure of the thesis as a whole.

1.1 Introduction

We are living in a constantly improving world, where technology pervades almost every aspect of our lives. Governments worldwide have begun policy reforms aimed at aligning educational practices within the context of globalisation, highlighting the important role that ICT would play in schools (Ball, 2021). In education, the use of technology has begun its entrance with most universities today offering some form of e-Learning with education free of the restrictions of space and time (Alrikabi et al., 2022). Although definitions of e-Learning in the literature are diverse, the general consensus implies that e-Learning in some way involves the use of information on computers and the internet to enhance teaching and learning activities (Akhter et al., 2021). Due to the broad spectrum of activities and tools involved in various definitions of technology and e-Learning, a more concise description of these terms are necessary to contextualise research endeavours. For the purposes of this study, the term technology refers to computers and relevant software (Akhter et al., 2021) and e-Learning stems from the use of these technologies in a teaching and learning environment. Technology used for e-learning will henceforth be described as a digital platform from which teaching and learning takes place in the online (digital) classroom.

Recently, at a school level, teachers have been challenged to implement knowledge needed for the delivery of e-Learning due to advances in technology and changing social demographics (Lukas & Yunus, 2021). Teacher education institutions as all other modern vocational training institutes have to prepare for graduate teachers who are competent participants in the 4th industrial revolution (Bühler et al., 2022; Mhlongo et al., 2023). The term 4th industrial revolution, coined by Klaus Schwab (2016) is a description of a world where people manage their lives by merging digital domains with their offline reality. The implications for education appear extensive and far reaching as teacher education institutions will need to prepare teachers to facilitate the teaching and learning process using interactive strategies to construct knowledge for their students most likely on digital platforms (Atibuni et al., 2022). Teacher education should consider the pedagogical value that the use of technology in teaching brings (Moll, 2021). However, the challenge lies in fully understanding how teacher professional knowledge when operating on a digital platform could differ from what we currently define it to be.

In science education, Pedagogical Content Knowledge (PCK) is widely accepted as the teacher professional knowledge for teaching science effectively (Shulman, 1986). At the heart of PCK, is the key benefit of knowledge that enables the teacher to pedagogically transform their own understanding of content into forms that are accessible and understandable by learners. PCK is more valued when considered in specific topics , as the kind of teacher knowledge that aims to transform the content knowledge of the specific topic (Abell, 2008; Botha et al., 2023). At a topic level, that kind of knowledge has been termed Topic Specific PCK (TSPCK) (Mavhunga & Rollnick, 2013) However, the introduction of technology in education, is visibly rendering the use of the traditional conceptual framework such as TSPCK insufficient. Technological advances usher-in an explicit demand for a new kind of teacher knowledge (Hutson & Ceballos, 2023) to create powerful learning environments for the next generation of students (Schoenfeld, 2020). The new kind of teacher knowledge would need to enable the pedagogical transformation of content to happen digitally. The purpose of this study therefore seeks to explore and define this kind of teacher knowledge, as well as determine its manifestation in the planning and building of digital lessons, using electromagnetism as an example topic. Furthermore, it is important to note the digital lesson considered in this study is an asynchronous digital lesson. As asynchronous digital lessons, in the context of this study, can be uploaded by teachers onto a learning management system or a digital cloud storage for student access at a time when convenient, that is, in a context

of South Africa, when steady supply of electricity is available. The question then arises about how to import the widely attested value derived from TSPCK into operation in the digital realm of teaching. Furthermore, what would TSPCK in the digital realm entail?

This study begins with a posit that TSPCK demonstrated within a digital platform is a slightly different teacher knowledge as TSPCK demonstrated in a traditional blackboard-and-chalk classroom. The idea of a refined teacher knowledge for the digital realm, when fully developed, could initiate the development of possible responses to the cited criticism about e-Learning in education as a superficial management system relying on ready-made e-resources often lacking supporting pedagogical foundation onto which teaching and learning is grounded (Muvango, 2021). These digital systems and resources are often developed by non-education specialists, driven from a commercial and/or managerial perspective (Aitchison et al., 2020; Sharov et al., 2021). As a result it creates tensions between the designers and the teachers who use the resources, driving them towards designing their own pedagogically reasoned online content (Akhter et al., 2021; Tomczyk & Walker, 2021). The challenge however remains that in a digitally evolving society, little is known of the kinds and description of teacher professional knowledge for pedagogical transformation of content digitally. This is different from the teacher's mere use of technology (whether emerging and even ubiquitous technology) in a traditional classroom as would be described by the conceptual framework of TPACK (Cox & Graham, 2009). Furthermore, little is known about the ways of helping teachers acquire the new kind of teacher professional knowledge for enabling digital pedagogical transformation of content. This study acknowledges all these challenges, but purposefully focusses on the initial task of conceptualising the new kind of teacher professional knowledge, as a theoretical construct for enabling digital pedagogical transformation of content, and to assist in-service teachers acquire it in a specific topic of electromagnetism.

1.2. Problem statement

The 21st century requires people to adapt to the changes in their work-places (Qizi, 2020), therefore Atibuni et al. (2022) noted that educational systems need to reform in response to the changes. e-Learning has emerged as a new paradigm in modern education systems (Maqsood et al., 2021), yet, teaching and learning, in the South African science classroom specifically is lagging behind due to lack of access to technology and the skills to use it (Olanrewaju et al., 2021; Skhephe et al.,

2020). Scholars point to the implementation of technology in South African schools as underdeveloped, with unclear objectives and strategies (Skhephe et al., 2020). This point is partly illustrated by the state of nation address in 2019, by the President of South Africa, President Cyril Ramaphosa, where he described an initiative for the next six years to provide every child in school with digital devices and resources (Ramaphosa, 2019). In line with this initiative, teachers would be trained to respond to the emerging technologies from using the internet to artificial intelligence (Ramaphosa, 2019). While this is a positive development, the implementation falls short of sound pedagogical considerations as there is currently no framework for developing teachers to teach within this framework. For example, the training of practicing teachers would be left trusted in the hands of commercial publishers and software developments rather than the teacher education institutions (Aitchison et al., 2020). Tomczyk and Walker (2021) warn that these types of projects could not be supported on a long-term basis as ICT should be integrated with support of pedagogy for effective teaching and learning.

Without a clearly defined framework incorporating teacher knowledge and technology, the available e-resources teachers can use in their classrooms will remain wanting (Akhter et al., 2021). This is a problem seeking solutions through a pedagogical lens. While, extensive work has been done in developing and understanding the nature of teacher knowledge such as a refined consensus model of PCK (Carlson & Daehler, 2019) and the topic specific teacher knowledge TSPCK (Mavhunga, 2012), a gap in the literature emerges. The need for a meaningful merger of the kind of technology knowledge that enables the development of pedagogically transformed lessons onto a digital platform with TSPCK arises and what it would take to develop it among science teachers.

1.3. Rationale

There is a global call for quality education in schools. PCK as the theoretical construct describing knowledge for teaching has proven to positively influence the quality of teaching and learning activities in the classroom. e-Learning has become the face of interactive, multimedia teaching and learning, requiring teachers to reason about their planned pedagogies in order to facilitate the cognitive connections to be made by their learners (Moore, 2018). Atibuni et al. (2022) emphasised the need for educational theory revisions to keep up with the infiltration of technology into science classrooms as they are still far behind in this aspect. A possible solution is to be found in calling teachers and teacher educators to design educational materials used in their classrooms.

It is therefore important to have research assisting the bridging of content influenced by pedagogical reasoning and digital platforms (Alrikabi et al., 2022) for educational practices to transition into the digital era, hence this study. Ways in which TSPCK and digitalization technologies could be integrated in meaningful ways that effect pedagogical transformation of content in the creation of a digital lesson are not known. The perceived outcome from such an integration would afford teachers greater control of the technology using a pedagogically sound, and reasoned framework. Such understanding will avoid teachers being relegated to mere end users of pre-packaged teaching software, with no say in the design.

1.4. Research Questions

The challenge of merging two distinct domains of professional teacher knowledge such as the knowledge that enables pedagogical transformation of content knowledge of specific science topic, defined as TSPCK, and the extensive growing field of digitalization technologies offers an opportunity to explore the new emerging version of teacher knowledge for teaching science. Thus, the main research question asked in this study is:

What would teacher professional knowledge for effectively teaching a science topic digitally entail?

In order to elicit responses assisting in answering the main question, the following sub-questions are asked:

1. How could teacher professional knowledge for the pedagogical transformation of content in the digital realm of teaching and learning be conceptualized?

2. How does the conceptualized teacher knowledge manifest in the planning and the teaching of electromagnetism digitally, when animation teaching videos are used as a format for a digital output?

1.5 Researcher and Positionality

When I completed my undergraduate B. Sc degree I worked as a secondary school teacher for ten years, where I was teaching Physical Sciences. In 2009, I was promoted to a departmental head in Physical Sciences, Life Sciences and Technology and was appointed as a Deputy Principal in

2016. At the end of 2021 I was appointed as a principal at a secondary school which allowed me to manage changes in the means of curriculum presentation, leaning more towards e-learning as a platform. During this time, I began my part-time post-graduate studies researching TSPCK for my Master's degree. I became more aware of the gap between traditional teaching and teaching on online platforms, and the need to close the gap as learners were already exposed to digital media outside the classroom. It became clear to me that learner interest was leaning toward the stimulation received online more than traditional teaching in the class. If teachers were more in line with the learners' level of digital exposure, I felt that their quality of education would improve.

As a researcher, I consider myself with pragmatist drawing on interpretivism (Teddlie & Tashakkori, 2012; Wahyuni, 2012). For this research paradigm the ontology suggests a subjective search for understanding social and experiential factors in research (Alharahsheh & Pius, 2020). From an epistemological view of the interpretivism paradigm, the human factor is a key role player in the research itself as their knowledge, opinions and experiences cannot be excluded from the knowledge gained during the research process (Alharahsheh & Pius, 2020). Considering the nature of this study under the interpretivism paradigm, a qualitative methodology was deemed most beneficial. Alharahsheh and Pius (2020) description of the characteristic interpretivism paradigm, specifically its context-bound, yet in-depth rich exploration of individual experiences based on varied data collection methods including interviews were found to be valuable justification for the chosen methods of qualitative data collection in this study. The next section of this chapter provides an outline of the structure and content of the subsequent chapters of this thesis.

1.6 The Structure of the Thesis

Nine chapters make up this dissertation. Below is a brief outline of these chapters. Chapter 2 is the summary of the literature review underpinning this study with a focus on PCK, specifically the grainsize of TSPCK, e-learning and the teaching and learning in electromagnetism. The chapter continues with a brief overview of teaching science with technology and focuses on teaching electromagnetism in the South African school setting, the focus topic of this discussion. The chapter ends with a postulation for a new theoretical construct and its positioning in the TSPCK framework.

Chapter 3 discusses the research method employed in this qualitative study. The research strategy being a case study is argued, outlining its interpretive nature of investigating. The research method

is divided into two specific segments. The first segment is the conceptualization of the theoretical construct that enables teachers to design their own pedagogically sound teaching animations, with the second part is the operationalization of the newly conceptualized theoretical construct with practicing Physical Sciences teachers. This segment explores the manifestation of the newly conceptualized construct in the design and creation of teaching animations on electromagnetism by the participants (in-service teachers). This chapter concludes with a brief discussion of how issues of ethics have been considered in the study.

Chapter 4 provides the technical details in starting the building of a conceptual argument for a new theoretical framework for teaching science in digital formats through digital platforms. A description of the steps followed in conducting a systematic, meta-synthesis literature review on the use of technology in Science is provided.

Chapter 5 presents the findings of the systematic literature meta-synthesis in chapter 4, delivering a conceptual argument presenting a new conceptual framework, describing teacher professional knowledge for teaching science digitally. Key to this new conceptual framework, is the effort to retain pedagogical transformation of content knowledge for learner understanding as a valued benefit retained from the experiences in the traditional realm of teaching.

Chapter 6 describes the development of a digital intervention program for practicing Physical science teachers to create animation videos incorporating the newly conceptualized teacher knowledge construct. The intervention provided the opportunity to explore the manifestation of the newly conceptualized framework in the planning and actual creation of digital lessons by the participants. This contributes towards establishing validity of the newly conceptualized theoretical framework as a construct. Chapter 7 outlines the analysis of the varied data sets collected at various points of the intervention with respect to the newly conceptualized teacher knowledge for enabled pedagogical transformation of content digitally, and the collaboration of the evidence for its presence. These data sets include pre-intervention teaching videos, animation planning CoRe Storyboards, completed animations and final stimulated recall interviews, which were triangulated for the confirmation of emerging patterns and validity.

Chapter 8 renders a summary and the discussion of the findings of this study inferred from the presentations in the previous chapters. Here the premise of a newly defined theoretical construct that enables practicing science teachers to pedagogically transform content of a science topic onto

a digital animation platform is corroborated by empirical findings providing supported responses to the research question asked in this study. The final chapter, 9, provides responses to the research questions and a reflection on contributions to new knowledge emanating from the synthesis of the findings. The efficiency of the research design employed in the study is reviewed. The study concludes with implications of the findings and recommendations for teacher development.

In summary, Chapter 1 provides the rationale of the study based on the identified challenge that comes with the migration of education globally to digital platforms. The Chapter presents research questions that will guide the study. The research questions allude to a need to create an opportunity to re-think our traditional teacher knowledge theoretical frameworks, and possible evaluate the effectiveness of newly constructed ones. The next Chapter, Chapter 2, outlines the literature review supporting the presented argument for teacher knowledge refinement and the demands of teaching on digital platforms in science education.

Chapter 2

2. Literature Review

This chapter looks at the move of education into the digital realm. It presents arguments for the need to be vigilant and support teachers with updated and refined teacher knowledge constructs sentient to the times. The chapter continues with a brief overview of teaching science with technology and focuses on teaching electromagnetism in the South African school setting, which is the focus topic of this discussion. Note is made of the difficulties experienced in the teaching and learning of the abstract topic of electromagnetism. The chapter ends with a postulation for a new theoretical construct and its positioning in the TSPCK framework.

2.1 Introduction

Science teaching on a digital platform certainly faces a dilemma as noted in Chapter 1. This lack of personalized, pedagogically reasoned online material encourages the science teaching community to look at pedagogically sound transformation of content that would enhance the nature of digitized material. The motive for evaluating and possibly transforming digital content is to provide learners with effective content who, for any reason, may not be in the classroom, but learning online. Firstly, many current online science teaching materials were created by companies whose content creators might not have the necessary teacher pedagogical content knowledge (Aitchison et al., 2020; Sharov et al., 2021). Online searches for digital science that are posted, are often at the rudimentary level of digitalization, with the material either being a PDF upload or it is a recording of a synchronous lesson delivered in front of a laptop. When teachers began large-scale online teaching due to the COVID-crisis, the time to develop material was limited. Secondly, if it were expected for teachers to be ideal content creators, they would need to possess a new kind of teacher knowledge (Akhter et al., 2021) where traditional TSPCK alone would not suffice. Hence it is time to take a step back and ask, "How do we bring what we know as TSPCK for science education into the digital realm?"

2.2 Teaching Science with technology

The frameworks of teaching science with technology was not developed as a result of the COVID-19 disruption, even though many teachers and students have remained on the digital platforms

post-COVID. Researchers from Shulman (1987) to Guzey and Roehrig (2009) among others, alluded to the incorporation of emerging technologies in the PCK framework. When we look at science education, a popular framework for the use of technology in the classroom has been documented below as TPACK (Koehler & Mishra, 2005). The TPACK framework focused on incorporating technology into traditional classrooms (Koehler & Mishra, 2009) with great emphasis placed on the digital devices and software to be used (Gür, 2015; Voogt, 2010). Niess et al. (2009) developed TPACK standards and indicators of working in technology-rich learning environments, enabling measurement of the framework. Bower and Vlachopoulos (2018) noted that TPACK elaborated on teacher knowledge for technology enhanced learning design, but did not provide insight into the nature or practical implementation of the knowledge was. What TPACK seems to have ultimately overlooked was the importance of investigating the interactions between technology and the content of the lesson (Santos & Castro, 2021).

Research abounds in education regarding the implementation of technology into the teaching and designing of content for online use.

The Critical Digital Literacy (Hinrichsen & Coombs, 2014) framework noted that curriculum developed for digital literacy was too technocratic, suggesting a merge between critical literacy pedagogy and media education frameworks. Hinrichsen and Coombs (2014) described four resources for critical literacy with a focus on student engagement processes instead of syllabus requirements, namely:

Code breaking where texts are practically analysed in terms of content, grammar and text structure.

Text-participating to make meaning of the text narrative.

Text-using to create new text by implementing typing, printing, image editing among other skills.

Text-analysing critically to determine the motive and usefulness of the text for the teaching activity.

From a digital perspective, this framework replaced the printed text with a screen, whereas curricular aspect aimed at the use of devices and associated software (Hinrichsen & Coombs, 2014). Syllabus content was noted in the framework but it was not elaborated on in terms of

pedagogical transformation. Critical Digital Literacy placed emphasis on the teacher acquiring either technical skills or theoretical skills of critique without practically meeting the needs of an individual student outside the classroom (Pangrazio, 2016).

The SAMR (substitution, augmentation, modification, redefinition) framework (Puentedura, 2012) used the TPACK framework as a theoretical framework for its development. The absence of context in the framework was noted and could be attributed to its theoretical foundations. In addition, SAMR was described as a tool to describe a teacher's use of technology in the classroom, with emphasis placed on the product instead of any creation or design processes (Hamilton et al., 2016). SAMR also did not acknowledge a teacher's level of ability to use technology, the use of technology to emphasise pedagogy (Hamilton et al., 2016) or the educational context in which it is to be used (Blundell et al., 2022).

Science Teachers Learning from Lesson Analysis-STeLLA (Roth et al., 2011) video-analysis-of-practice professional development framework aimed to increase a teacher's ability to develop student thinking, PCK and the context storyline of a science lesson (Taylor et al., 2016). Roth et al. (2011) indicated that teacher PCK increased proportionally to their teaching practices when analysing the teaching and learning videos. In a similar study to the STeLLA framework, Seidel et al. (2011) noted similar outcomes to teacher PCK improvement, however the self-defence mechanisms employed by the teachers viewing themselves inhibited their critical articulation and reflection of the teaching and learning scenarios. The lacking aspect relevant to this study is the development of teachers to actually create their own digital content for teaching purposes instead of review purposes.

ICT-based teaching (Dawson, 2008) described the teacher's ability to use ICT in the form of word processing, internet research, email and PowerPoint presentations. As students are more familiar with the use of technology than their teachers, (Molnár, 2016) suggested teachers gravitate toward LMS (Learning management systems) which support the teacher to create an online environment while the teacher facilitates the learning experience, supporting changes in student learning (Donnelly et al., 2011). With the factors enhancing the use of ICT in classrooms determined by access to computers, teacher confidence, skills and workload (Dawson, 2008) pedagogical transformation of content does not strongly feature.

Technological Pedagogical Science Knowledge-TPASK (Jimoyiannis, 2010), based on the TPACK framework presented a new model for the professional development of science teachers. This framework was said to represent what science teachers needed to know about ICT in science education, Jimoyiannis (2010) proposing authentic learning experiences which take the educational context into account. The technical skills required by teachers were defined by the use of the tools in teaching and learning to create lessons (Jimoyiannis, 2010), not to design or transform the content themselves.

Microcomputer-based learning (Lavonen et al., 2003) Microcomputer-based learning offers teachers another tool to add to their list of digital applications, using a virtual laboratory instead of an actual one, emphasis is placed on performing computer-based experiments (Zakaria, 2017) in the same way that TPASK is represented (Rodríguez-Becerra et al., 2020). The tools for this framework consisted of a package of ready-created hardware and software, requiring the teacher merely to learn how to use the technology in a practical lesson in a student-centred approach (Abdullah & Yaacob, 2019).

The RBeLEs (online resource-based learning environment) framework describes teacher use of online resources in the teaching process. RBeLEs consists of four components to enable the use of online ICT, namely: construction of e-learning environments enabling the use of the internet, creation of context, selection of resources and adoption of scaffolds (Fernandes et al., 2020).

Creation of contexts by teachers are real or virtual settings of the topics to be taught.

Selection of resources by the teacher for the core information to be presented.

Use of tools to search, collect, organise and communicate data.

Adoption of scaffolds involve teaching practices such as question and discussion sessions, searching and selecting, observing and conceptualising during the teaching and learning of a topic (So, 2012). The disadvantages of this framework is that collection of tasks and resources by the teacher still constitutes effective use of ICT and not at a level of pedagogical transformation of content by the teacher and does not cater for the individual learner out of the traditional classroom (So, 2012).

The UNESCO ICT competencies framework for teachers is progressive and open to the development of multiple levels of sophistication with which teachers can engage with technology. Within the UNESCO ICT competencies framework the progression of a teacher's technological competency skills within a discipline is ranked from basic digital literacy to knowledge deepening and finally the creation of discipline-based digital content knowledge (UNESCO, 2011). Furthermore, it enables teachers to rationalise their choice of use of specific digital platforms and software which evokes the value of PCK of aiming for 'appropriateness' in technology usage (Shulman, 1986). The UNESCO ICT framework speaks to multimedia and what is considered to be a good educational video or multimedia lesson that would enhance the engagement of the student in accepting and retaining a greater percentage of the topic taught in the created product.

In this study, interest did not lie with the mere enhancement of traditional lessons using technology, rather with actual transformation of the content onto a digital platform, building a lesson that is digital in format. The nature of this study was for teachers to use technology as a resource to design and pedagogically transform science content that can be used by individual students outside the traditional classroom setting. The choice of framework was dependant on its ability to enable teachers to become autonomous in their creation of lessons, in this case teaching animations.

Two factors were therefore to be addressed at this point:

1. In order to work with ICT, the teacher would need to have developed some digital skills, like how to develop an animation and how to edit a video.
2. There needed to be a frame of reference indicating how to do that well, and when the teacher knew how to create their own content, what would considered to be good content for the purposes of teaching?

Competence to work on a digital platform

Classrooms whether real or virtual, would soon require all teachers to be empowered to apply technology to effectively teach the subject content. Engaging with digital platforms require teachers to acquire a set of practical skills to navigate through the use, design and application of technology ranging from installing hardware and software in the class to designing and presenting topic specific lessons. UNESCO (2011) has formulated an ICT framework arranged as a set of education improvement approaches for teachers to become competent technology users in their classrooms, which are presented as a hierarchy of skills to be developed:

- *Acquiring technological skills*. Teachers would know how, where and when to use different technologies in their teaching, administration and management tasks. These competencies include basic digital literacy skills, the ability to select and use educational software and equipment. In a pedagogical context, basic technology literacy would allow the teacher to use technology to perform basic teaching functions usually reserved for the blackboard. An example of this would be when a sentence is displayed on the screen and the teacher adjusts the sentence in real time as the lesson progresses.

- *Increase the ability to use these technological skills through teacher professional development to provide teachers with the skills to use more sophisticated technologies*. These competencies reflect pedagogical reasoning by the choice the teacher makes to manage information, integrate open-ended software applications and applying them to life-situations and facilitate collaboration projects during the lesson using technology.

- *Enabling the creation of knowledge using technology*. Teachers collaborating to produce new knowledge using a variety of digital resources and platforms. They would be able to design digital learning resources and use ICT to support knowledge creation and critical thinking in their students. In terms of PCK, the reasoning behind the resource design process would take into account the level of difficulty of the topic, and how to present it in a more agreeable format; the specific aspects of topic content to be emphasised in the resource; the types of representations of content to be included in the lesson and in which sequence.

  The UNESCO guidelines do not contribute to the formulation of the components of the new kind of teacher professional knowledge for the transformation of content, rather they set out the levels of sophistication of the use of technology. This is useful in developing a teacher knowledge framework for teaching practices speaking to both the transformation aspects and the sophistication of the use of technology, supplying the terminology to grade the quality of teaching practices. Using the above guidelines as a developmental trajectory would enable teachers to develop increasingly sophisticated skills needed to effectively plan, design and teach with technology for the greatest level of understanding by their students.

  The end-product (science lesson) would be a pedagogically transformed topic for the use of a student who would not be in a traditional classroom. The student would engage with the transformed digital content without the presence of a teacher or peers to collaborate with. What

would need to be considered as we move towards digitalization of lessons is the established best practices of how learning happens through multimedia.

2.3 Teaching electromagnetism using technology

2.3.1 Teaching difficulties in teaching electromagnetism

Electromagnetism is an important concept in science, providing the foundations of most current technologies, therefore it is seen as a central topic in the science curriculum (Michelini et al., 2007). Literature shows that students perceive electromagnetism as a difficult topic partly due to the level of mathematical skill required and interpretations of three-dimensional representations (Roussel & Hélier, 2012). The concepts of electromagnetism are highly abstract as most of the phenomena cannot be directly observed, while terminology used in everyday life, for example voltage and flux cause conflict when used to describe scientific terms (Michelini et al., 2007).

In order to counter the decline in interest in electromagnetics, initiatives implementing virtual experiments and pedagogy have shown to be effective in teaching the topic (Roussel & Hélier, 2012). The TEAL (Technology Enabled Active Learning) approach has shown to enhance student knowledge retention of the topic by merging pedagogy, visual effects and simulation technology into a well-structured course (Dori et al., 2007). There is therefore ground to build on these promising findings and explore the feasibility of technology not only as a representation, but a representation whose make-up is informed by the pedagogical transformation of content knowledge.

2.3.2. Electromagnetism in the South African School Syllabus

In South Africa electromagnetism is introduced in Grade 11, and continued for examination in Grade 12 the last and exit of the school system. One of the concepts taught is Faraday's law. Textbooks and simulations begin with the representation of the magnetic field around a current-carrying conductor, progressing to the magnetic field around a coil (Horner, 2012). The topic continues to lace the coil in a static magnetic field, and suddenly the student is introduced to the equation for induced EMF resulting from the spinning coil interacting with the static magnetic field. Raduta (2005) noted that students interpret electric and magnetic fields to have static natures and are unsure how EMF is induced, leading to difficulties in using the equation. In my own years

of teaching this topic to Grade 11 students, I found, similar to the studies by Smaill et al. (2011) that students find the 3D rotation of the coil linking to the variations in the magnetic flux linkage a difficult concept to grasp. The abstract nature of the topic (Raduta, 2005) and the sequence in which the topic is unpacked in the syllabus make for a conceptually challenging lesson. The incorporation of a new technological platform with which to pedagogically transform this content could assist in the understanding of these concepts.

There are many challenges that lie ahead as we seek to unpack what a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content would fully entail, however, this study can be seen as paving a needed pathway for provision of science education into the 4th industrial revolution.

2.4. A future change in teaching teachers how to teach

If the changes envisioned in this study are to be realised in the classroom, teachers would be expected to teach electromagnetism in a way they might not have considered before. They would be mastering the teaching of the subject while developing a professional digital competence through their teacher education to meet the pedagogical requirements of teaching their subject (Røkenes & Krumsvik, 2016). I predict that TSPCK, although valuable and cherished among the science education community, and similar isolated models of content transformation may no longer be sufficient creating the need for teachers to adopt new skills. The findings of this study and the arguments brought by the study have implications for the way future teachers will be taught in pre-service and in-service programs. If proven valid, this new kind of teacher professional knowledge for enabling digital pedagogical transformation of content could be the possible vehicle to explore the kind of competencies that would be needed and develop the teacher knowledge.

2.5 Theoretical Framework

The purpose of this study is to develop a refined conceptual framework for describing a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content. This study builds the framework on the foundation of TSPCK for its successful historical focus on pedagogical transformation of content knowledge and the TSPCK framework is known for that. But as seen with studies with TPACK, which laid emphasis on the use of technology in traditional classrooms (Gür, 2015) incorporating it with the TSPCK framework would not be effective for a

complete move to a digital lesson format. When focusing on the digital realm, a refined framework is needed that will help to format the entire lesson digitally while enabling the pedagogical transformation of content to happen. So, this study begins with the acknowledgement of the TSPCK framework as the foundation from which digitization would stem.

Therefore, this study is located in the broader theoretical framework of PCK, specifically at the grainsize of topic-specific PCK (TSPCK) merged with technology for teaching purposes. At this point, a specific framework that defines such a version of PCK is yet to be conceptualized and validated in the PCK literature, hence the purpose of this study. However, provided herein is the discussion on the foundational theoretical framework of TSPCK from which the newly refined conceptual framework construct is postulated to be founded. The development of a theoretical construct in no way excludes practical applications, as Gay and Weaver (2011) noted that good theories underpin the best practices. PCK literature refers to both the planning (theoretical) and the practical enacted as one and the same thing but manifesting in different realms of teaching. The same way we look for PCK in planning is the same way we look for PCK in teaching- the definition does not change.

As alluded earlier PCK is the teacher knowledge first described by Shulman (1986) and accepted widely in science education (Gess-Newsome, 2015; Mavhunga, 2013). Researchers in science teacher education have recently found a way to communicate the multidimensional nature of PCK without ambiguity. The Refined Consensus Model of PCK (RCM) reflects this complexity of PCK (Carlson & Daehler, 2019).

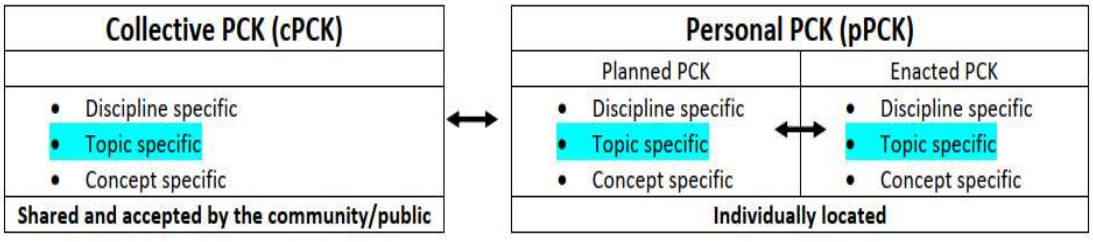


Figure 2.1 A simplified illustration of the multidimensional nature of PCK in the RCM of PCK (Mavhunga, 2019)

The representation in Figure 2.1 represents the simplified illustration that demonstrates the multidimensional nature of PCK in the Refined Consensus Model. The first dimension of PCK is

shown through the interrelated realms of PCK where the first realm is Collective PCK (cPCK). cPCK refers to formal, published knowledge of PCK often presented in a formal course, or gained from a long period of a reflective experience in teaching (Carlson & Daehler, 2019; Mavhunga, 2019). The second realm of PCK is Personal PCK (pPCK), consisting of Planned and Enacted PCK. pPCK refers to the PCK that teacher would have as an individual derived from cPCK. The realms show the path of the development of professional teacher knowledge(Carlson & Daehler, 2019).

The second dimension of PCK reflected in the RCM are the three grainsizes of PCK portrayed in each PCK realm (Carlson & Daehler, 2019). In the past, Veal and MaKinster (1999) described the grainsizes of PCK in terms of hierarchy with discipline-specific, domain- and topic specific PCK. In the RCM the grainsizes of PCK are defined as discipline –specific; topic specific- and concept specific-PCK. As this study draws upon the topic specificity of PCK in electromagnetism, it befits topic specific PCK as the grainsize appropriate for the study. Figure 2.1 positions it as a grainsize within each of the PCK realms enabling research studies to explore it across the realms. The proposed study is on an area that has not been studied, a version of topic specific PCK, that is infused with technology as a genuine component for consideration when content knowledge is to be pedagogically transformed when teaching on a digital platform. The study attempts to define and validate an aspect of topic specific PCK in relation to a digital platform and, possibly in turn avail knowledge gained for development of an understanding that could be part of cPCK with reference to technology. In order to build and formulate an informed postulation defining the new version, a discussion on the traditional topic specific PCK is provided below:

Topic Specific Pedagogical Content Knowledge,

The topic specific grain size of PCK has been explored by various scholars (Aydin et al., 2015), who pointed at PCK at the topic level visibly reflected by selective components in the Magnusson model (Magnusson et al., 1999) and not by all components. Studies have shown that PCK is developed by teachers, one topic at a time (Van Driel et al., 1998). The works of Mavhunga conceptualised and argued for TSPCK to be a theoretical construct with a pictorial model (Mavhunga & Rollnick, 2013; Mavhunga, 2012).

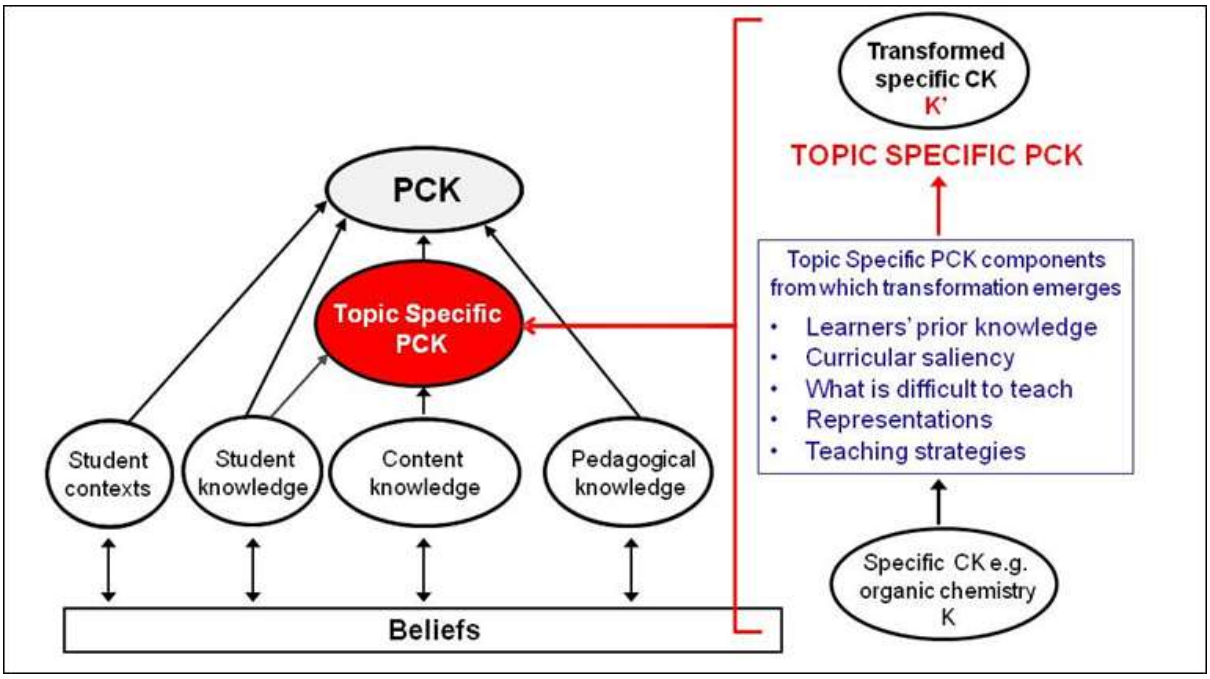


Figure 2.2. The model of TSPCK (Mavhunga, 2012)

The specific components of TSPCK interact within lesson planning and presentation to transform specific subject matter knowledge drawing on the knowledge bases of teachers. The transformed content brings about a greater understanding of the topic by the student. These components are defined as follows:

i. Learner Prior knowledge.

Learners' knowledge about a particular topic before the lesson begins. This knowledge includes identification of misconceptions or alternative conceptions a learner may have, confronting the misconception with an effective teaching strategy or representation to confirm accurate understanding of the concept.

ii. Curricular saliency.

This is the understanding of which topics are central or peripheral relative to the curriculum by identifying the big ideas of the concept to be taught. It includes providing a logical sequence for these ideas identification of pre-concepts and using them in reference to explaining the big ideas in a topic.

iii. What is difficult to teach or understand.

This refers to the knowledge of the the teacher to link to specific gate-keeping concepts that, when not fully understood, adds to the difficultyof understanding the concept. These are concepts that are not necessarily a misconception but just diffiucult to understand because of either being understood differently in another topic.

iv. Representations.

These are examples, analogies, simulations, demonstrations or models used to represent subject matter. Each type of representation illuminates a different aspect of a phenomenon which brings about a holistic understanding.

v. Conceptual teaching strategies

These are effective instructional strategies used to meet the objectives of the lesson, address difficult or important concepts, considers aspects related to curricular saliency and effective use of relevant representations to emphasise important conceptual aspects of the topic into a logical and informed teaching plan.

A number of studies have explored the nature of TSPCK and has been found to be teachable to pre-service teachers (Mavhunga & Rollnick, 2013). TSPCK as a construct affords pre-service and practicing teachers the benefits of honing their teaching repertoire and reflecting on the effects of the implementation of specific component interactions in order to improve their lessons in the future. Despite this benefit, the developments in the TSPCK literature lack a clear approach for regard of the advances afforded by the instructional design technology and software. It is for this reason that the possible merger of TSPCK and a technology based theoretical construct is considered as informing the postulation of the envisioned new kind of teacher professional knowledge for enabling digital pedagogical transformation of content.

2.6 Postulated theoretical framework for a new kind of teacher professional knowledge enabling digital pedagogical transformation of content.

As alluded above, this study begins by postulating that a new kind of teacher professional knowledge enabling digital pedagogical transformation of content is the teacher knowledge needed to pedagogically transform content knowledge of a topic on a digital platform. The essence of this study is to define a conceptual framework that would define this new construct in a valid way. The preliminary thinking about where the framework would emerge lies in the idea that pedagogical transformation, learning through multimedia platforms and technological integration are key on a digital platform. Therefore, the new construct, a new kind of teacher professional knowledge enabling digital pedagogical transformation of content is to be explored. While the starting point is the TSPCK conceptual framework as a foundation, TSPCK is far from being sufficient as a construct describing the new kind of teacher knowledge, hence the purpose of this study. Guided by the arguments of (Kane, 2012), a conceptual argument needs to be developed, and it will need to be tested empirically for its manifestation as per the definition for regard as a theoretical construct. This is the main purpose of the study, to build a valid conceptual argument that would be a conceptual framework describing the kind of teacher knowledge needed for pedagogical transformation of content on digital media.

2.7 Chapter summary

This chapter presented the challenges of the current shift of education into the digital realm. It presented an argument for the need of a refined conceptual framework supporting this shift. A brief overview was given of the challenges of teaching the topic of electromagnetism in the South African school context and the teaching of science using technology. The chapter ends with a postulation for a new theoretical construct and its positioning in the TSPCK framework. In the following chapter, the research methodology employed to gather emprirical evidence pointing to the manifestation or the existence of the new construct will be discussed.

Chapter 3

Chapter3. Research methodology

Chapter 3 discusses the research method employed in this qualitative study. The research strategy employed is a case study due to the interpretive nature of the investigation. The research design was divided into two specific phases. The first phase was the conceptualization of the conceptual framework that enables teachers to design their own pedagogically sound digital teaching animations. The second phase entailed the operationalization of the newly conceptualized framework in developing the capacity of teachers in the new teacher knowledge. The operationalization stage provided opportunities for visualizing the manifestation of the developing teacher knowledge, and its evaluation against its presented definition. The topic of electromagnetism was used in the intervention. This chapter concludes with a review of the potential encapsulated in the newly defined conceptual framework.

3.1 Introduction

In order to provide possible a response to the main question seeking for the description of a new theoretical construct describing refined teacher knowledge for teaching science digitally, the requirement for the development of a theoretical construct by Kane (2012) is brought to the view. Kane's construct valdity process requires first a coherent conceptual argument presenting the rationality of the new potential construct. The process further requires emprirical evidence pointing to the manifestation or the existence of the new construct as per the presented conceptual argument or definition. The research design therefore was comprised of two major parts, each responding to the two elements of the construct validity process respectively.

3.2 Research Method

The study employed a qualitative research design. Krefting (1991) broadly defined qualitative research as observations made of people within a specified context and setting with one of the approaches including phenomenology and personal characteristics of the participants playing a role in the type of data to work with. One of the strengths of a qualitative study lies in the

naturalistic, unique setting of the study lowering the number of variables to be controlled (Krefting, 1991) but limits the generalisability of the study. This kind of research design links with an interpretivism or constructivism paradigm, which promotes the belief that there are multiple realities intertwined (Yvonne Feilzer, 2010). This paradigm affords the advantage of engaging with interpretivism and inquiry so that reality is not merely accurately represented, but is useful in its representation (Creswell, 2014). The review of qualitative research by Doyle et al. (2009) highlight that this research approach allowed several benefits to researchers. Firstly, triangulation of data is possible increasing trustworthiness, and secondly, offsetting the weaknesses of one dataset providing stronger inferences and thirdly, enabling different research questions in a single study to be answered (Doyle et al., 2009). At a general level, as with mixed methods, qualitative studies follow different approaches based on the data to be collected and analysed. A convergent parallel design Creswell (2014) allows for the qualitative aspects of the study to be performed independently and roughly at the same time, and be triangulated to develop the overall interpretation of the data to answer the research questions. In the sequential multiphase approach, a study is conducted in two phases, using the results of the first phase to inform the second phase (Creswell, 2014) in terms of sampling procedure and types of questions to be asked of the sample. In order to develop an argument for the introduction of a new framework, this study requires collection and interpretation of information and data as part of a sequential multiphase design (Creswell & Garrett, 2008) where qualitative data is collected and informs the subsequent research stage. In acknowledgement of the tacit and complex nature of the new kind of teacher professional knowledge for enabling digital pedagogical transformation of content, similar to that of PCK (Gess-Newsome, 2015) it becomes fitting to address this construct from a holistic approach. Care will be taken when articulating how the various elements of collected data relate to one another as convergence points (Creswell, 2014).

3.3. Research Strategy

This research was a case study to investigate the teacher professional knowledge of practicing (in-service) physical sciences teachers for teaching the topic of grade 11 electromagnetism through the creation of digital animations. These animations would be part of a digital lesson accessed on digital teaching and learning platforms asynchronously.

A case study is an in-depth review of phenomena whilst retaining the characteristics of real-life events (Heale & Twycross, 2018; Phelan, 2011) popular in the interpretivism paradigm (Bertram & Christiansen, 2014). Heale and Twycross (2018) note that a case study involves the collection of several different types of data while investigating the small sample of participants as they develop their context-based knowledge and skills in the process (Flyvbjerg, 2011) although it is not common practise to make generalisations of the findings. This case study is characterised by the use of a particular group of people who share common and defined functions during the same time period from which the data and findings are generated (Opie, 2004), in this case, four practising Physical Sciences educators in Gauteng in the teaching of Grade 11 Electromagnetism. They will indergo an intervention practising creating teaching animations for Electromagnetism while they simultaneously learn about the components of the new construct. The case study approach would be useful in this study for the conceptualisation of the construct, allowing the defining of specific boundaries to the people to be observed. Crystallisation of what the new kind of teacher professional knowledge for enabling digital pedagogical transformation of content would look like in addition to the conceptual argument would need the observation of that construct with a specific well-defined group of teachers who are a case. Trustworthiness concerns regarding the inability of the case study data to be generalised or transferability to other cases (Bertram & Christiansen, 2014) would be mitigated through the variety of data collection and convergence analysis. The discussion on participants, data collection and analysis differs based on the phase of the study. The discussion below outlines the participants and data collection that was done at each of the two phases of the study.

3.4 Data Collection

The discussion below explains the data collection within each phase.

Phase 1: Conceptualization of professional teacher knowledge for teaching science digitally

In an effort to formulate a conceptual argument defining the new teacher professional knowledge for enabling digital pedagogical transformation of content, a systematic literature metasynthesis was performed from which a conceptual argument emerged.

A Literature Review through meta-synthesis

The literature review for the conceptualization of the new teacher professional knowledge for enabling digital pedagogical transformation of content was conducted following a qualitative

meta-synthesis procedure (Thunder, 2016). At the forefront of the literature review is the understanding that the key benefit of any version of PCK, even as topic specific PCK as is in this study, is its ability to enable pedagogical transformation of content for learner understanding. In this study, cases that signalled such benefit on a digital platform were of great interest for exploration. This understanding and the specification for inclusion of digital technology as an intergral component of the mix of knowledge that yielded pedagogical transformation were of high interest. This understanding and specification influenced the determination of the boundary of studies of interest. The analysis and interpretation findings from deliberately selected studies with the intention of synthesising and interpreting the findings were used to inform a sound conceptual argument defining the new kind of teacher professional knowledge for enabling digital pedagogical transformation of content (Thunder, 2016).

The review of literature from a qualitative meta-synthesis procedure differs from the general literature review in that it has a specific purpose of collating and reviewing within defined boundaries (Thunder, 2016). Thus, the clarification of the non-negotiable specifications or understanding that undergrid the formulation of the new teacher professional knowledge for enabling digital pedagogical transformation of content , drawing from traditional TSPCK and ICT use in teaching as mentioned above is crucial. The procedure followed the steps outlined by Thunder (2016) in the synthesis of the identified literature as follows:

Step 1: Identifying the research question

This step required the formulation of a research question to be answered by the literature meta-synthesis. For this study, the question was based on the Research Question presented in this study as sub-research question 1, described in the meta-synthesis process in Chapter 4.

Step 2: Conduct a comprehensive search

This step required a slightly broad search of existing relevant literature to serve as a base of the systematic search, retrieval and validation process.

Articles were reviewed based on compliance with the following criteria:

- TSPCK and digital competency related.
- The article should attempt to define the construct explicitly.
- Description of the components of the construct.
- Examples and elaborations of the construct components.

- Planned and/or enacted teacher knowledge can be included.
- Application of the construct to the use of technology in planning and teaching.

Step 3: Select initial relevant studies

This step required the formulation of criteria reflecting the purpose indicated in the research question in Step 1 above, to frame the selective identificatin of relevant articles from the baseline in step 2. The criteria included reference to the TSPCK and digital competency.

Step 4: Appraise the quality of initially selected studies

This step required that each study was read and evaluated to ensure that the inclusion criteria were sufficient while becoming familiar with the content of each study.

Step 5: Synthesise findings of selected studies using qualitative techniques.

Extraction of the findings of each study were placed into a single document of coding that was informed by the purpose of the study, theoretical framework and type of synthesis of literature performed.

Step 6: Present synthesis findings across the studies to address the research question.

Visual displays of the categorisation and classification of the literature was made using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement (Sarkis-Onofre et al., 2021). The PRISMA statement generated a replicable audit trail of the selected studies, their salient features, outcomes and use for the study(Shamseer et al., 2015). This summary served as a collective body of work from which evidence-based findings could be reported transparently and limited bias (Shamseer et al., 2015). .

The expected output from this process constituted the body of literature from which the preliminary theoretical description of what the new kind of teacher professional knowledge for enabling digital pedagogical transformation of content was drawn. This would allow the composition of likely description of preliminary knowledge components and their argued features or nature. Armed with this preliminary argument, the next process, continued to develop the new kind of teacher professional knowledge for enabling digital pedagogical transformation of content components evident in planning and enactment.

Phase 2: Empirical evidence pointing to the new teacher knowledge.

In alignment with Kane (2012) concession in the development of a theoretical construct, both the conceptual argument and, in this case, empirical evidence of the emerging new knowledge must

be presented. Therefore, in this study the design of an intervention followed the literature meta-synthesis. This phase involved the development of an intervention targeting the development of the newly defined teacher knowledge emerging from phase 1.

The intervention was a case study of four practising physical science teachers to teach them how to plan and create their own pedagogically reasoned teaching animation on the topic of electromagnetism The intervention was designed to teach the participating teachers to digitally create their own teaching animations on the topic from the Grade 11 syllabus of Electromagnetism. The animations were the product of undergoing an intervention structure in accordance to the emerged conceptual argument for a refined version of teacher knowledge. The intervention was structured such that technological skills and pedagogical considerations were taught simultaneously, throughout. The reasoning behind the structure of the intervention was to avoid a linear approach where either the skills preceeded pedagogical reasoning or vice versa, and participants are expected to pull all these together at the end with likelihood of seeing these knowledge bases always separate. The outline of the intervention is described below:

Stage 1: Pre-intervention. teachers submitted videos of themselves teaching their normal classes with technology. The duration of this stage was two weeks for teachers to submit their chosen video-lesson.

Stage 2: Planning: Teachers were introduced to the new teacher knowledge construct in the planning of their animation using a CoRe storyboard which will be fully discussed in Chapter 6. This stage was performed online using MS Teams, tutorial videos and Whatsapp discussions. This stage used 4 hours over a two week period.

Stage 3: Animation creation: Teachers implemented the planned lesson using the Animaker software. This stage took place online for the first 2 hours and the remaining 6 hours was face-to-face in a period of four weeks where the team also discussed difficulties on the group WhatsApp space.

Stage 4: Video editing: The animations created were edited and final technical adaptations were made. This also took place as face-to –face sessions for 4 hours over two weeks. Finalised animations were then submitted for analysis.

Since the intervention is a key emprical activity from which the results are generated and interpreted, a full chapter (Chapter 6) has been dedicated to outlining the above steps in detailed.

3.5 Participants

Four practising Physical Sciences teachers drawn from public Secondary Schools (ex-model C) in the Gauteng province were the participants in this case study. Practising teachers were considered for this study to develop a new kind of teacher knowledge for pedagogically transforming content on a digital platforms as it was assumed that they would have had time to develop TSPCK, a pre-requisite knowledge for the intervention. With the assistance of a district subject facilitator, an invitation was made to teachers on the Ekurhuleni South Science whatsapp group to join the study. Initially ten teachers agreed to be part of the study, but withdrew due to work commitments. The intervention was designed to teach the participating teachers to digitally create their own digital content, in this case as teaching animations on the topic from the Grade 11 syllabus of Electromagnetism.

Table 3.1. Profile of participating teachers

Educator	Gender	Age	Qualification	Years of experience in teaching Physical Science
T	Male	28	B. Ed	5
N	Male	27	B. Ed	4
G	Female	32	M. Sc	9
M	Male	30	B. Tech (PGCE)	5

The four remaining participants were majority male and varied in age from 27 to 32 years. These teachers each had more than 4 years of teaching experience in the Grade 11 Physical Sciences syllabus and varied in their level of qualification from B. Ed to M.Sc obtained from universities in Gauteng. They were all computer literate and had the ability to use technology to

plan and deliver lessons on a digital platform ranging from powerpoint slides to smartboards, whatsapp and zoom meetings.

3.6 Data collection and data analysis of the intervention

Various forms of data were collected before, during and towards the end of the intervention. Prior to the intevention, participating teachers were required to submit self-recorded videos of their classroom teaching reflecting their normal use of technology in their teaching. These self-recorded vidoes were collected prior to the intervention, thus constituting a data source from which a baseline on their teacher knowledge and use of technology could be established. During the intervention, the teachers were introduced to the the new teacher professional knowledge for enabling digital pedagogical transformation of content components through a CoRe storyboard. A CoRe storyboard is a lesson planning tool adapted from the traditional CoRes and PaPers tools (Loughran et al., 2004). Its layout allowed for the pedagogical reasoning through the Big Ideas of the topic of electronagnetism, and further fostered planning of all the content and digital aspects that needed to be incorporated into an animation. The teacher's completed CoRe storyboards were collected as data reflecting the planning for building a digital lesson. During the exposure to the pedagogical reasoning, learner considerations and the integrated digital (technological) skills needed to build a purposeful animation for teaching electromagnetism digitally, the teachers' tutrial efforts and the responses to the support provided were collected. On completion of the intervention the participanting teachers were requested to build animation snippets, that would be used in compiling a teaching video on the topic. These purposefully built animation snippets were collected as data from which the emergence the enacted version of the newly defined teacher knowledge construct could be studied. Table 3.2 below summarizes the data collected for Phase of the research design.

Table 3.2. Structure of the data collected at each stage of the intervention

Intervention phase	Description	Data artefact collected
Pre-intervention	Submission of video of classroom teaching using technology.	Self-recorded video lessons
During Intervention • Planning • Animation creation	Introduction to planning a digital lesson and the considerations to be made as per the new teacher knowledge construct. CoRe storyboard used as a tool to capture the planning.	Completed CoRe Storyboards (planning for digital lesson)
	Integrating technology skills with developing pedagogical reasoning. Animaker software used for creation of animation snippets.	Created Animation snippets Whatsapp discussions. Stimulated recall interviews
End of the intervention • Video editing	Finalising the building of the animation snippets and pulling all into a teaching vidoe format using the Hitfilm Express software.	Created animation based teaching videos

The data collected from the intervention, includes the pre-intervention teaching video, CoRe storyboard, animation video, reflective whatsapp messages and stimulated recall interviews made of the teachers during the creation process. The varierty of the collected data enabled rich qualitative description of the nature and quality of the growing competencies towards the new teacher professional knowledge. It further fostered ease of triangulation to increase the trustworthiness of the findings.

3.7. Ethical Issues

Before meeting with the teachers to plan the study, ethical clearance to perform the research was applied for and granted. The Gauteng Department of Education, participating schools, teachers and participating students were given consent forms to authorise the use of the classroom videos

as part of the study. The consent forms contained information regarding the purpose of the study and that information gathered though the study would be reported on in a thesis and possible journal articles. The consent form informed participants of their voluntary participation in the study and guaranteed their choice to withdraw participation in the study if they so chose. Participants signed informed consent declarations allowing data generated though their participation to be used. Students who were in the classrooms during the filming of the lesson were not placed in the scenes and filming occurred from the back of the classes to prevent the identities of learners to become known. Consent from the principals of the participating schools of these teachers were asked for and given. Data collection assured individual anonymity and preservation of confidentiality. The names of the schools, teachers and their students have not been used for analysis purposes.

Each participant received an information sheet, explaining the nature of the research project. Participating teachers were asked for the details concerning age, qualifications and teaching experience and were informed that these details would be used to create a demographic for the study only. When analysis of the resulting data commenced, each participant was allocated a code for referencing purposes. The risk to the participants was classified as low due to the fact that the teachers planned and executed lessons they would have done as part of their normal duties as teachers for this topic. Upon completion of the project, the research data was be scanned and kept electronically and protected by a password. The data would finally be kept in a safe place by the supervisor, to ensure that no unauthorised access to the information was obtained for three years and would then be destroyed.

3.8. Reliability and trustworthiness

As a qualitative study, trustworthiness and reliability of the data must be shown. To ensure accuracy in data collection and trustworthiness of the literature meta-synthesis, the PRISMA Statement (Sarkis-Onofre et al., 2021) checklist was applied in the gathering and classification of the reviewed articles. The PRISMA Statement is a systematic approach to conducting a literature review that includes a review protocol that contributes to making the methods explicit and reproducible (García-Peñalvo, 2022). A peer review of the selection criteria for gathering literature was performed to strengthen the trustworthiness and reliability of the selected literature. Peer review of the CoRe storyboards, video-analyses and stimulated recall interviews were performed. Thereafter the data sets of the intervention phase were triangulated to generate the overall description of the new teacher professional knowledge. According to Aguilar Solano (2020) triangulation is a rigorous methodological strategy improving the quality of the research by increasing the validity of the data analysed. In this study, the pre-intervention videos, CoRe

Storyboards, final animation videos, post intervention interviews and whatsapp groups would be triangulated with each other to formulate a clearer set of evidence whether the teachers initially had TSPCK and/or new teacher knowledge. Furthermore it would be possible through this triangulation to determine whether there is evidence of digital-TSPCK exhibited by the teachers after the intervention, indicating that teacher development of new teacher knowledge had occurred. This method of data analysis could enable the identification of new teacher knowledge components not visible in certain artefacts due to the nature of the construct, but confirmed by the participants or other artefacts, detailing the nature of the interaction of the components.

Chapter 4

4: Conceptualization of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content: Literature meta-synthesis

This Chapter is phase 1 of a 2 –phase discussion building a conceptual argument for a new theoretical construct to be validated for teaching science in digital formats through digital platforms. In this first phase, a description of the process of conducting a meta-synthesis literature review on the use of technology in Science is provided. The Chapter begins by noting how global factors influence the future of education. This is followed by literature meta-synthesis of theoretical frameworks contributing toward the pedagogical transformation of science content for the use of technology in teaching. The chapter closes with an emerging framework of teaching science on a digital platform leading to an expanded discussion in the next Chapter that closes with a conceptual model for a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content.

4.1 Introduction

Our human society is currently moving into a new era of digitalization. This global process seems to have a life of its own, independent of country, policy or economic status. Notably, one tiny deadly virus has accelerated the intake of digitalization across many economic sectors including education almost overnight. The onset of a global COVID-19 pandemic has forced educational institutions to re-imagine their teaching approaches as face-to-face classes were suspended for extended periods of time, leaving online/distance learning as the only option to teach students (Hebebci et al., 2020; Orlov et al., 2021). In Africa, while as early as 2015, the African Ministerial Forum of the African Union (AU) had pronounced its aims through Africa's Agenda 2063 to reposition the continent in the global arena by transforming it into an e-Society, starting with the integration of ICT in education; it is the outbreak of the corona-19 virus that illuminated vividly the vast inequalities in accessing technology and the stark challenges facing Africa in reaching this vision. In South Africa, as early as 2 decades ago, the White Paper on e-Education in 2004 (Education, 2004) set forth aims to ensure that all learners have access to ICT with the expectations that schools become e-schools, integrating ICT in teaching and

learning. Progress towards attaining this policy goal fully has been at a snail pace (Graham et al., 2020). Despite the introduction of ICT in many urban South African schools over the last few years, teachers have failed to fully utilize these resources in their classrooms (Sherman & Howard, 2012). Research has further shown that in provinces where computer access has been provided, namely Gauteng and the Western Cape, many of the teachers have experienced difficulties integrating it with their teaching due to conflicting beliefs regarding their choice of and use of technology and its perceived value in the classroom (Soomar, 2021; Webb, 2004). This observation is in line with the global analysis pointing at the unfortunate manner in which technology has been implemented generally in teacher professional development programs often as once-off, short workshops with minimal post-workshop to support permanent changes to teaching practices (Campbell et al., 2015; Soomar, 2021). As a result, little has been gained in understanding the complex ways in which technology is integrated within discipline specific pedagogies particularly in science education (Fernandes et al., 2020). What is however becoming evident from the few studies exploring the integration of technology within specific discipline pedagogies, point to complex and more difficulty challenges being experienced as compared to face to face settings (Graham et al., 2020; Webb & Cox, 2004). Klieger and colleagues argue that teacher training programs would benefit from implementing a more differentiated discipline- and topic-specific training approach with regard to the integration of technology within disciplines (Klieger et al., 2010). This statement is aligned with the one purpose of the study presented in this Chapter, which is the development of a theoretical framework for teaching science as digital content and through digital teaching and learning platforms. As alluded in the introductory Chapter (Chapter 1), the theoretical construct to be described by such a framework has been described as a new kind of teacher professional knowledge enabling digital pedagogical transformation of content. Like the traditional theoretical construct of TSPCK, this new teacher knowledge attempts to enable pedagogical transformation of the specific topic content for learner understanding, but extended to the creation of such transformed content as digital content to be presented through digital teaching and learning platforms in asynchronous formats such as teaching video. The two phase process for the development of a theoretical construct (Kane, 2012) has informed the framing of next following Chapters. According to (Kane, 2012), theoretical construct validity requires both the formulation of conceptual argument, and a statistical or empirical process as discussed in Chapter 3 to validate it. Accordingly, this Chapter marks the

beginning of the process leading to the formulation of a conceptual argument for a new kind of teacher professional knowledge enabling digital pedagogical transformation of content in science education is presented. Due to the complexity and length of the discussion, the development of the conceptual argument for a new kind of teacher professional knowledge enabling digital pedagogical transformation of content is extended over two Chapters, Chapters 4 and 5. In this Chapter, the process of conducting a systematic review of literature through meta-synthesis on how technology has been used in science education is presented, and the outcome built into few other learning considerations is pulled into a pictorial model presenting a comprehensive conceptual argument of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content in the next Chapter, Chapter 5.

4.2 A literature review through meta-synthesis

In the broader field of education, interest has grown in the integration of findings across qualitative studies to discover patterns and deepen understanding of evidence-based practices (Yore & Lerman, 2008). There are three distinct types of systematic integration of related research: literature reviews, meta-analysis and qualitative meta-synthesis (Thunder, 2016) which are briefly elaborated upon below.

A Literature review is a convention in which researchers locate their original inquiry within the context of previous studies to convince the reader that this additional study is justifiable, the results of the study will have relevance to some aspect of advancing the body of literature. Literature reviews summarise the strengths and weaknesses of previous research for purpose of establishing that previous findings and claims are relevant to the current focus of inquiry. The conclusion of a literature review suggests that the new study could fill a strategic gap in existing literature.

Qualitative meta-synthesis involves the analysis and interpretation of findings from selected studies. Researchers use a deliberate process of selecting studies with an emphasis on synthesising, analysing and interpreting findings across the selected studies (differentiating it from the summary, description and critique of a literature review). A qualitative meta-synthesis seeks to interpret findings for deeper understanding across a selection of studies.

*Meta-analysis u*ses a statistical procedure that aggregates and condenses a body of quantitative research studies to a common standard metric. This type of literature study is used to summarise, replicate findings, and determine the cause and effect of investigated phenomena.

The rationale for employing a qualitative meta-synthesis approach to the selection and analysis of articles for this study stems from the purpose of the study. The qualitative meta-synthesis approach was chosen as a suitable approach for this study because of its affordance to explore deeper insight from a related set of studies, where the findings serve as fertile ground from which a conceptual argument for a theoretical construct may emerge (Erwin et al., 2011). Within the qualitative meta-synthesis approach for analysing literature, four variations in procedures exist as noted by Finlayson and Dixon (2008):

- Meta-study - sample, evaluate & analyse studies following a linear and structured procedure. It is characterised by an exhaustive literature search using a priori approach with formal appraisal criteria.

- Meta ethnography - synthesising individual ethnographic studies to describe broader relationships using metaphors.

- Grounded formal theory - coding is used to categorise and develop an abstract, general theory to explain relationships.

- Cross-case analysis - systematic coding, refining and cross-referencing descriptive meta-themes and meta-categories.

The cross-case analysis used in this study enabled cross-referencing of emerging similarities and meta-themes emerging in the literature to show relationships among the categories of components of each of the frameworks and logical gaps that emerged from the analysis. The analysis and interpretation findings from deliberately selected studies with the intention of synthesising and interpreting the findings were used to inform a sound conceptual argument towards defining emerging components for a new kind of teacher professional knowledge enabling digital

pedagogical transformation of content (Thunder, 2016). The procedure followed the steps outlined by Thunder and Berry (2016) in the synthesis of the identified literature.

Step 1*: Identifying the research question*

This step required the formulation of a research question which should be answered by performing a literature review. This question was based on the main research question of the greater study as mentioned earlier, refined to highlight the sought association of TSPCK learning theories and technology, namely: In what ways could the postulated theoretical idea of the new kind if teacher professional knowledge for enabling digital pedagogical transformation of content be conceptualized from a theoretical argument perspective? As a starting point, a specific research meta-question to be answered through the literature meta-synthesis was used to further clarify the original research question:

How are the professional knowledge components of TSPCK and teaching with technology frameworks conceptualized in Science Education studies?

In Science Education, TSPCK has been used widely as the teacher knowledge for teaching science in specific topics demonstrating its operationalisation, while theories on technology use and learning through technology have made their impact on changing the way science education professional development has evolved. Therefore, it was reasonable to start by looking at how the components of these constructs are described and measured in Science Education studies. It was hoped that understanding how these are described and measured in operation, would cast light towards building a conceptual argument for the new kind of teacher professional knowledge for enabling pedagogical transformation of content.

This question was formulated to open up to studies that are exploring the teaching of science based on the widely accepted knowledge for teaching science (PCK) and the ways in which technology has been used in the practice. In Science education, the teaching of science has been linked commonly to teacher professional knowledge described through PCK and more lately to the related grainsize –TSPCK. While TSPCK, does not refer to technology explicitly, other theoretical constructs like TPACK, TPASK, SAMR, STeLLA and others have been used in the science education literature as frameworks to inform the use of technology in the teaching practice. These

theoretical constructs were highly noted and in mind when formulating the research question to guide this meta-synthesis. Once the meta-question was defined, providing the broad scope from which the criteria were to be derived, it was then possible to begin with the literature search.

Step 2: Conduct a comprehensive search

This step required a broad search of existing relevant literature to serve as a base of the systematic search, retrieval and validation process. Initially criteria were determined for the selection of articles for the study, and new criteria were added in an iterative process for secondary and tertiary analysis of selected articles.

Articles were searched for using the keywords: *TSPCK, Topic Specific Pedagogical Content Knowledge, Teaching with technology, tools, rubrics, and digital competency*. Article collection took the form of a broad internet search, with articles broadly referring to journal articles, books, book chapters and theses identified by the search engines. The search engines used were: Google scholar, the Academia and Web of Science search directories, with the abovementioned list of criteria as keywords. The time frame parameter was set from 2000 to the year 2023. Articles found were sent to my email where I was able to store and review them. Initially, a total of 978 articles were found. The articles were then sifted using the keywords: Teaching with technology, TSPCK, and the Boolean operator AND with the keywords 'measurement of' to reveal the articles most relevant to the research question of the literature meta-synthesis. 155 articles had been collected as recorded in Addendum F.

Step 3: Select initial relevant studies

The abudance of information generated by the review of the collected articles required efficient management for the valid interpretation of the findings (Sandelowski & Barroso, 2006). As noted by Sandelowski and Barroso (2006) the formation of an audit trail, detailing the procedures and findings of the review, would validate the procedure and aid to standardise the interpretation of the subsequent results. Using an iterative process adapted by Thunder and Berry (2016) articles were analysed for their relevance and information collected and grouped for further synthesis as indicated in the Figure 4.1 below.

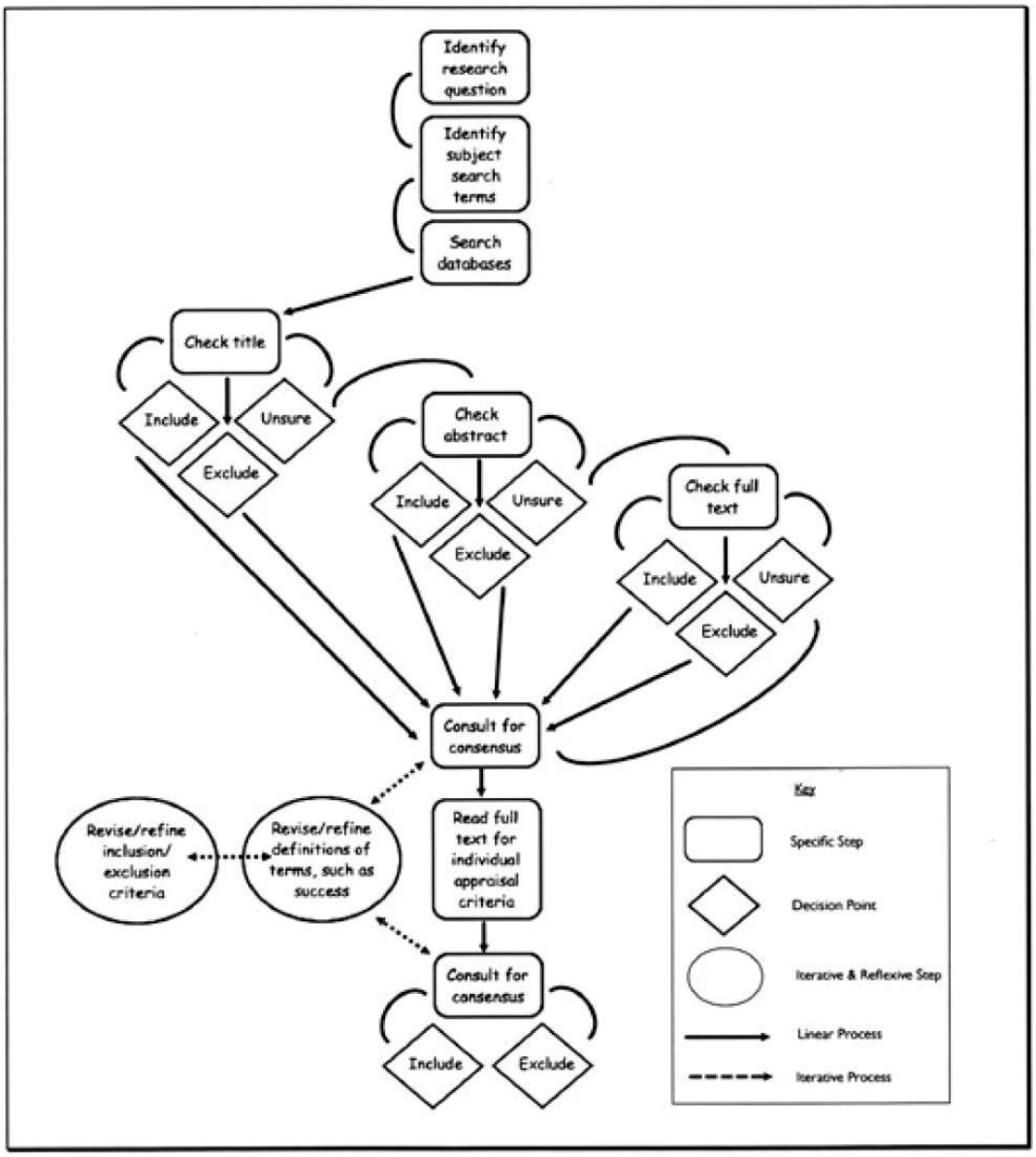


Figure 4.1. Flow diagram of the search, retrieval and validation process of literature meta-synthesis adapted by Thunder and Berry (2016). Adapted with permission.

This step required the implementation of the criteria reflecting the purpose indicated in the research question in Step 1and 2 above, to frame the selective identification of relevant articles from the baseline in step 2. This step was the Primary article analysis whereby the keywords and abstracts of each article were read to search for the keywords in the criteria and mention of the following aspects:

- Description of each of the theoretical constructs' model components.

- Measurement of each of the theoretical constructs including respective tools

- Rubrics used to categorize the quality of each of the theoretical constructs.

- The study being based on digital lessons rather than technology use in a traditional classroom settings.

The aim of the primary analysis was to sift through the large quantity of articles to extract the most relevant in terms of naming, describing and measuring the components of each model. All 155 articles gathered were analysed at this stage and information per article recorded as seen in Addendum F. In addendum F articles were coherently presented on a systematic review search tracking grid based on the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Statement (Sarkis-Onofre et al., 2021). This provided a transparent audit trail of the articles used in the literature meta-synthesis indicating the number of articles analysed, their objectives and outcomes in an attempt to remove bias and increase reproducibility (Shamseer et al., 2015). The article review columns were reflective of the nature of the study and the type of information deemed valuable to the review of this study.

Step 4: Appraise the quality of initially selected studies

Individual appraisal of each article allowed insights into their suitability for the metasynthesis with regards to meeting the inclusion criteria while strengthening knowledge of the article content (Sandelowski & Barroso, 2006). The browsing search strategy (Bates, 1989) was implemented in the initial process of sorting through the gathered articles.

Due to the open nature of qualitative studies, there were findings discussed in the articles that were not necessarily anticipated (Sandelowski & Barroso, 2006), but relevant to this study. Several articles reviewed in the secondary article analysis made reference to framework components/instruments adapted from other authors, but did not show them in their article. As a result, these referenced articles were berry-picked (Bates, 1989) in order to gather their instruments reflecting the components.

Each article was read and evaluated to ensure that the inclusion criteria were sufficient while becoming familiar with the content of each study. Articles from the primary analysis were sorted

according to their match with the search criteria. Articles found to list components, mention model-measuring tools, rubrics and definitions of model components were selected for a secondary stage of article analysis. A total of 89 articles (listed in Addendum F) from the basket of 155 articles were found applicable and evaluated during this step. Article evaluation entailed reading the entire article with the enlisted criteria as the backdrop. The following factors were noted for relevance to the study:

- Description of the construct's components.
- Context of the study.

- Did the study focus on the planning or enactment phase of teaching or both?
  - Data collection tool.
  - List of components for the model.
  - Findings/discussion on the nature of the construct.
  - Possible useful references to collect and explore later outside this process.

Several articles reviewed in the secondary article analysis made reference to framework components/instruments adapted from other authors or previous publications, but did not show them in their article (Almasseri & AlHojailan, 2019; Fisser et al., 2015; Jiang et al., 2017; Kopcha et al., 2014; Lyublinskaya & Tournaki, 2013; Mishra, 2005). As a result, these referenced articles were collected in order to gather their instruments reflecting the components. There were articles found in the primary article analysis which did not refer specifically to TSPCK as a construct, but did contain description and measurement of PCK at the topic level, to name a few: (Aydin et al., 2014; Chan & Hume, 2019; Nilsson & Loughran, 2012; Park & Chen, 2012). These articles formed the secondary article analysis. In-article references referring to the same criteria of the literature meta-analysis were added to the tertiary analysis which was made out of 5 additional articles. In total a collection of 94 articles formed the basis of the final analysis. A summary of the article analysis conducted up to this stage is shown in table 4.1 below.

Table 4.1. Articles collected as a three tier iterative literature review process adapted by Thunder (2016).

Tier of article analysis	Number of articles	Focus of analysis for each article
Primary	155	Sifting for relevant articles based on the keywords: TSPCK, Learning with technology, ICT framework, Technology integration.
Secondary	89	Context of the study: Instruments that measure each construct Components of each construct Findings/discussion on the nature of the construct
Tertiary	5	In-article references to data-collection tools containing the construct components, description of, or lists of components

Step 5: Synthesise findings of selected studies using qualitative techniques

In this stage the findings from the previous stages are synthensized. It is important to note that the process of literature meta-synthesis goes beyond mere summary of findings, it affords a contemporary interpretation of targeted phenomena within the literature (Sandelowski & Barroso, 2006). Several approaches to a qualitative literature meta-synthesis exist as described by Sandelowski and Barroso (2006):

(i) *Taxanomic analysis* is based in grounded theory and uses inductive analysis for the development of theories based on the literature. Taxonomic analyses show the conceptual range of findings, establishing possible relationships, providing a foundation for the development of conceptual models or theories. The advantages are that not only are the theoretical findings of the articles highlighted, logical gaps in the theory are displayed, making way for a more pervasive synthesis.

(ii) *Constant targeted comparison* requires a deliberate search for similarities and differences between the topic phenomenon and another phenomenon not addressed in the research articles. The aim is

to define overlapping attributes and to showcase specific relationships between the phenomena, best performed after a taxanomic analysis has been done on the literature.

(iii) *Imported concepts* could be used to integrate findings not featuring in the current literature set in order to present findings as groupings of specific phenomena. An example of this could be of the grouping of the findings of the study under the concept of virtual teaching practices, which did not explicitly show in the findings, but can be used to group ceratin articles due to the implementation of virtual environments, per se.

(iv) *Reciprocal translation and synthesis of in vivo and imported concepts,* an adaptation of meta-ethnography, entails constant comparison of a combination between imported and intra-study concepts.

This study lent itself to a taxanomic analysis of the 'Teaching with technology frameworks' and TSPCK models whereby the analysis of the articles would enable the revelation of the constituent components of each framework, their use and their relation to each other where used together. Extraction of the findings of each study were coded according to the purpose of the study, theoretical framework and level (primary, secondary or tertiary) of synthesis of literature performed. Based on this elective process of content analysis, the components of each construct became visible whether in planning or enactment in the studies that were reviewed which described the frameworks. The components and their descriptions of each framework were used to form a composite list to describe each framework according to the literature.

Step 6: Present synthesis findings across the studies to address the research question

A visual display as shown in Table 4.1 of the categorisation and classification of the literature was designed as a summary of the three levels of article analysis and subsequent visual depiction of the interaction between the components of the two constructs within the context of teaching a science topic. This summary served as a collective body of work from which evidence-based findings can be reported. From the article meta-synthesis, the key finding made regarding the articles and the frameworks discussed, was that none of the studies clearly used all both constructs, the articles focussed on either ICT integration or TSPCK in terms of the description of teaching activities or measurement activities

From the analysis of the set of articles on how each construct is used was possible to construct a list of components that were visible in planning and or actual classroom teaching and their descriptions which best represents how each framework contributes to the aspects of teaching science topics as shown in the Tables below. Looking at studies that employed the TSPCK construct, Table 4.2 presents the summary.

Table 4.2. Consolidated TSPCK components from the literature meta-synthesis

TSPCK Component descriptions	Source articles describing specific components
Learner prior knowledge	(Davidowitz & Potgieter, 2016; Davidowitz & Rollnick, 2011; Loughran, 2012; Loughran et al., 2004; Makhechane & Mavhunga, 2021; Malcolm et al., 2019; Mavhunga, 2012; Mazibe, Coetzee, et al., 2020; Miheso, 2018; Miheso & Mavhunga, 2020; Muvoti, 2020; Ndlovu, 2017; S. O'Brien, 2017; Pitjeng-Mosabala & Rollnick, 2018; Potgieter & Davidowitz, 2010; Schultz et al., 2018; Vokwana, 2013; Zondi, 2018)
Curricular saliency	(Aydin & Boz, 2013; Aydin et al., 2014; Chan & Hume, 2019; Chan et al., 2019; Davidowitz & Potgieter, 2016; Loughran et al., 2004; Magnusson et al., 1999; Makhechane & Mavhunga, 2021; Malcolm et al., 2019; Mavhunga, 2012; Mazibe, Coetzee, et al., 2020; Miheso, 2018; Miheso & Mavhunga, 2020; Muvoti, 2020; Ndlovu, 2017; Nilsson & Loughran, 2012; S. O'Brien, 2017; Park & Chen, 2012; Park & Oliver, 2008; Pitjeng-Mosabala & Rollnick, 2018; Rollnick & Davidowitz, 2015; Schultz et al., 2018; Vokwana, 2013; Zondi, 2018)
What is difficult to teach or understand	(Aydin & Boz, 2013; Aydin et al., 2014; Chan et al., 2019; Davidowitz & Potgieter, 2016; Loughran, 2012; Loughran et al., 2004; Magnusson et al., 1999; Makhechane & Mavhunga, 2021; Malcolm et al., 2019; Mavhunga, 2012; Mazibe, Coetzee, et al., 2020; Miheso, 2018; Miheso & Mavhunga, 2020; Muvoti, 2020; Ndlovu, 2017; Stephanie O'Brien, 2017; Park & Chen, 2012; Pitjeng-Mosabala & Rollnick, 2018; Rollnick & Davidowitz, 2015; Schultz et al., 2018; Vokwana, 2013; Zondi, 2018)

Representations	(Aydin & Boz, 2013; Chan & Hume, 2019; Loughran et al., 2004; Makhechane & Mavhunga; Malcolm et al., 2019; Mavhunga, 2012; Mazibe, Coetzee, et al., 2020; Miheso, 2018; Miheso & Mavhunga, 2020; Muvoti, 2020; Ndlovu, 2017; Nilsson & Loughran, 2012; S. O'Brien, 2017; Park & Chen, 2012; Pitjeng-Mosabala & Rollnick, 2018; Potgieter & Davidowitz, 2010; Rollnick & Davidowitz, 2015; Schultz et al., 2018; Vokwana, 2013; Zondi, 2018)
Conceptual teaching strategies	(Aydin & Boz, 2013; Aydin et al., 2014; Chan et al., 2019; Davidowitz & Potgieter, 2016; Loughran, 2012; Loughran et al., 2004; Magnusson et al., 1999; Makhechane & Mavhunga, 2021; Malcolm et al., 2019; Mavhunga, 2012; Mazibe, Coetzee, et al., 2020; Miheso, 2018; Miheso & Mavhunga, 2020; Muvoti, 2020; Ndlovu, 2017; Stephanie O'Brien, 2017; Park & Chen, 2012; Pitjeng-Mosabala & Rollnick, 2018; Rollnick & Davidowitz, 2015; Schultz et al., 2018; Vokwana, 2013; Zondi, 2018)

In Table 4.2, the first column lists the descriptions each of the original components obtained from the literature meta-synthesis. The last column lists the articles where the components were sourced. It can be noted that most of the articles used the same components and descriptions with a few articles modifying the criteria according to the context of their study. For example, the component "Learner prior knowledge" included the description "Explanation demonstrates conceptual understanding" in Rollnick and Davidowitz (2015), Davidowitz and Potgieter (2016) and Pitjeng-Mosabala and Rollnick (2018). For the component "Conceptual teaching strategies" Mavhunga (2012) and Malcolm et al. (2019) included "Highly learner-centred lesson". Ogbonnaya et al. (2020) applied the TSPCK components to Economics, and adapted the descriptions to be specific to the study, and was therefore not used in this meta-synthesis. From the articles reviewed where TSPCK was not explicitly mentioned as a construct, they referred within their articles to the topic-specificity of PCK (Aydin & Boz, 2013; Kind, 2019; Nilsson & Loughran, 2012; Schultz et al., 2018) and measured PCK of pre-service teachers or practicing teachers when teaching a specific topic. Several studies used adapted Cores such as Loughran et al. (2004), Nilsson and Loughran (2012) and (Schultz et al., 2018); while the (Magnusson et al., 1999) model was used as a basis to elicit topic specific components for measurement (Aydin et al., 2014; Park & Chen, 2012). Chan et al. (2019) incorporated the topic-specific components of 'knowledge of understanding of science', 'recognition of variations in student understanding' and 'knowledge and selection of instructional strategies' of PCK in the Grand PCK Rubric (Chan et

al., 2019) and was therefore placed within the TSPCK table. Differences were noted in the wording of component descriptions for conceptual teaching strategies in articles by Mazibe, Gaigher, et al. (2020), Rollnick and Davidowitz (2015) and Muvoti (2020) but were understood to describe the same component and therefore included in the meta-synthesis.

In summary, the construct of TSPCK has been used widely to described and measure teacher knowledge pertaining to the planning and teaching of specific science topics. The five components of the TSPCK have been used largely intact in exception by few the studies for example Mazibe, Gaigher, et al. (2020). On the whole, the pedagogical transformation of content knowledge remained the key focus in these studies with that understanding that it emerges from the interactive use of the components. It was noted that studies that used the TPACK construct dominated in science education. These spread across studies used the construct to analyse effect of a technological device (computer, tablet, projectors, mother-board, RAM.), software (Windows, PowerPoint presentations, Media player, Moodle, simulations, downloads, etc.). The TPACK studies mostly showing three components including:

- Understanding how to represent concepts with technologies, pedagogical techniques that use technologies in constructive ways to teach content.
- Knowledge of what makes concepts difficult or easy to learn and how technology use can help students learn.
- Use ICT to actively construct knowledge that integrates with learning areas.

However, none of the components are clearly helping with the creation of digital-content which is what a teacher would be doing most of the time in a digital lesson and therefore the component that speaks to the creation of content and deepening of knowledge is sought after. This requirement meant the exclusion of many studies using constructs, not only TPACK, but also RBeLEs, and STeLLA, although they were picked by the review process, thorough analysis pointed the relevancy of the technology used to be more tuned to traditional classroom settings. Table 4.3 presents the summary of articles reflecting that have specifically referred to the use of ICT in science lessons.

Table 4.3. Articles that reflected the use of ICT in Science teaching

ICT in Sciences Framework	Source articles
Technological pedagogical Content and Knowledge (TPACK)	(Jang & Chen, 2010; Jang & Tsai, 2013; Savec, 2020; Setiawan et al., 2019; Sheffield et al., 2015)
UNESCO ICT Framework	(Eilks, 2015; Fensham, 2008; Holbrook & Rannikmae, 2007; Lestari & Prasetyo, 2019; Moore et al., 2016)
Critical Digital Literacy	(Akhyar et al., 2021; Demirbag & Bahcivan, 2021; Kaeophanuek et al., 2019)
Substitution, augmentation, modification and redefinition (SAMR)	(Caukin & Trail, 2019; Flores & Adlaon, 2022; Tsybulsky & Levin, 2016, 2017; Wahyuni et al., 2020)
Science teachers learning from lesson analysis (STeLLA)	(Eskrootchi & Oskrochi, 2010; Ginters, 2008; Roth et al., 2011)
ICT-based teaching	(Cullen et al., 2019; Maharaj-Sharma et al., 2017; McFarlane & Sakellariou, 2002; Savec, 2020; Shanmugam & Balakrishnan, 2019)
Microcomputer-based learning	(Bernhard, 2003; Espinoza, 2007; Han, 2002; Kamtoom & Srisawasdl, 2014; Mokros, 1985; Park et al., 2008; Wong et al., 2020)
Technological pedagogical content and science knowledge (TPASK)	(Ezzeldin, 2022; Hernández-Ramos et al., 2023; Jimoyiannis, 2010; Mugot & Fajardo, 2021; Rodríguez-Becerra et al., 2020; Widowati et al., 2020)
Online resource-based learning environments (RBeLEs)	(So et al., 2015; So, 2012)So (2012, 2015), Fernandez et al. (2020)

Looking at the studies that used technology in science education, Table 4.3 presents a summary of components found in articles of predominant frameworks referring to teaching with technology. Of these frameworks, the UNESCO ICT competency framework for teachers and TPACK appeared to be the most predominant when looking through the lens of adding value to the TSPCK framework on a digital platform. The components of these two frameworks have been illustrated in Table 4.4 below.

Table 4.4. The components of predominant teaching with technology frameworks

UNESCO ICT framework	**Description of components**	**Source articles**
Technology Literacy	Computer literacy Application of ICT, Use of ICT	Moore et al. (2016), Mtebe (2020), UNESCO (2011), Midoro (2013), Ansong-Gyimah (2017), Avdeeva et al. (2016), Schols and Bottema (2014)
Knowledge deepening	Acquisition of knowledge Solving the integrated tasks Complicated tools Help and supervision can be given to others	Moore et al. (2016), Mtebe (2020), UNESCO (2011), Midoro (2013), Ansong-Gyimah (2017), Avdeeva et al. (2016)

Knowledge creation	Production of knowledge Imitation of innovations Skills of a mentor Capacity for self-education Proliferating technologies	Mtebe (2020), UNESCO (2011), Midoro (2013), Ansong-Gyimah (2017), Avdeeva et al. (2016)
TPACK component criteria		**Source articles**
Technological Knowledge TK		(Adipat; Agyei & Keengwe, 2014; Schmidt et al., 2009) Bora & Ahmed (2018), Sahin (2011), Mishra & Koehler (2005, 2006, 2008), Chai et al. (2013)
Pedagogical Knowledge PK		
Applying different learning theories and approaches (eg: Constructivist Learning, Multiple Intelligence Theory, Project-based Teaching)		Schmid et al. (2020), Schmidt et al. (2009), Sahin (2011), Mishra & Koehler (2008)
Content knowledge CK		
Knowing about key subjects in my area, actual subject matter to be learned/taught, central facts, concepts and theories, explanatory frameworks that organise and connect the ideas.		Schmid et al. (2020), Schmidt et al (2009), Sahin (2011), Mishra & Koehler (2008), Bora & Ahmed (2018)
Technological Pedagogical knowledge TPK		
Choosing/adjusting technologies appropriate for my teaching/learning approaches and strategies		Schmid et al. (2020), Schmidt et al. (2009), Sahin (2011), Chai et al. (2013), Bora & Ahmed (2018) Lyublinskaya (2013)
Pedagogical Content knowledge PCK		
Selecting appropriate and effective teaching strategies for my content area to guide teaching and learning		Schmid et al. (2020), Schmidt et al. (2009), Sahin (2011), Chai, Koh & Tsai (2011), Bora & Ahmed (2018), Harris et al(2010), Niess (2013)
Technological content knowledge TCK		
Critically interpreting, evaluating and using area-specific/ topic specific computer applications/software		Schmid (2020), Chai et al. (2011),(Sahin, 2011), Jimoyannis (2010), Mishra & Koehler 2008)
Technological, Pedagogical and Content knowledge TPACK		
Flexibly navigating technology, pedagogy and content to become responsible for the total curriculum package		Schmid et al. (2020), Schmidt et al. (2009), Sahin (2011), Mishra & Koehler (2005, 2008), Bora & Ahmed (2018), Agyei & Keengwe (2014), Adipat (2021)

In Table 4.4, the first column lists the UNESCO ICT framework knowledge component description as captured in the different articles that made reference to it (enlisted in column 2). As noted in column 2, not all articles made all the knowledge components of the construct visible. Each description seemed to emphasize a slightly different aspect of the same knowledge component. A description that deemed most explanatory to the component was included. The use of the framework differed between articles, as Moore et al. (2016) employed the UNESCO ICT competency framework for teachers to create shareable learning materials, whereas Ansong-Gyimah (2017) created field tests for the measurement of the teacher competencies in the field. Needless to say, these articles all used the basic components of the UNESCO ICT competency framework for teachers. The UNESCO ICT competency framework for teachers (UNESCO, 2011) was represented as a progressive framework that scaffolds the gain in teacher knowledge. The basic knowledge of digital literacy are listed as the entry-level to teaching with technology (UNESCO, 2011) with a gain in knowledge allowing a teacher to digitally solve integrated tasks (Moore et al., 2016). At the highest level the teacher has the knowledge to be able to innovate and create their own digital knowledge. As this study argues for a new kind of teacher knowledge that allows for the pedagogical transformation of content knowledge on a digital platform, the UNESCO ICT competency framework for teachers would enable content transformation onto a digital platform. The first impression observations derived from the studies on the two constructs UNESCO ICT competency framework for teachers and TSPCK, the following salient points emerged:

1. At an operational level TSPCK components such as: Learner Prior knowledge, Representations and Curricular Saliency were commonly visibly evident in the data collected, findings made and also in cases of studies with a focus on measurement of teacher knowledge Mavhunga (2012), Mavhunga and Rollnick (2013), Rollnick and Davidowitz (2015), Malcolm (2018)and Vokwana (2013).

2. The component of conceptual teaching strategies was not seen in its own right but implied from the strategies evidently drawing on multiple components, used to confront a difficult to understand concept or learner misconceptions. (Malcolm, 2018; Rollnick & Davidowitz, 2015).

3. Components of learner prior knowledge and What is difficult to teach were in some cases obscured in nature, evidence pointed to the implied evidence of the presence.

4. Teacher digital competencies as described by the UNESCO ICT competency framework for teachers appear to pull technology across the three levels of sophistication as needed in building a digital lesson. Both the understanding of entry and higher levels of digital competency is needed and used for different aspects of the lesson.

5. The taxonomic analysis used in this review, allowed for the description of logical gaps arising from the captured relationships seen across the studies reviewed and represented in Table 4.3. For this specific systematic literature meta-synthesis, the following elements emerged as gaps in relation to TSPCK on a digital platform not adequately or covered at all by the two theoretical constructs and even from their transactional relationships. These are:

i. Consideration for the alone learner who receives content in a digital form through the digital teaching and learning platforms.

ii. The development of technological competence, not only choose applicable technology, but to create new discipline based digital content.

The results that we have seen they have shown us the components of each construct that are visible, the relationships across the components, but they have not shown us the considerations of the alone learner who now receives content in a digital format through the digital teaching and learning platforms. In order to address these gaps, the abovementioned foundations of these results will now be built upon in order to argue for what the knowledge of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content needs to be able to do to help our teachers develop the competencies to use technology and also consider the learner in ways that are appropriate for multimedia and still be able to transform.

In summary, the TSPCK framework, known for the topic-specific pedagogical transformation of science content for teaching and learning purposes, was found wanting in the new era of teaching and learning on digital platforms. An investigation through a literature meta-synthesis revealed

numerous frameworks related to teaching science with technology as noted in Table 4.3. Each framework allowed for the improvement of a teacher's use of technology, be it hardware or software, in the classroom and plan lessons accordingly. However, it was the UNESCO ICT competency framework for teachers that afforded teachers the scope wide enough for creation of content and not only a gain of knowledge in use of the technologies for teaching science, but an additional aspect useful to this study. The UNESCO framework's outlook tended toward the teacher becoming the designer of their own science content, enabling the teacher to pedagogically transform their science topics onto a digital platform, the one knowledge area to complement the TSPCK framework. Further development of the definition of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content is required. Therefore, in the next chapter I build on these findings and pull theories that can help close the gaps identified in this chapter.

Chapter 5

5: Defining the new construct of teacher professional knowledge for enabling digital pedagogical transformation of content

This chapter builds on the findings of the systematic literature meta-synthesis, arguing that the TSPCK framework alone is insufficient for building teacher's digital competence in the realm of creating digital teaching animations. Incorporation of the UNESCO ICT competency framework for teachers and the learning with multimedia principles into the TSPCK framework instead of similar frameworks will be discussed. Thereafter, a formal definition of the construct describing a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content will be presented.

5.1 Introduction

At this point in the literature meta-synthesis process I have described two frameworks which, when used on their own, are insufficient to produce the kind of teacher professional knowledge required to enable digital pedagogical transformation of content.

An important constant in the conceptualization of a new construct has been the retention of the power of pedagogical transformation of content derived from TSPCK as a discipline-specific pedagogy. The literature meta-synthesis in Chapter 4 concluded with a preliminary description of the manner in which the two emerging frameworks could complement each other to form a construct meeting the abovementioned requirements.

5.2 Merging TSPCK and the UNESCO ICT teacher competency framework

There were several valuable contributions made by the UNESCO ICT teacher competency framework in terms of technological knowledge and skills towards this transformation of content due to the need to include a framework that allowed pedagogical content while building digital teaching competence. While studies have shown that TSPCK allowed for the pedagogical transformation of content, it was the knowledge of the principles of the UNESCO framework that created the reality of the reasoned TSPCK component interactions expressed in a digital format.

In the process of pedagogical transformation of content, teachers would naturally need to use all three levels of sophistication described by the UNESCO ICT framework. By merging the UNESCO ICT framework to TSPCK, the UNESCO ICT framework would be operational at all three levels and bring into view the transformation of content that TSPCK is doing. For that transformation to happen, it requires teachers to be digitally literate (UNESCO level 1- Digital literacy). When using technology, teacher would have to be able to make choices regarding the digital material that is available that they would be incorporating into their lessons (UNESCO level 2-Knowledge deepening). Thirdly, teachers would need to use what was gathered during lesson planning and create a new version of the content which was not necessarily there before, which came from within the teacher, considering all the issues of the TSPCK framework and that is the content creation (UNESCO level 3- Knowledge creation) (UNESCO, 2011). Teachers with the knowledge to become creators of digital content, would have the ability to use TSPCK in the development of any digital content. The teacher would be responsible for presenting their choice and format of representations and the content information that accompanies it. As noted from the literature meta-synthesis of the teaching science with technology frameworks, only the UNESCO framework afforded the teacher autonomy from planning to presentation regarding the type of technology used and the format of the final digital product.

Teacher factors associated with innovative pedagogical use of ICT (Voogt, 2010) include the belief of teachers as lifelong learners, who adapt to innovations and readily implement ICT in their classrooms. Two factors were therefore to be addressed at this point:

1. In order to work with multimedia, the teacher would need to have developed some digital skills like how to develop an animation and how to edit a video.

2. There needed to be a frame of reference indicating how to do that well, now that the teacher knows how to create digital content (in this study, an animation), what is considered to be a good animation for the purposes of teaching?

Competence to work on a digital platform

Classrooms whether real or virtual, will soon require all teachers to be empowered to apply technology to effectively teach the subject content. Engaging with digital platforms requires teachers to acquire a set of practical skills to navigate through the use, design and application of

technology ranging from installing hardware and software in the class to designing and presenting topic specific lessons. UNESCO (2011) has formulated an ICT framework arranged as a set of education improvement approaches for teachers to become competent technology users in their classrooms which are presented as a hierarchy of skills to be developed:

- *Acquiring technological skills*. Teachers would know how, where and when to use different technologies in their teaching, administration and management tasks. These competencies include basic digital literacy skills, the ability to select and use educational software and equipment. In a pedagogical context, basic technology literacy would allow the teacher to use technology to perform basic teaching functions usually reserved for the blackboard. An example of this would be when a sentence is displayed on the screen and the teacher adjusts the sentence in real time as the lesson progresses.

- *Increase the ability to use these technological skills through teacher professional development to provide teachers with the skills to use more sophisticated technologies*. These competencies reflect pedagogical reasoning by the choice the teacher makes to manage information, integrate open-ended software applications and applying them to life-situations and facilitate collaboration projects during the lesson using technology.

- *Enabling the creation of knowledge using technology*. Teachers collaborating to produce new knowledge using a variety of digital resources and platforms. They would be able to design digital learning resources and use ICT to support knowledge creation and critical thinking in their students. In terms of PCK, the reasoning behind the resource design process would take into account the level of difficulty of the topic, and how to present it in a more agreeable format; the specific aspects of topic content to be emphasised in the resource; the types of representations of content to be included in the lesson and in which sequence.

The UNESCO framework brings the acknowledgement that skills and theory are to be combined for the creation of multimedia lessons; in this case, the skills required are even outside the discipline of science education. The theory of knowledge philosophy has voiced the sentiment that teaching and the design of teaching activities are not a neutral practice but an important practice in developing powerful knowings in the students they teach (Carlgren, 2020). Knowledge

is no longer defined by the rationalist view of propositional knowledge (knowing that) but encompasses a wider view including a practical perspective (knowing how) bringing theory and practice, explicit and tacit knowledge(Polanyi, 1966) together into a more relational view on knowledge. It is with this view of building knowledge that teachers strive to connect their students with the world, enabling growth in their interface with the world around them within the context where the known is functional (Carlgren, 2020). It is within this view of knowledge that teachers build knowing in students with either practice or theory, as needed, but more so at the intersection of the two according to Dewey and Bentley (1960). This view acknowledges the knower and the context in which the knowledge comes to function in some form and as our context is multimedia, it is now possible to bring together digital teaching competence, TSPCK and a theory that can describe the new knower (learner) into the context of multimedia. The UNESCO guidelines do not contribute to the formulation of the new construct's components, rather they set out the levels of sophistication of the use of technology. This is useful in developing a tool to measure best teaching practices speaking to both the transformation aspects and the sophistication of the use of technology, supplying the terminology to grade the quality of teaching practices. Using the above guidelines as a developmental trajectory would enable teachers to develop increasingly sophisticated skills needed to effectively plan, design and teach with technology for the greatest level of understanding by their students.

Frame of reference to evaluate the quality of educational animation

As alluded in the rationale of this study multimedia learning has become the face of education. Teachers are required to apply their TSPCK to develop lessons which will now be administered through technological platforms. At this point the call for educational theory revisions to stay abreast with the infiltration of technology into science classrooms seems more urgent than ever (Gane, 2006). There are best practices for designing educational resources documenting the characteristics of the most effective educational videos and animations (Brame, 2015) but there is a need for a framework in order to develop these animated lessons to reflect the best practices of instructional design.

In summary, merging TSPCK with the UNESCO ICT framework bears the potential to visualise the transformation of content and also providing the ability to work on a digital platform. As this study is topic specific, it means this kind of competence can now be built one topic at a time.

5.3 A gap in the new framework

The merge between TSPCK and the UNESCO ICT framework as a complete theoretical construct was still premature. A gap in relation to TSPCK on a digital platform not adequately covered by the two theoretical constructs and even from their transactional relationships was noted. If the teacher has been empowered to pedagogically transform content on a digital platform with the digital functions as described by the UNESCO ICT framework, the missing factor would be the recognition that the product of transformation would be in a digital output format for the learner. Consideration for the alone learner who received content in a digital form through the digital teaching and learning platforms had to be addressed. In a traditional classroom there has always been the benefit of the teacher and peers present for the learner to engage with on the lesson. However, when the learner is alone with the digital product considerations for the learner must be made explicitly and consciously in acknowledgement of them being alone. The results that we have seen have shown us the components of each construct that are visible, the relationships across the components, but they have not shown us the considerations of the alone learner who now receives content in a digital format through the digital teaching and learning platforms. In order to address this gap, the abovementioned foundations of these results would have to be built upon in order to argue for what the knowledge of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content needs to be able to do. The new construct would be enriched in order to help our teachers develop the competencies to use technology and also consider the learner in appropriate ways for multimedia and still be able to transform content digitally.

The need to incorporate a theory that speaks explicitly to multimedia and what is considered to be a good educational video or multimedia lesson (in this case, an animation) was noted in the learning theories for multimedia. They included aspects of science teacher professional development frameworks that involve the cognitive processes of learning, specifically when ICT tools are implemented in the science class.

Various frameworks have been given much attention since ICT integration has been adopted in classroom situations:

- The Cognitive Theory of Multimedia Learning (Mayer, 2014a)

- Computer-supported collaborative learning environment (Strømme & Furberg, 2015)

- Teacher factors associated with innovative pedagogical use of ICT (Voogt, 2010)

Computer-supported collaborative learning environment (Strømme & Furberg, 2015) was a collaborative student-centered model departing from traditional teaching methods. The teacher facilitates lessons and supports students as they work through computer-based activities. Very little emphasis was placed on the pedagogical aspects of teaching, with the computer and student collaboration taking center stage, raising concerns regarding the gap created when the teacher does not direct student attention or assists learners to make cognitive links they may not make without the teacher (Strømme & Furberg, 2015).

The Cognitive Theory of Multimedia Learning (Mayer, 2014a) best described the path of multimedia stimuli toward meaning making and effective methods of pedagogy and technological applications to achieve greater understanding of content through the effective use of multimedia tools and the design of technology-based lessons. This theory was considered most useful for this study after gathering the literature. The learning theory from a psychological perspective known as the cognitive load theory was adapted for multimedia purposes. (Sweller, 2005, 2011) explained that the cognitive load theory applies the knowledge of human cognitive functioning to create more effective educational episodes (Kirschner et al., 2018). According to the cognitive load theory, any learning experience has 3 components (Brame, 2015):

- Intrinsic cognitive load: the level of complexity and connectivity inherent to the content.

- Germane cognitive load: the level of cognitive activity needed to reach the desired learning outcome.

- Extraneous cognitive load: the cognitive effort applied to information in the lesson that slows down cognitive processing (confusing instructions, extra information).

Effective multimedia lessons would be designed to minimize the extraneous cognitive load and consider the intrinsic cognitive load of the content whilst prompting the limited working memory to accept, process and export information to the long-term memory.

Mayer (2014a) advanced the theory for use in multimedia to describe the best practices in multimedia design that will engage students while guiding them to more meaningful learning. The basic premise of the multimedia principle is that learning occurs with greater intensity when words and pictures are presented together than from words alone (Mayer, 2014a). Multimedia instructional messages refer to communication with students aimed at promoting learning that contain words (printed or spoken) and pictures (static illustrations or dynamic animations or video clips) (Mayer et al., 2001). Mayer (2014a) did however point out that the act of simply adding pictures to words had no guarantee for effective learning, a link was needed to the mechanisms of the working of the mind.

The cognitive theory of multimedia learning identifies three memory stores in the mind as shown in figure 5.1.

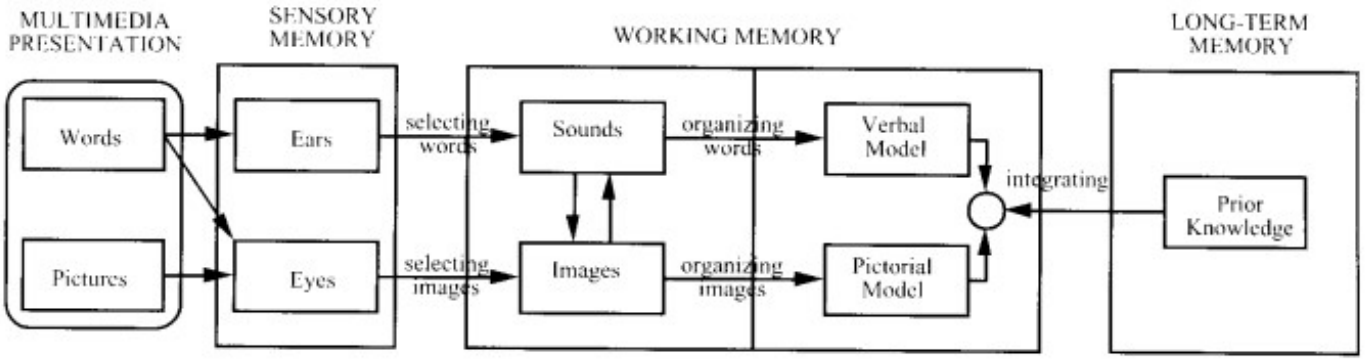


Figure 5.1. Cognitive theory of multimedia learning (Mayer, 2014a).

The first memory store is sensory memory where words, pictures and sounds are briefly held. The second memory store, the working memory consciously manipulates knowledge from the sensory memory to create links between the images and sounds received during a presentation which has a very limited capacity (Johnstone, 1988). The third memory store, long-term memory, links prior knowledge to the knowledge in the working memory. Long-term memory is the only memory store capable of holding a vast amount of knowledge for a long time, but the knowledge must be brought into the working memory for a student to actively think about it.

Mayer (2014a) identified five cognitive processes to form meaningful learning across the three memory stores which integrate the verbal and pictorial representations with each other and prior knowledge but do not necessarily occur in the same linear order:

- Selecting relevant words for processing in verbal working memory.
- Selecting relevant images for processing in visual working memory.
- Organizing selected words into a verbal model.
- Organizing selected images into a selected pictorial model.

Mayer (2014a) noted that the cognitive processes that enable learning were guided by three cognitive science principles.

The dual channel information processing system (audio/verbal and visual/ pictorial). Sensory information is processed in the channel it was presented. Audio presentations will therefore be processed through the ears and visual presentations through the eyes unless the presentation includes on-screen printed words. These words are received through the eyes but processed verbally. Students have the ability to convert information between the verbal and visual channel as they process information in the working memory where sounds can be perceived as images and vice versa.

Each channel has limited capacity for processing. The average working memory span ranges from 5 to 7 images or words or segments at a given time. Fortunately, it is possible to increase the average memory span by placing multiples of information into each segment which will enhance the capacity of the working memory. When applying this principle from a PCK perspective, the teacher could plan to group carefully selected key words or concepts together in order to present more information to the students in a shorter space of time with the knowledge that the information would most likely be retained.

Active learning involves carrying out a coordinated set of cognitive processes during learning. Cognitive load theory makes the assumption that humans actively engage in cognitive processing to construct new knowledge.

The pedagogical implication of this principle would be that teachers would plan lessons with a coherent structure. The presented material should guide concept building in the working memory and activate knowledge in the long-term memory. Conceptual teaching strategies which engaging the students actively in the lesson could encourage link-building between concepts and memory stores.

How then can we reap the benefits of new educational technologies such as multimedia learning environments? A reasonable solution is to design multimedia lessons that are grounded in research-based theory to apply the following best-practice principles adapted from Moreno and Mayer (1999):

- Present explanations using two modes (visual and auditory) as it is more effective than using one at a time.

- Links can only be made between presented words and pictures if they are in the working memory at the same time.

- Explanations should present words as auditory narrations rather than visual text.

- Individual learner differences in amount of prior knowledge needs to be taken into account when designing lessons.

- Explanations should use few rather than many superfluous words and pictures.

- Coherent summaries of content are processed in the working memory more easily that a long explanation.

- Place on-screen text near rather than far from the corresponding portion of the graphic, minimising extraneous processing. In contrast, when a few keywords are printed next to the corresponding portion of the diagram, learners may be better able to engage in essential cognitive processing (such as selecting relevant words and images) that results in improved performance on subsequent tests.

- The motion in an animation may help direct the learner's attention to the relevant portion of the graphic.

The benefit to be derived from the CTML principles is a balance of the cognitive loads experienced by the learner whose mind is assimilating the content. Armed with this preliminary argument, the next process would be to continue the development of construct components to include the CTML aspects of multimedia learning. Table 5.1.

Table 5.1 Consolidated CTML principles

Visible Knowledge Component	Description	Source
Segmenting	Breaking the topic lesson into segments no longer than 3-4 minute segments Coherent summaries of content are processed in the working memory more easily that a long explanation.	(Sorden, 2012), Mayer & Mayer, 2005; Mayer, 2014; Mayer et al., 2001; Mayer & Johnson, 2008; Mayer & Moreno, 1998, 2003), (Jiang et al., 2017), (Cavanagh & Kiersch, 2023), (Greer et al., 2013)
Signalling	The motion in an animation, colour change, sounds, text or imagery, may help direct the learner's attention to the relevant portion of the graphic	(Sorden, 2012), Mayer & Mayer, 2005; Mayer, 2014; Mayer et al., 2001; Mayer & Johnson, 2008; Mayer & Moreno, 1998, 2003), (Ibrahim, 2012), (Jiang et al., 2017), (Cavanagh & Kiersch, 2023), (Greer et al., 2013)
Weeding	Explanations should use few rather than many superfluous words and pictures. Place on-screen text near rather than far from the corresponding portion of the graphic, minimising extraneous processing. In contrast, when a few keywords are printed next to the corresponding portion of the diagram, learners may be better able to engage in essential cognitive processing (such as selecting relevant words and images) that results in improved performance on subsequent tests.	(Sorden, 2012), Mayer & Mayer, 2005; Mayer, 2014; Mayer et al., 2001; Mayer & Johnson, 2008; Mayer & Moreno, 1998, 2003), (Ibrahim, 2012), (Jiang et al., 2017), (Cavanagh & Kiersch, 2023), (Greer et al., 2013)

Matching modality	Selecting relevant words for processing in verbal working memory. Present explanations using two modes (visual and auditory) as it is more effective than using one at a time. Explanations should present words as auditory narrations rather than visual text	(Sorden, 2012), (Mayer & Mayer, 2005; Mayer, 2014a, 2014b; Mayer et al., 2001; Mayer & Johnson, 2008; Mayer & Moreno, 1998, 2003), (Ibrahim, 2012), (Jiang et al., 2017), (Cavanagh & Kiersch, 2023), (Greer et al., 2013)
Content control	Students have the ability to control the time they can spend on a specific topic or segment. Individual learner differences in amount of prior knowledge needs to be taken into account when designing lessons.	(Cavanagh & Kiersch, 2023)

Table 5.1 presents a list of studies on the description of principles to be taken into account when transforming content into a digital format in a way that allows for greater conceptual understanding and lowering the cognitive load of the student (Mayer & Mayer, 2005). Five pedagogical principles emerged commonly across the studies based on CTML. These are Segmenting, Signalling, Weeding, Matching modality and Content control. Segmenting recommends that only small quantities of content be delivered to students at a time, lowering the cognitive load on them whereas signalling draws students' attention to specific parts of the content for enhanced memory of the content. Weeding limits the amount of non-useful information projected with the content to lower the extraneous cognitive load experienced during the learning process. Matching modality as a principle would link visual and audio stimuli in order to enhance the cognitive acceptance value of the presented content. The overall emerging aspect from the studies on CTML, is the complementary nature of the CTML principles among themselves, while each brings an inherently unique consideration.

5.4 Merging TSPCK, UNESCO ICT and CTML

In education there is a need to support the development of science teachers as society depends more upon the use of technology to prepare and teach lessons. With the merging of the three theoretical frameworks, new kind of teacher professional knowledge for enabling digital

pedagogical transformation of content would come into existence. Their interacting components aimed at a common goal of creating digital lessons require a more formal encapsulation of the framework interactions in the form of a new theory of knowledge (Deng, 2018). It would be a comprehensive, robust framework for science teacher development in creating pedagogically reasoned digital content. That need leads to a construct that that allows for pedagogical transformation of content through the use of technology and the research question therefore asks,

"What would teacher professional knowledge for effectively teaching a science topic digitally entail?" This question is explored through these sub-questions:

1. How could teacher professional knowledge for pedagogical transformation of content in the digital realm of teaching and learning be conceptualized?

2. How does the conceptualized teacher knowledge manifest in the planning and the teaching of electromagnetism digitally, when animation teaching videos are used as a format for a digital output?

The new construct of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content embodies the pedagogical transformation of content through the implementation of technology and technological processes to teach science lessons. However, this is not a comprehensive definition of the construct, which has visible as well as tacit aspects. It is important to take into account all the factors that explain the features of the construct and the affordances offered to the science classroom.

The formulation of a new kind of teacher professional knowledge for enabling digital pedagogical transformation of content construct consists of the foundational framework of TSPCK enriched by the teacher digital competencies guided by the UNESCO ICT framework and CTML principles. This new teacher professional knowledge, termed digital-TSPCK is shown in Figure 5.2 below.

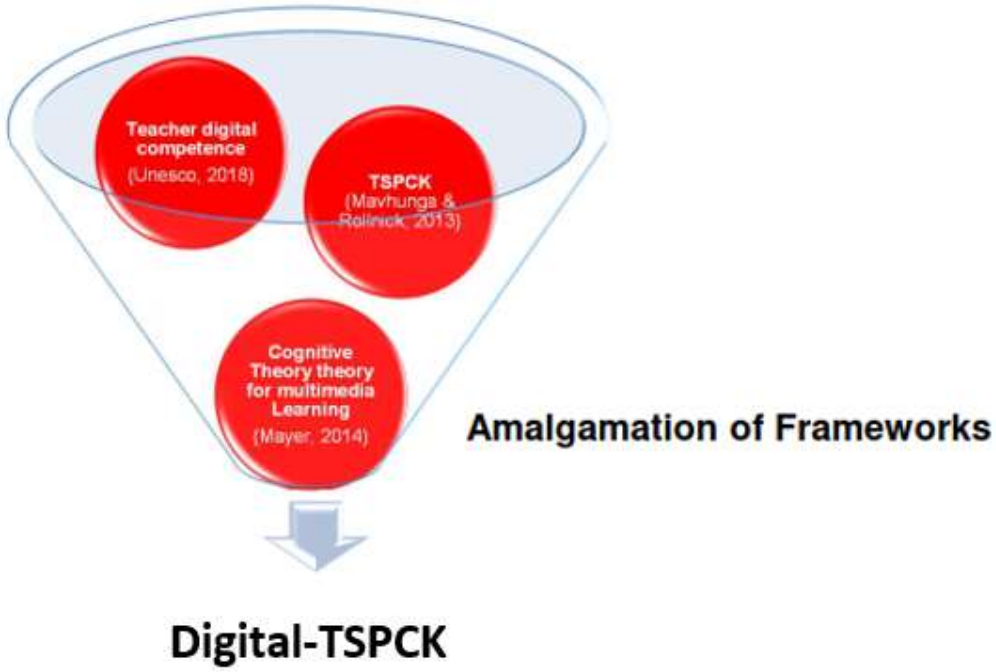


Figure 5.2. Representation of the formulation of the digital-TSPCK model.

The funnel in Figure 5.2 represents the amalgamation of the contributing theoretical frameworks used to form the new construct which, when acting together, strengthen the transformed content that learners receive on a digital platform.

The mechanism of the functioning of digital-TSPCK to pedagogically transform content knowledge input into a digital format lesson output as seen in Figure 5.3.

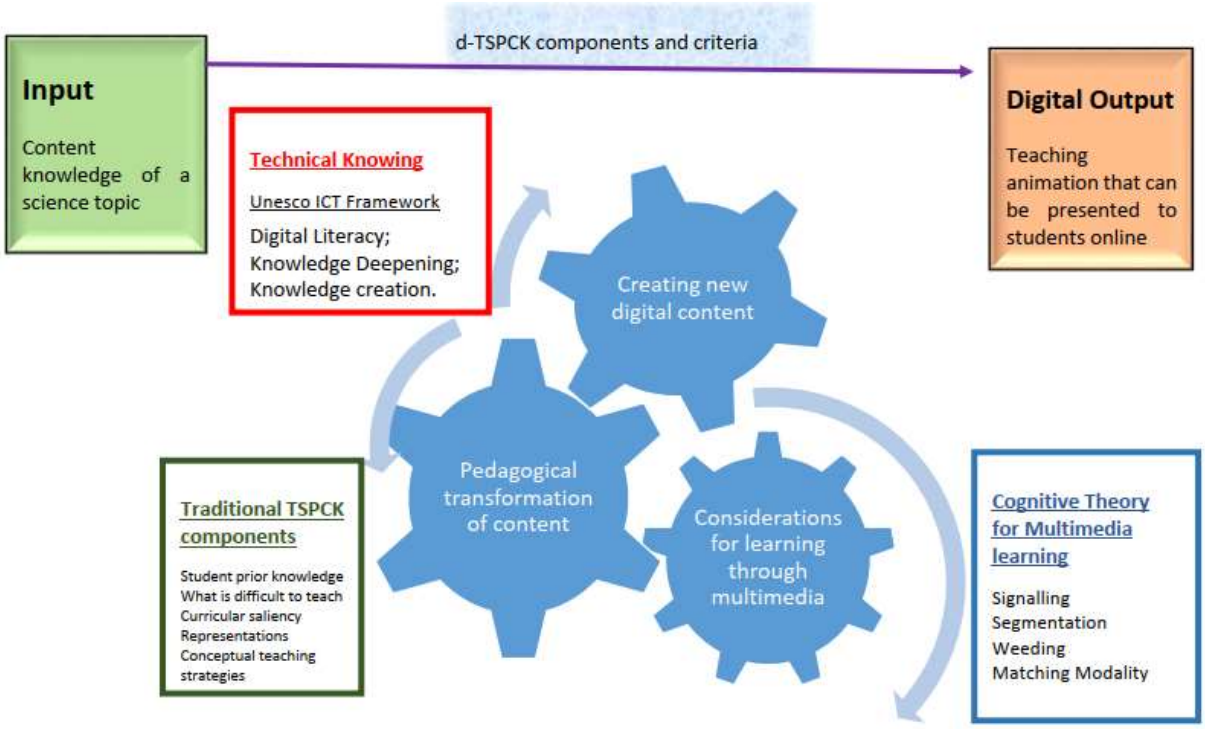


Figure 5.3. The mechanism of content transformation by digital-TSPCK

The purpose of designing a digital lesson starts with the transformation of the input of content knowledge of the science topic to be taught that ends with a digital output of, as in this study, a teaching animation that is presentable to students online. The mechanism of digital-TSPCK lies in the transformation that occurs between the content input and animated output by the teacher as a designer with the pedagogical and technological skills to effect the content transformation. The complexity of the construct lies in the transactional relationship interactions of the components of the merging constructs to give the teacher this transformation skill to manipulate the content into a digital format that not only addresses the pedagogical aspects of a lesson but takes into account the cognitive science principles of learning. The merging of TSPCK and the UNESCO ICT framework made the pedagogical transformation of the content visual on a digital platform. Thereafter the focus shifts from technology to the visualization of the pedagogical transformation. It is seen that the CTML principles need to guide the actual presentation of the scenes presented by addressing the cognitive load delivered in each of the scenes with reference to the learner.

The process of defining what digital-TSPCK is has led to the development of the following descriptive features of the construct:

- Digital-TSPCK leads to a digital product.

- Digital-TSPCK is associated with lessons that are digital, digital outputs.

- Cannot say digital-TSPCK exists in a traditional lesson due to the 'digital' component.

- Digital-TSPCK is seen in digital lessons, associated with digital lesson outputs/formats (evolution from traditional teaching).

- It is not the use of technology in the traditional classroom, it encompasses the use of technology in building of the lesson but specifically for purposes of a digital lesson output/product.

- It involves transformation of content knowledge.

- Learner considerations are done in at least 2 ways: one through the pedagogical transformation process and another through the cognitive load considerations.

- It does require the skill of developing the digital format, whatever it is.

- There are aspects that are tacit and aspects that are visible. The tacit aspects would be the pedagogical transformation, digital skill that you need to develop the digital format and the considerations for cognitive load.

  The pictorial amalgamation of the three theoretical frameworks to form digital-TSPCK is shown in Figure 5.4

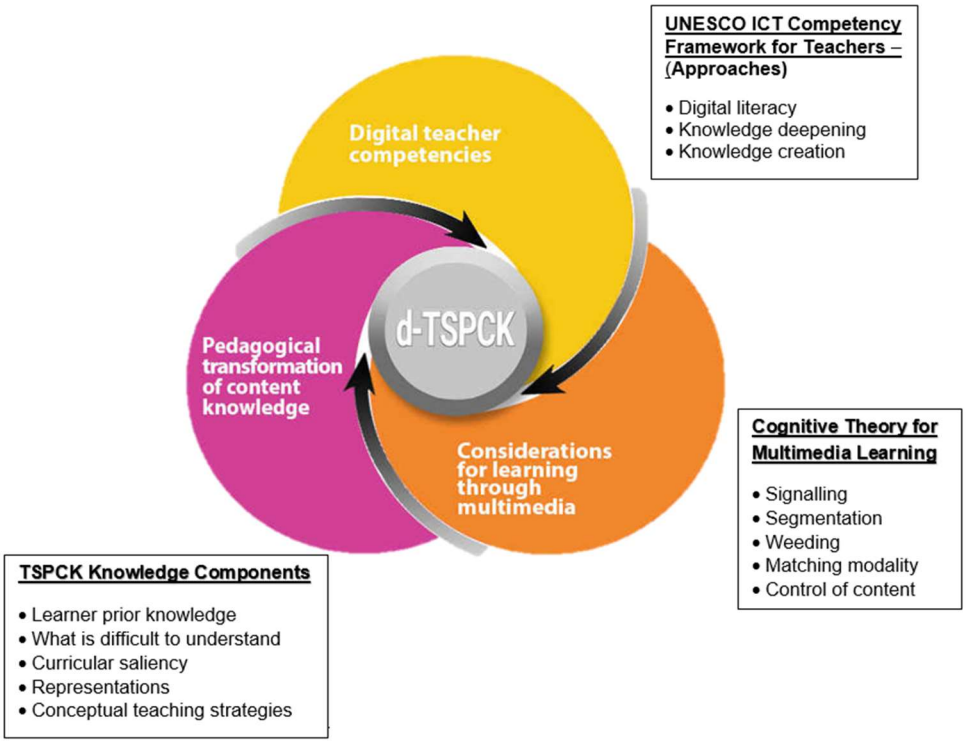


Figure 5.4 An illustrative model of digital-TSPCK

In Figure 5.4 each of the contributing theoretical frameworks are brought together at a central point of merging to work together to form digital-TSPCK. Each framework contributes specific elements toward digital-TSPCK to reach the output of pedagogically transformed content as a digital product with consideration of the cognitive considerations of the student who is expected to understand the presented content outside of a traditional classroom. TSPCK contributes pedagogical transformation of the content through the planned interactions of its components (Mavhunga & Rollnick, 2013). The teacher evaluates the content based on what the student would have learnt in previous grades, together with what could be difficult concepts to understand (or misconceptions) and decides how to represent it as a lesson, incorporating conceptual teaching strategies to assist in the understanding of the content. The UNESCO ICT teacher competency framework (UNESCO, 2011) makes the TSPCK component interactions digitally visible. The creation of transformed content requires the teacher to have digital knowledge and skills. The UNESCO framework describes three levels of digital knowledge required by the content creator. Firstly the teacher requires basic digital competence in order to use the digital technology. Secondly knowledge deepening affords the teacher the ability to solve problems, choice of

technology, and the competency to make modifications to the digital content collected for the lesson (UNESCO, 2011). Finally the highest order of digital competence, knowledge creation links directly with TSPCK as the teacher is digitally enabled to transform and create the content into a digital product. The third contributing framework, CTML principles guide and format the transformation of the content to control the cognitive load experienced by the student. Techniques of signalling, weeding, content control, segmenting and matching modality are applied to the digitally visual content as students have a limited capacity for learning, known as a cognitive load (Mayer, 2005). Teachers can control the cognitive load using digital competency skills when pedagogically transforming the content. The three frameworks each serve a function in digital-TSPCK but all three interact with each other in order to create the final product of a digital lesson to be given to a student to learn from outside a traditional classroom setting.

Digital-TSPCK is associated with lessons that are in digital format and leads to a digital product with online applications. Evidence of digital-TSPCK is visible in digital lessons and not only constitutes the use of technology in the classroom but also the use of technology in building the lesson specifically for making a digital product requiring teachers to possess the skill of developing digital products. Digital-TSPCK involves the tacit aspects of transformation of content knowledge that promotes effective cognition of the content as it is presented to learners on a digital platform by acknowledging learner considerations in terms of pedagogical processes and cognitive load.

It is postulated that digital-TSPCK defines the kind of teacher knowledge that enables pedagogical transformation of abstract content knowledge that is packaged in a digital format such as videos, animations etc. for a smooth learning experience by learners over digital platforms. This is far different from the mere integration of technology of some kind into a traditional lesson. Digital-TSPCK can therefore be defined as the teacher knowledge needed to digitally create science content that has been pedagogically transformed for learner understanding to be accessed through online teaching and learning platforms.

In order to establish digital-TSPCK as a theoretical construct, Kane's process of validation will be followed by using an intervention to teach digital-TSPCK to practising Physical Sciences teachers in their own creation of a teaching animation as described in Chapter 6.

Chapter 6

6: Developing the intervention for teaching electromagnetism using digital-TSPCK

The central theme of this study is the transformation of content knowledge on a digital platform. The link to PCK and TSPCK has been discussed in the theoretical framework of Chapter 2. Chapter 5 defined a new construct to pedagogically transform content knowledge on a digital platform. The literature meta-synthesis amalgamated three constructs of TSPCK, ICT framework and CTML as the first part of the study to describe the new teacher knowledge to teach on a digital platform. The second part of the study involves an intervention with practicing physical science teachers to design and create their own teaching animations. In this chapter, a description of the development of a digital intervention program will be made for practicing Physical science teachers to create animation videos incorporating digital-TSPCK components.

6.1 The intervention: A case study

The intervention was located in the Gauteng area of practicing physical sciences educators who have been using technology to teach. As the focus chapter of electromagnetism takes place in the third term of the Grade 11 syllabus, the intervention took place in the second term to empower educators to create their animation videos in preparation of using the videos in their actual teaching time with their learners.

The intervention took a two-pronged approach:

- Familiarizing the educators with the digital-TSPCK framework and its components.
- Teaching the technical skills of creating their own teaching animation.

Due consideration was given to the limited time teachers have to attend intervention programs and the time it would take to acquire the skills necessary to create the animation videos. The schedule for the intervention program is shown in Table 6.1.

Table 6.1. Digital-TSPCK intervention schedule and time frame

Intervention Phase	Description	Time frame
Planning	Introduction to digital-TSPCK using the CoRe Storyboard	4 hrs spread over 2 weeks
Animation creation	Implementing planned lessons using the Animaker software	8 hrs spread over 4 weeks
Video editing	Finalizing the animation using the Hitfilm Express software	4 hrs spread over 2 weeks

Practicing educators were assumed to have the required content knowledge needed to teach their subject, therefore the intervention did not include teaching the topic of electromagnetism. The intervention program aimed to teach educators the technical skills required to create animation videos as they needed the skills to create a pedagogically reasoned digital lesson, thereby incorporating the digital-TSPCK components as they learnt the technical skills.

6.2 Planning the creation of the animation

The TSPCK framework was used to design an intervention for pre-service educators to teach Electromagnetism by Coetzee (2018) in the form of a CoRe (Loughran et al., 2004; Nilsson & Loughran, 2012) to present the teacher knowledge about the topic and incorporate the components of TSPCK. This CoRe was adapted for this study in order to show the format of the intervention from a traditional TSPCK perspective in order to convert that lesson plan into a digital-TSPCK based format. Below in Table 6.2, is the adapted lesson plan from Coetzee (2018) displaying the Big Ideas identified that underpin the understanding of the topic of electromagnetism and how the TSPCK components should be addressed in a traditional classroom setting.

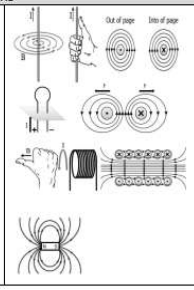
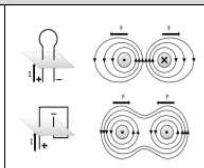
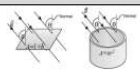
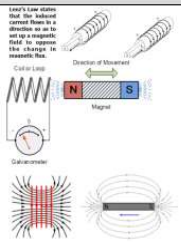
Table 6.2: Lesson plan for electromagnetism displaying traditional TSPCK adapted from the lesson plan CoRe by Coetzee (2018)

TSPCK components	Big idea 1	Bid idea 2	Big idea 3	Big idea 4
	There is a magnetic field around a current-carrying conductor	A current-carrying conductor experiences a force in a magnetic field	Magnetic flux and the change in magnetic flux	Electromagnetic induction-Faraday's law
A. Curricular Saliency				
A1. What do you intend the learners to know about this idea?	• When current passes through a conductor, a magnetic field is induced around the conductor. • The strength of the magnetic field decreases as the distance from the wire increases. • The direction of the magnetic field can be determined by using the right-hand rule. • For a wire loop the magnetic field is the sum of the individual magnetic fields around the single wires at each end. • For a solenoid (coil of loops) the magnetic field is the sum of the individual magnetic fields around the single wires and the right hand solenoid rule shows the direction of the resultant magnetic field.	• Moving charges experience a force in a magnetic field. • If the moving charges are in a wire, the wire will experience a force. • This is as a result of two interacting magnetic fields (current-carrying wire generates a magnetic field and the magnetic field of the magnet)	• Magnetic flux is the result of the product of the perpendicular component of the magnetic field and the cross-sectional area the field lines pass through. • Ø=BAcosϴ • Magnetic flux linkage is the product of the number of turns on the coil and the flux through the coil.	• When a magnet is brought close to a metal wire, it causes movement of charge in the wire, and vice versa. • Mechanical energy is converted to electrical energy. • The direction of the induced current can be determined using Lenz's law • Lenz's law states that the induced current flows in a direction so as to set up a magnetic field to oppose the change in the magnetic flux. • EMF is induced in the wire • Only a change in magnetic flux will induce a current • Faraday's law states that the emf induced is directly proportional to the rate of change of magnetic flux (flux linkage)

				• $\varepsilon = \frac{-N\Delta\emptyset}{\Delta t}$ • the induced emf can be increased by: increase the rate of change of magnetic flux(increase speed of movement) increased number of loops in the coil increase the change of flux by changing the angle Θ from a minimum of 0° to a maximum of 90°
A2. Why is it important for learners to know this?	• To be able to interpret and apply Lenz's law for determining the direction of the induced current. • To understand why a current-carrying conductor will experience a force in a magnetic field (gr12 motors)	• To explain why a current-carrying coil would move when placed in a magnetic field once the current is switched on.	• Understanding the concept of magnetic flux as the way magnets interact with the conductor • The rate of change of magnetic flux is an important concept for Faraday's Law.	• The concept has a practical application in the principle on which the generator operates in the grade 12 curriculum. • To understand how AC current and DC currents are generated. • To understand the way transformers work.
A3. What concepts need to be taught before teaching this idea?	• Magnetic fields are created by moving charges (every spinning electron is a tiny magnet) (Gr10-domains in ferromagnetic materials) • The direction and shape of a magnetic field around a permanent magnet (Gr8)	• The concept of forces (attractive and repulsive) • Interaction between different magnetic fields of a magnet (N-N and N-S)	• Magnetic field and magnetic field lines. • The vector (A) is perpendicular to a surface and indicates the magnitude of	• Magnetic field lines are imaginary lines that help one to visualize the direction and strength of the magnetic field. • Mechanical energy and electrical energy. • Magnetic flux.
	• Magnetic field lines are imaginary, used to visualise the direction and strength of a magnetic field. • A compass needle is a magnet. • The effect of a magnetic field on a compass needle.		the area of the surface and the orientation of the surface.	• The concept of current and EMF.
A4. What else do you know about this idea (that you do not intend learners to know yet?)	• Moving charges experience a force in a magnetic field. • If the moving charges are in a wire, the wire will experience a force. • This is as a result of two interacting magnetic fields (current-carrying wire generates a magnetic field and the magnetic field of the magnet)	• Functioning of an electric motor with the rotation of the coil in the magnetic field.	• How the rate of change in magnetic flux relates to the magnitude of the induced EMF.	Applications of Faraday's Law and Lenz's Law in transformers and generators.
B. What is difficult to teach or understand?				
B1. What do you consider difficult about teaching this idea?	• Imaginary field lines is a very abstract concept to grasp. • Learners have difficulty understanding how magnetic fields around conductors strengthen/cancel each other in different circumstances.	• Cables rolled up, experiencing a force when switched on, this is not visible to learners.	• Learners have no experience/prior knowledge about the idea of magnetic flux. • How can a surface area be described by a vector? • Learners' ability to visualize the vectors and angles in 3-D is limited, hence	• Abstract concepts because magnetic field lines cannot be seen. • Induction is a new concept, time is needed for the learners to grasp. • Learners struggle to identify the angles required for the calculations-(the perpendicular component of the magnetic field and the cross-sectional area

			the inability to understand the relevance of, or to determine the angles between the magnetic field and the area vector.	the field lines pass through)
C. Learner Prior knowledge (misconceptions)				
C1. What are typical misconceptions when teaching this idea?	• Magnetic poles are charged (confusion between electric and magnetic fields)-learners then believe that magnetic poles exert forces on charges whether the charges are moving or not. • The magnetic field around a straight conductor has a north and south pole. • Magnetic field lines indicate the "flow" or "movement" of the magnetic field.	• Misconceptions about how a current-carrying conductor in a magnetic field experiences a force as a result of an interaction between the magnetic field of the conductor and the external magnetic field. Learners might see it as charge-carriers in the wire experiencing the force.	• Distinguishing between changes in magnetic flux as opposed to the existence of flux. • Magnetic flux seen as the "flow of magnetic field" • Magnetic flux is an actual physical quantity even though magnetic field lines are just an imaginary pictorial aid to understand magnetic field.	• Current will be induced even if the magnet is stationery on the solenoid. • Learners confuse the presence of magnetic field lines with the change in magnetic flux (how does the change come about?)
D. Conceptual teaching strategies				
D1. What teaching strategies would you use to teach this big idea?	• Demonstrations/experiments to show the magnetic field around the current-carrying conductor. • Question and answer sessions to describe and explain observations.	• Demonstration with explanation, simulation of how a current-carrying conductor moves when placed in a magnetic field. Note to be made that the placement of components are made with current switched off, then switch on the current and see the conductor move, alternatively, move the magnet. • Prediction of outcome by learners with discussion, then Questions and answers to formalize the concept. • Make reference to resultant magnetic fields of different poles near each other.	• Demonstration with explanation, simulation showing the magnetic field lines, how to determine the flux and change in flux. • Prediction of outcome by learners with discussion, then Questions and answers to formalize the concept.	Demonstration and simulations of connecting a coil to a galvanometer. Draw learners' attention to the fact that there is no source of emf in the circuit. Emphasise that the current is only detected when the magnet is moving/coil is moving. The direction of the current changes as the direction of motion is reversed.
D2. What questions would you consider important to ask in your teaching strategy?	• How can you prove the existence of a magnetic field? • How can a compass needle indicate the direction of a magnetic field?	• Do you think magnetic fields exert forces on each other? • Name 2 types of forces you could identify in this situation (attractive/repulsive) • Why do they attract/repel? • How would we note these forces acting on	Before suggesting ways to change the magnetic flux, ask learners to think of ways in which the magnetic flux can be changed. When rotating the loop, changing its orientation relative to the flux, ask: • When is ø = 0? • When is ø = max/min?	• When connecting the coil to the galvanometer ask: What is the function of the galvanometer? • What happens when the magnet moves relative to the coil? • How is it possible for the magnet to interact with the conductor without touching it?

			• Magnetic field lines indicate the "flow" or "movement" of the magnetic field. Do not incorporate movement in the arrows of the magnetic field lines, make them as translucent as possible to maintain the imaginary nature of the field line
What concepts need to be in place for learners to engage with this video?	• Magnetic fields are created by moving charges (every spinning electron is a tiny magnet) • The direction and shape of a magnetic field around a permanent magnet • Magnetic field lines are imaginary, used to visualise the direction and strength of a magnetic field. • A compass needle is a magnet. • The effect of a magnetic field on a compass needle.	**What other factors may influence your teaching of this idea when making this video?**	Using different levels of representations Attempting to make representations as 3-D as possible. Laying verbal and visual cues near the abstract concepts on the screen to assist with understanding.
What else do you know about this Big Idea that you do not want to include in this video, and why.	• Moving charges experience a force in a magnetic field. • If the moving charges are in a wire, the wire will experience a force. This is as a result of two interacting magnetic fields (current-carrying wire generates a magnetic field and the magnetic field of the magnet). It is a follow-up concept in this video series that will be elaborated on later.	**What do you consider easy or difficult to understand about teaching this Big Idea that inspired you to make this video?**	• Imaginary field lines is a very abstract concept to grasp. Animations can represent translucent phenomena in a way that learners know they are there but are "unseen" • Learners have difficulty understanding how magnetic fields around conductors strengthen/cancel each other in different circumstances. Animation can show how the lines are compresses or spread out depending on the nature of the interactions of the magnetic fields, resulting in attraction of repulsion forces existing.
What representations are you going to use in this video for teaching the Big Idea? **Provide a list of the representations (including digital resources) you envisage to use and also describe how they are to be used in each case.**			
	Video can be created of a Phet simulation, edit in the arrows, labels and sound track. https://www.youtube.com/watch?v=Z927bDX1I04 https://www.youtube.com/watch?v=9p3t9NOfCtA	Representation of the magnetic field around a straight current-carrying conductor. Conductor could show moving charges as the current flows, but magnetic field lines to remain static and translucent. Later add some compasses around the conductor to validate the field lines. Try to phase	

		a wire in a magnetic field?	• When is the rate of change of flux a max/min?	• Which energy conversion is taking place in this situation?	
E. Representations					E. Representations
E1. What representations would you use in your teaching strategy?				 Simulations to be shown	E1. What representations would you use in your teaching strategy? 

As shown in Table 6.2, Four Big Ideas or key concepts were identified and reasoned through the lens of each TSPCK component to create the lesson for Electromagnetism as listed below:

- There is a magnetic field around a current-carrying conductor
- A current-carrying conductor experiences a force in a magnetic field
- Magnetic flux and the change in magnetic flux

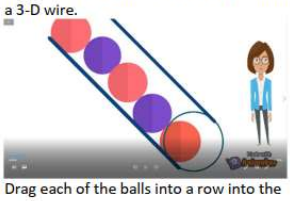
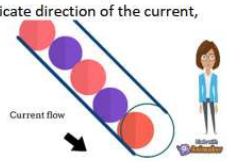
- Electromagnetic induction- Faraday's law

For each of these big ideas, TSPCK components, namely curricular saliency, learner prior knowledge, what is difficult to teach, representations and conceptual teaching strategies, were applied in order to interact for the presentation of a well-reasoned pedagogically sound lesson segment or episode. In order to transform a lesson from a traditional classroom setting onto a digital platform, the lesson plan was adjusted to incorporate the technical skills as well as the mode of learning and memory formation. This lesson plan acted as a foundation from which the lesson would be converted into an animation, requiring each big idea to be broken down into scenes which had pre-planned cognitive cues based on learning through multimedia and how best to represent the content knowledge itself. Table 6.3 is an example of the lesson plan of the Grade 11 Electromagnetism topic used to create the animations for the intervention, referred to as a CoRe storyboard, the template was designed by the WITS TSPCK research team.

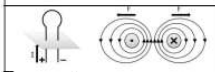
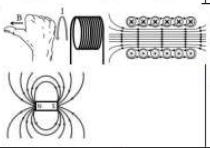
Table 6.3: CoRe storyboard for Grade 11 Electromagnetism displaying digital-TSPCK.

Title/Topic: Electromagnetism Grade 11			
Single Big Idea in the animation video:		**There is a magnetic field around a current-carrying conductor**	
What do you intend learners to learn about this Big Idea from the video?	• When current passes through a conductor, a magnetic field is induced around the conductor. • The strength of the magnetic field decreases as the distance from the wire increases. • The direction of the magnetic field can be determined by using the right-hand rule. • For a wire loop the magnetic field is the sum of the individual magnetic fields around the single wires at each end. • For a solenoid (coil of loops) the magnetic field is the sum of the individual magnetic fields around the single wires and the right hand solenoid rule shows the direction of the resultant magnetic field.	**What do you consider to be most important to be learnt in this Big Idea?**	The existence and shape of magnetic fields around current-carrying conductors
Why is it important for learners to know this and how did this inform your rationale in making the video?	• To be able to interpret and apply Lenz's law for determining the direction of the induced current. Therefore emphasis must be placed on showing direction in as many ways possible • To understand why a current-carrying conductor will experience a force in a magnetic field (gr12 motors). Therefore there should be indications of areas around conductors where magnetic fields interact.	**Describe the typical learner misconceptions about this Big Idea. How will you address them in this video?**	• Magnetic poles are charged (confusion between electric and magnetic fields)- learners then believe that magnetic poles exert forces on charges whether the charges are moving or not. Show readings increase in sync to increased movement between magnet and coil, show zero reading when items are stationery-this can be verbalised to draw attention to this concept. • The magnetic field around a straight conductor has a north and south poles. Show as a continuous circle around the conductor, explain that there is no poles at the ends of the magnetic fields of the solenoid.

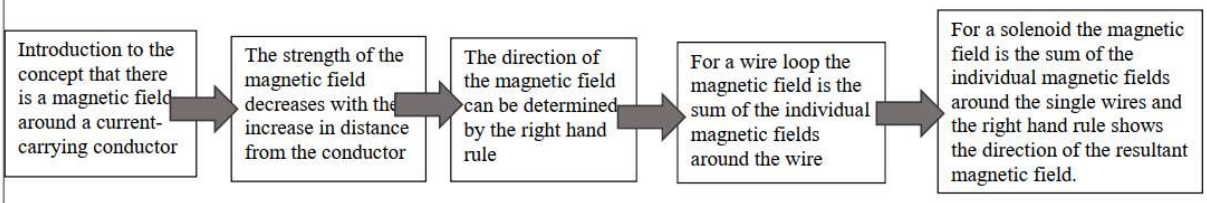
When you create the animation, what considerations will you take into account?	Soundtrack must be recorded in a very quiet place to eliminate possible background interference. Select magnets of the same colour so that the animation sequence has continuity in presentation and does not confuse the learners. Create pause time within the segment for learners to assimilate what they have seen and heard.
When you edit your video, what considerations will you take into account?	Soundtrack and imaging must be perfectly synchronised. Script to avoid word/Phrases like: magnetic field moves /flows from north to south. Do not make reference to magnetic poles for the magnetic field around conductors. Do not show any physical movement of the magnetic field, ty not to let the arrows of the field move-rather fade in and out. Ensure that animation segments are edited together into a seamless stream. Do not clutter the screen with too many add-ins at a time, let them fade out if new ones are to be introduced.

Animation video creation		
Video shot 1	Video shot 2	Video shot 3
Current carrying conductor	Current-carrying coil	Solenoid
Description: the animation will start by showing a straight conductor. The wire will be shown to carry current with moving charges in the wire. The magnetic field will appear around the conductor, a hand will appear and indicate the direction of the magentic field.	Description: the current-carrying coil will be shown, and the magnetic field will appear. Focus on the shot of two interacting fields from conductors and the force they exert on each other.	Description-the soleniod will be shown together with a representation of the magnetic field that forms, a right hand will also show the direction of the magentic field, arrows to point to the field from the hand
Script: When current passes through a conductor, a magnetic field is induced around the conductor because each charge. The strength of the magnetic field decreases as the distance from the conductor increases. The direction of the magnetic field can be determined by using the right-hand rule. The thumb of your right hand points the direction of the current, and the curling of the rest of the fingers points the direction of the magnetic field around the conductor.	Script: if we bend the conductor to make a loop, and we draw a line across the loop to investigate the magnetic field for both parts of the loop, we see that the magnetic field is the sum of the two individual magnetic fields around each part of the wire. The magnetic field lines for each wire point in the same direction between the two conductor sections, strengthening the magnetic field because there are more field lines in that area.	Script: when we make a coil of loops of the conductor, we call it a solenoid. Here we see that the magnetic field is the sum of the magnetic fields and forms a field similar to that of a bar magnet.
Technical notes when using Animaker to create	**Technical notes when using Animaker to create**	**Technical notes when using Animaker to create**
1. Click on new project 2. Select a character to be on the screen 3. Click on character, then choose actions of the character.	1. 1.Click on new project 2. Select a character to be on the screen 3. Click on character, then choose actions of the character.	Animaker was not used for this section, Phet simulation was the software and other images downloaded from internet. Only editing will take place for this segment.
4. Click on Properties, choose/search for shape-ball/sphere. 5. Choose colour and click on pane to make it smaller. Right click on the object, copy and paste until there are enough balls to make a set of charged particel in a wire. 6. Click on images, choose straight line,-choose it again to make the outline of the wire. 7. Right click on wire line and send it back so that it does not block the ball images. 8. Click on images, choose circle. Move it between the two lines of the wire to make it a 3-D wire.  9. Drag each of the balls into a row into the wire. 10. Go to the scene pane and click on duplicate slide so that the next slide looks identical except for the parts you will move. 11. From the third image insert text and arrow to indicate direction of the current, 	4. Click on Properties, choose/search for shape-ball/sphere. 5. Choose colour and click on pane to make it smaller. Right click on the object, copy and paste until there are enough balls to make a set of charged particel in a wire. 6. Click on images, choose curved line,-choose it again to make the outline of the wire. 7. Right click on wire line and send it back so that it does not block the ball images. 8. Click on images, choose circle. Move it between the two lines of the wire to make it a 3-D wire on each side. 9. Drag each of the balls into a loop into the wire. 10. Go to the scene pane and click on duplicate slide so that the next slide looks identical except for the parts you will move. 11. Move the balls downward one by one 12. Click on scene duplicate and continue to duplicate and move balls for at least 12 frames. 13. For each scene on the timeline, click on the scene block and drag it to shorten the frame. Each frame should be max 1 second. 14. Then press publish, animaker will render the animation and send it via email to save on PC. Save it in a file for importing to Hitfilm later.	

12. Move the balls downward one by one 13. Click on scene duplicate and continue to duplicate and move balls for at least 12 frames.  14. For each scene on the timeline, click on the scene block and drag it to shorten the frame. Each frame should be max 1 second. 15. Then press publish, animaker will render the animation and send it via email to save on PC. Save it in a file for importing to Hitfilm later.		
Technical notes when using Hitfilm express to edit	**Technical notes when using hitfilm express to edit**	**Technical notes when using hitfilm express to edit**
1. Select animaker file to import to the timeline. 2. Type topic Electromagnetism Grade 11 on the viewer using text option (Choose colour white with a dark background), enlarge and center it from the controls panel). 3. On the viewer type Magnetic field around a current-carrying conductor in bold using control panel to make it bold. 4. Do a voice over (of the planned script.) from the file option 5. Add arrows for the direction of the current and magnetic field. Fade them in and out according to the mention in the script. 6. Do a voice over including –magnetic field lines are imaginary, do not move and decrease in strength as the distance from the conductor increases. 7. Type "Right hand rule for magnetic field direction" on the viewer using text option (Choose colour black),) position the text at -950%, font 200% and highlight system with colour black. And do a voice over on the words reading over what is being said. 8. Save the slides as pictures and insert them on the timeline. Make sure as you speak about each term the voice matches the picture that comes up. 9. Save as images and insert the pictures on the timeline in that order.	1. Select animaker file and other animation files gathered from the internet to import to the timeline. 2. On the viewer type Magnetic field around a current-carrying coil in bold using control panel to make it bold. 3. Do a voice over (of the planned script.) from the file option	Animaker was not used for this section, Phet simulation images were capturedand other images downloaded from internet. Only editing will take place for this segment in Hitfilm. Do a voice over (of the planned scriptP from the file option. 1. Select file to import to the timeline. 2. On the viewer type Magnetic field around a current-carrying coil in bold using control panel to make it bold. 3. Do a voice over (of the planned script.) from the file option

		out from an upright image to tilt into an image from above-adds to the 3-D aspect and enables learners to connect to the two images as representing the same object but from a different angle.
	https://www.youtube.com/watch?v=zv4t_4fHvn4	Representation of the magnetic field around a current-carrying coil. Focus on showing current moving, the two magnetic fields in different directions
	https://www.wikipedia.org/wiki/Electromagnetic_induction#/media/File:Electromagnetic_induction_-_solenoid_to_loop_-_animation.gif https://phet.colorado.edu.faraday	Representation of a solenoid. Focus on the resulting magnetic field lines, match it up to the magnetic field lines of a bar magnet

Provide your teaching sequence below



In what ways will you ensure that the scene outlined above for your video will help learners to focus on the big idea that you are aiming to teach through this video? Think about, and enlist the technological functions that will make your video functional and effective for learning. Think about how you consider:
Signalling
Segmenting
Weeding
Matching modality

Signalling-highlight the important terms as the verbal script makes reference to it, try to add arrows that point to the items as they are discussed.
Segmenting-only this section of the topic will be discussed in this animation video which is a set of 4 videos of max 4 minutes each.
Weeding-avoid using background music as distraction, remove arrows and labels that are not needed in a specific clip.
Matching modality- make sure that the soundtrack matches the pictures, spoken and written words to appear on the screen at the same tme as the object in the segment.

The digital-TSPCK storyboard broke down each big idea into the three aspects needed for the animation video to be produced, the pedagogical transformation of the content, the cognitive aspects of digital media and the technical tasks to be performed in order to deliver a digital lesson. There was a measure of integration of these aspects where, for example, a learner misconception should be visually addressed using a technical skill of placing an arrow in the right place, next to the appropriate image, along with the accompanying script. Across all the areas of video creation, whether it be representation of content or the sound track, the creator of the animation had to incorporate the digital-TSPCK components so that the resulting video was appealing and understandable to learners.

As described in chapter three, the digital-TSPCK intervention occurred in three phases of multiple sessions each to allow reflection on the teachers progress and challenges during each phase of animation creation,where they were assisted on the Whatsapp platform and ideas to manage difficult animation steps were shared among the group. The intervention phases are represented in Table 6.4. During the intervention sessions, participants requested to meet face-to-face in order to simplify discussions and also have the researcher on hand to assist them with technical difficulties. Therefore at the end of the intervention, after all COVID restrictions had been lifted,

there were face-to-face sessions where participants worked on their animation creations and the researcher was able to move between them and facilitate the creation process.

Table 6.4. Structure of the phases of the intervention

Intervention phase	Description
Pre-intervention	Submission of video of classroom teaching using technology before the intervention.
1. Planning	Introduction to digital-TSPCK using the CoRe storyboard, the tutorial video and online discussions.
2.Animation creation	Implementing planned lesson using the Animaker software using online discussions, whatsapp group discussions and face-to-face sessions.
3. Video editing	Finalising the animation using the Hitfilm Express software using online discussions, whatsapp group discussions and face-to-face sessions.

Before the intervention began, teachers were requested to submit videos of the lessons they normally teach in their class. These videos were analysed to determine the level of enacted TSPCK was exhibited during the lesson (which is a prerequisite to the existence of digital-TSPCK) and then to determine the existence and extent of the digital-TSPCK present in their videos before being exposed to the construct. The planning phase entailed a video-tutorial of a class planning session describing the development of a CoRe storyboard for one of the Big Ideas for the topic of Electromagnetism.

The teachers received the tutorial video together with a resources package in a linked google drive folder as seen in addendum I. In the folder there was a list of resources they needed to download, including links to the software to be used in the intervention: Animaker, Vectr and Hitfilm Express. A set of snapshots of the animaker software home page with clear guidelines describing the name and use of each of the icons on the home page where they were shown how to log into the Animaker software and how to navigate through the icons of the software, was included in the resource material. The storyboard planning process was further discussed during online sessions on Microsoft Teams meetings to illuminate the reasoning process behind the completion of the storyboard using the example in the tutorial video.

6.3 Creating the animations

Teachers completed their own CoRe storyboards for the planning of their own animations. They could choose to create an animation video of any of the four Big Ideas listed in Table 6.2. Questions arising during the completion of the storyboards were open on the whatsapp group, and answered. Following the planning process, the online meeting to show teachers how to proceed from their storyboards into the physical creation of the animation were held. A full descritpion on the method of animation creation can be seen in addendum H. Once they knew how to place images on the screen, we discussed what the first items were that we wanted to show in the shot. The discussion regarding what the script for the shot preceded the visuals as they informed the accurate display of the content to be taught and was planned beforehand. We then discussed how the wording choice contributed to learner understanding without creating misconceptions, or addressing existing misconceptions.

Imaging was discussed through the lens of the digital-TSPCK components, bringing them to the attention of the educators and how the animation should be designed to ensure that the representations, cues and highlights occur at the right time without placing too much extraneous load on the learners' working memory. Once the initial shot had been created to the satisfaction of the group, each participant were tasked to create their own animation of a chosen segment of the topic for a homework activity. They planned the design of the shot in a digital-TSPCK storyboard format and submitted it with the created animation. The storyboard indicated the pedagogical and technical reasoning behind their creation. Comparison between the storyboard and the end- product, were analyzed for an indication of the technical skills mastered and which aspects need to be reinforced with the educators, listed as their technical difficulties experienced during animation creation.

Teachers requested for additional face-to-face meetings so that the researcher could facilitate their animation process quickly and in person. Two of these sessions were held where the teachers designed their animations and were also introduced to the video-editing software Hitfilm express to finalise their animations.

The data collected from the intervention, included the pre-intervention teaching video, CoRe storyboard, animation video and reflective whatsapp messages of the teachers during the creation

process would be triangulated to create a rich qualitative description of the nature and quality of the growing competencies towards digital-TSPCK developed by each teacher as a result of the intervention.

Chapter 7

7: Analysis of intervention workshop data

The previous chapters 4 and 5 had presented an interpretive argument for digital-TSPCK as the basis for the design of an intervention that would create opportunities to capture and portray empirical data that point to digital-TSPCK manifesting as per the argued definition in action. Chapter 6 presented the actual intervention targeting the development of digital-TSPCK in the digital practice of four in-service teachers who create their own animated lessons based on electromagnetism. This chapter outlines the analysis of the varied data sets collected at various points of the intervention reflecting the presence or lack-of, of digital-TSPCK and the collaboration of the evidence for its presence.

7.1 Introduction

Chapter 6 described the intervention process where four practicing physical science teachers were taught the theoretical and technical skills required to create an animated science lesson on one of the identified big ideas identified in the topic of electrostatics. Teachers were required to submit videos of their classroom teaching before the start of the intervention program to enable a comparison of the teachers' level of digital-TSPCK before the intervention and after. The results of such a comparison could indicate whether teachers were able to benefit from the intervention and enhance skills in the teaching of science. Initially, due to COVID restrictions, meetings and training sessions took place virtually during Microsoft Teams meetings, guidelines on Google drive and discussions on a WhatsApp group.

Subsequent to the lifting of COVID restrictions, there was a call by the participating teachers to schedule face-to-face sessions where the animation creation process could be facilitated and discussed in a group setting. The result of the intervention process yielded several forms of data reflecting the complexity of the planning, creation and production process involved in delivering an animation as an end product. The following data sets were collected and analysed as shown in Table 7.1

Table 7.1 Data sets collected during the digital-TSPCK intervention.

Data collection point		
Before intervention	**During intervention**	**End of intervention**
Pre-intervention videos prepared by in-service teachers	CoRe-storyboards (capturing the planning of a teaching video) Video snippets on constructed animations Discussion notes and reflections captured through WhatsApp	Post-intervention videos. Stimulated recall interviews
Purpose		
To establish a baseline level.	To determine the nature of the emerging digital-TSPCK in the planning and in the building of animated videos, if any.	Verification of the components visible in the storyboards and animations. Questions regarding intent of use of specific components that were not explicitly visible in the animations. Feedback regarding the quality of the workshop and effect it has had on the participants.

The data sets collected followed a progression of evidence indicating the extent to which the digital-TSPCK construct has been taught to practicing science teachers from the planning through the execution phase until the reflection phase. This chapter outlines the analysis with examples in preparation of the ground for the presentation of findings in the next chapter.

7.2 Analysis of the pre-intervention videos

Before the teachers participated in the intervention, they were requested to submit a video recorded lesson showing how they typically taught science lessons within their school context. The videos were analysed to determine whether the participants exhibited evidence of TSPCK and possibly digital-TSPCK as the baseline for the interpretation of further development if any. Transcripts of the video recorded lesson were prepared for each submitted video with descriptions of the teacher actions and the resources they used. Thereafter sections in the transcripts were highlighted when a teaching segment in the recorded lesson showed evidence of a TSPCK episode. A TSPCK episode as in the previous empirical studies for example by Mapulanga et al. (2023) and Akinyemi and Mavhunga (2021) was based on the identification of visible evidence of a minimum of two

TSPCK components working interactively in the identified teacher task (teaching segment). It has been postulated, at the beginning of this study (Chapter 3) that a teacher cannot exhibit digital-TSPCK if they do not have evidence of TSPCK in their lessons.

Evidence of digital-TSPCK, as per the definition established in the interpretive argument, was based on the visible interactions across the components of TSPCK, teacher digital competency and the principles of CTML. So, a digital-TSPCK episode referred to a segment in the digital lesson that visibly reflects the interactions between TSPCK components, CTML principles and teacher digital capacity. A digital lesson in the context of the study referred to a lesson built for teaching and learning on digital platforms. The analysis for the TSPCK and digital-TSPCK episodes followed an in-depth qualitative analysis (Park & Oliver, 2008). In the in-depth qualitative analysis method, an overview of the lesson and the specific segment containing a TSPCK episode is provided. An excerpt of the evidence supports the overview. The TSPCK or digital-TSPCK components present in the episode are identified and their interaction described. Their interactions are portrayed using an illustration that is referred to as a TSPCK Map. In a TSPCK Map, the visible components of TSPCK are illustrated in solid circles. Those that are implied by the evidence, but not visibly seen are represented using circles with dotted lines. The specific task that the teacher is doing is explained in a rectangular box that serve as a platform for the circles. Interacting TSPCK components are represented with intersecting circles and an arrow indicates the sequence in which the interactions occur.

The topics of the submitted pre-intervention videos included electromagnetism and particulate nature of matter based on the dates they recorded according to the syllabus of that time. The videos illustrated a range of what Shulman (1986) called low technology representations of chalkboard descriptions, while others showed traditional classroom lessons with the use of projectors to show notes or downloaded content representations. It was evident in the formatting of the videos at a glance, as non were segmented, that the submitted lessons were simply digital recordings of a typical traditional lesson as expected, none were designed for use on digital teaching and learning. Thus, none would reflect evidence of digital-TSPCK as per definition, therefore the focus of analysis turned on TSPCK episodes only.

The analysis of TSPCK episodes

The submitted baseline videos exhibited varied sets of TSPCK episodes with differing TSPCK quality. TSPCK episodes were coded for ease of use in the analysis as follows:

CS = Curricular Saliency

LP = Learner prior knowledge

WDT = What is difficult to teach and understand

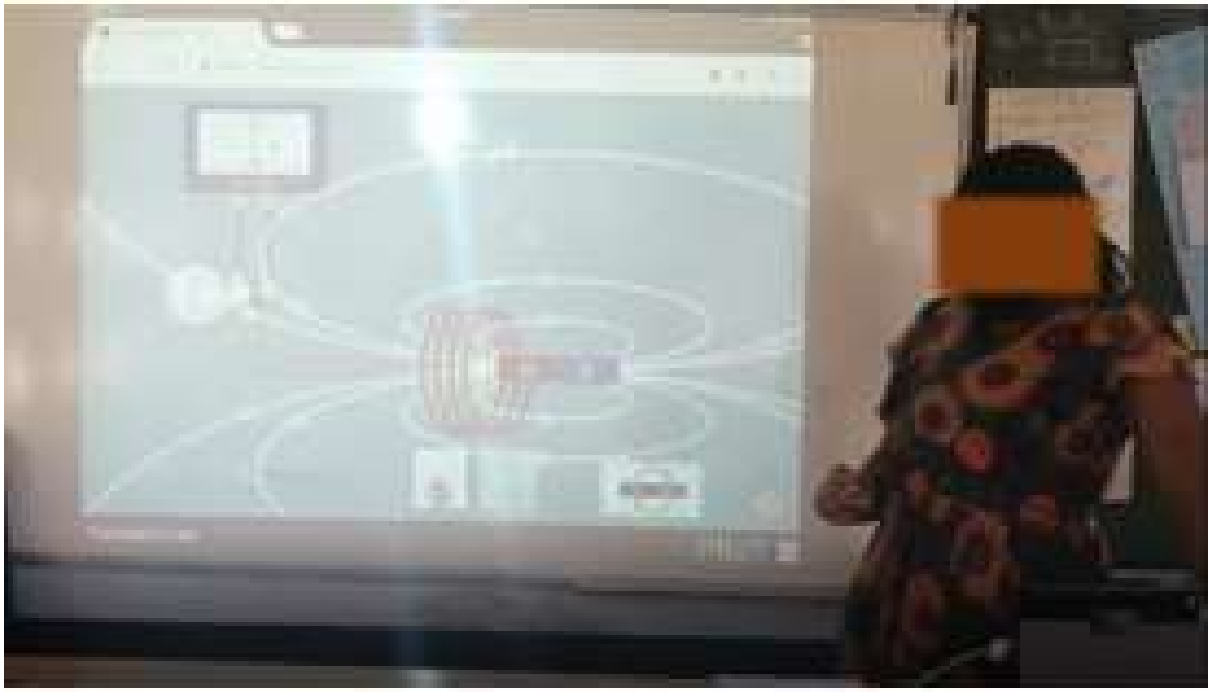
RP = Representations

CTS = Conceptual teaching strategies

Table 7.2 below presents the analysis of the recorded lesson submitted by Ms G on the topic of Electromagnetism for Grade 11 science learners.

Lesson overview: The lesson intended to cover Faraday's law as a concept, leading up to the use of the equation in a problem-solving activity. In the teaching episode below, Ms G explained the concept of magnetic flux. She first used a simulation to show the movement of a magnetic field through a coil to demonstrate electromagnetic induction, and the influence of magnetic flux on the brightness of the light bulb. She then used a teaching video (Jennifer Cash: Magnetic flux. https://www.youtube.com/watch?v=lEo-3yJFmYg) to explain the concept of magnetic flux and the conditions of increasing the flux through a coil.

Table 7.2. Pre-intervention video analysis for TSPCK episodes for Ms G

Teacher Ms G: Video Lesson on Electromagnetism	
	
Excerpt from transcript	
Time	
00:04	Ms G: So in the simulation I have is a magnet and I have a coil which is connected to the light bulb and the voltmeter (RP). So if I move the magnet into the coil (uses the mouse to move the magnet into the coil in the simulation) there are two things that are happening. Firstly the bulb glows and then also you are going to see the deflection in the voltmeter. So as we know around a magnet we have magnetic field lines (LP), let me just show you the magnetic field lines (shows magnetic field lines in the simulation). So now we have the magnetic field lines, OK, but first for us to understand Faraday's Law there are terms that we need to understand (CS). The first one is magnetic flux. So what do we mean by magnetic flux?
01:46	So magnetic flux is the measure of the field, of the magnetic field that are moving through the coil, so that's the first term (WDT). But then I will have a video that will explain more on the magnetic flux, let me just play it (RP). (used the information of the video and applied it to the simulation) She goes over to the video on the whiteboard. Video transcript:

07:49	Now let's look at magnetic flux. So flux in general: well we've already seen the concept of electric flux (LPK) and magnetic flux is really the same sort of concept (LP). And again that was a measure of the flow through the surface, in this case it's the flow of magnetic field lines through a surface, and so you can think of it kind of like in this picture (RP). If I've got a particular surface I've got some field lines going though it and I want to measure that. Now that magnetic flux is going to depend on three factors (CS): It's going to depend on the field strength. Remember that the field strength is represented by the density of the arrows, so the stronger the field is, the more arrows you've got more closely packed together representing those field lines. Then we've got the area. If your surface has more area, you're going to have more flow going through it than if you've got a smaller area. Then we talk about the angle of the surface. Depending on how the surface is tilted you could have more or less field lines going through that surface. We can wrap all of these concepts up with a single equation that says the flux is equal to BA Cosine Θ (RP). (Formula is displayed on the screen) Video stops. Ms G: OK so now that's it. Now we understand the magnetic flux.

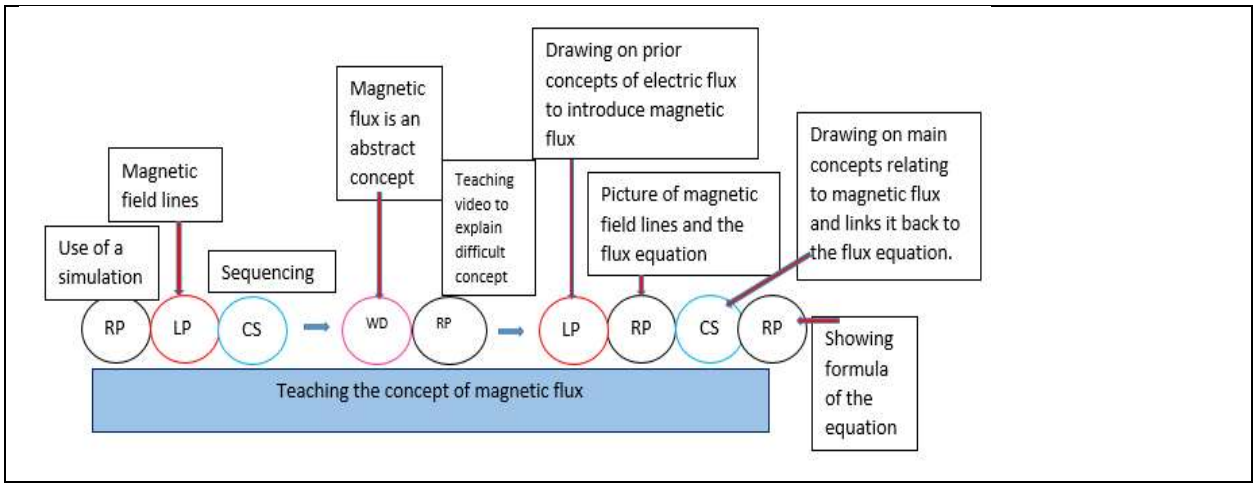
Analysis of the episode

Ms G used a representative simulation of a magnet that could move through a solenoid to depict electromagnetic induction. She discussed the magnetic field lines as the magnet is moved through the solenoid as prior knowledge, "so as we know around a magnet we have magnetic field lines". The episode also sequenced the main concept of magnetic flux as it relates to the magnetic field lines.

She described the concept of magnetic flux as it is a difficult term to understand so she introduced the visualization of the magnetic field through a descriptive teaching video that contains simulated magnetic field lines to explain magnetic flux.

The video itself referred to prior knowledge of electric field lines to link it to magnetic field lines using a representation (picture) of magnetic field lines passing through a surface. Sequencing of the key concepts in the description explaining the factors influencing the magnitude of the magnetic flux and finally linking it back to a symbolic representation of the equation to calculate magnetic flux: $\Phi = BA\cos\Theta$.

TSPCK map of Ms G's pre-intervention video lesson



From the TSPCK maps created of the pre-intervention videos, there is evidence showing that the teachers exhibit TSPCK knowledge skills in the way that their teaching sequences are structured to show multiple component interactions with two or more components interacting within a teaching segment and teaching episode as a whole. The assumption that the teachers already have TSPCK competencies allows the progression toward teaching them digital-TSPCK competencies in the intervention designed for this study.

Although the pre-intervention videos showed TSPCK episodes, there was little, if any evidence of teachers exhibiting digital-TSPCK as teachers were using and not creating their own content on a digital platform. The opportunity to note the effect of the impact that the digital-TSPCK intervention will have on these teachers will indicate development from the perspective of this baseline knowledge of the teachers.

The emerging conclusion indicates that the participating teachers currently use technology in portraying TSPCK in a traditional lesson that has been captured on video. Therefore, there exists the potential for teachers to acquire digital-TSPCK and potentially design digital lessons that exhibit digital-TSPCK, where their use of technology is at a design-level.

The question arises about the ways in which evidence of digital-TSPCK would be visible in the teachers' digital lessons to be created in reference to the definition provided in the interpretive argument. Furthermore, in what ways evidence would reflect the nature of digital-TSPCK episode differ from that of a TSPCK episode.

7.3 Analysis of the CoRe-storyboards

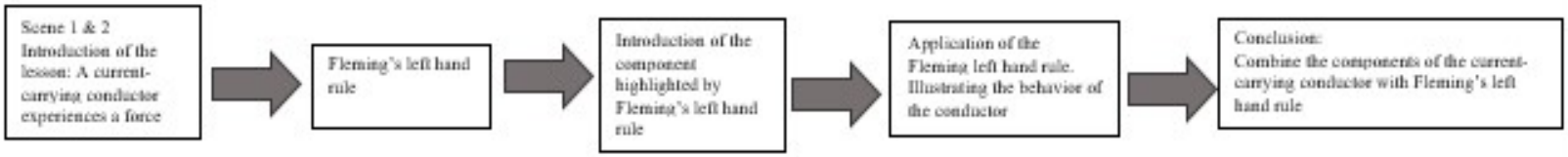
What a teacher knows about what they want to teach for a topic, and how they want to teach it is a tacit kind of knowledge that is often difficult to express on paper for others to learn from. Loughran et al. (2004) provided CoRes (Content Representations) as a means for teachers to portray their PCK representations. Later Loughran (2021) noted that CoRes enabled teachers to not only reflect on their teaching using a theoretical basis, but to articulate the reasoning that underlies the intention of what is to be taught. He described the CoRe as an instrument that could portray the teacher's pedagogical expertise as a knowledge-based practice (Loughran, 2021).

In this study, the theoretical framework has shifted from PCK to the grainsize of TSPCK and is now evolving to portray this teacher knowledge on a digital platform. More factors play a role in the planning for digitizing of content and the need for a CoRe that would reflect the complexities of the three theoretical frameworks in digital-TSPCK, namely TSPCK, the UNESCO ICT framework and the Cognitive theory of multimedia learning would need to be catered for. Researchers working in the field of TSPCK and the digitizing of content adapted the CoRe to a CoRe-storyboard. The CoRe-storyboard contained the components of digital-TSPCK as a planning tool for the choice of content to be used, and enables the teacher to plan a layout storyboard for each scene in the animation in order to reason about the content and its presentation-such as highlighting, type of image, text, sound or motion in reference to the intended message to be conveyed by the animation. One factor that is important to remember is that, in an animation, the creator begins with a blank slate on the screen. No items randomly appear on the screen. This shows the high level of intention with which a teacher has to plan and put together the animation in order to create a fully functional animation with intent. The CoRe-storyboard can therefore be used as a theoretically robust working document that assists the teacher in the placement of all aspects of their animation where they will be most effective in the teaching sequence.

A CoRe-storyboard provides a wealth of information regarding the teacher's intent and reasoning processes when planning to create the animation. The prompts of the CoRe-storyboard direct the teacher to think forward first on individual teaching considerations related to the individual three constructs making up digital-TSPCK, viz: components of the TSPCK, the CTML principles and the technology needed to realize the intentions. Towards the end of the CoRe-storyboard, the teacher is required to pull all the TSPCK considerations made earlier and suggest a sequence of

scenes with rich annotations about the perceived requirement for technology and CTML principles. In this storyboard the teacher decides which big idea is presented, which concepts they know are difficult to teach and understand and what they perceive as learner misconceptions, or what actions could trigger a misconception. The components of the CTML principles come into play with the TSPCK components where a representation is used. For example, in the case of electromagnetism, the teacher knows is difficult to understand teach the imaginary magnetic field lines, and by using dynamic arrows (signalling) could show the direction of the magnetic field line. Secondly, the teacher knows that learners tend to confuse electric fields with magnetic fields, and the movement of electrons, so the teacher could make the magnetic field arrows see-through, adding a dimension of invisibility to the arrow. The teacher would decide therefore, to ensure that the arrows remain stationary during the animation so as not to create a misconception that magnetic fields flow. Upon analysis of the CoRe storyboards a whole, a digital-TSPCK map can be drawn to reflect the components used and the nature of the interactions between the components. Below, Figure 7.1 shows an example of a completed CoRe storyboard.

Title/Topic: Electromagnetism Grade 11			
Single Big Idea in the animation video:		**A current-carrying conductor experiences a force in a magnet field.**	
What do you intend learners to learn about this Big Idea from the video?	Learners should learn about the behaviour of a current-carrying conductor in a magnetic field.	**What do you consider to be most important to be learnt in this Big Idea?**	The behaviour of the current-carrying conductor in the magnetic field
Why is it important for learners to know this and how did this inform your rationale in making the video?	The magnetic field exerts a force on a current-carrying wire in a direction that can be determine by the right hand rule	**Describe the typical learner misconceptions about this Big Idea. How will you address them in this video?**	The uniform magnetic field, I will address it by drawing uniform magnetic field lines that don't cross each other
What concepts need to be in place for learners to engage with this video?	The movement of a current-carrying conductor within the magnetic field Direction of the magnetic field The force exerted by the magnetic field	**What other factors may influence your teaching of this idea when making this video?**	Audio and voice should be clear. If vectors are not correctly chosen, they mislead learners.
What else do you know about this Big Idea that you do not want to include in this video, and why.	motors	**What do you consider easy or difficult to understand about teaching this Big Idea that inspired you to make this video?**	It's the challenge of applying Fleming's left hand rule
What representations are you going to use in this video for teaching the Big Idea? Provide a list of the representations (including digital resources) you envisage to use and also describe how they are to be used in each case.			
Cubes Arrows Left hand	Cubes represent horse-shoe magnets Arrows represent magnetic fields The hand to show Fleming's left hand rule	Digital sources Animaker soft. Vector soft. Microsoft words	
Provide your teaching sequence below			



In what ways will you ensure that the scene outlined above for your video will help learners to focus on the big idea that you are aiming to teach through this video?
Think about, and enlist the technological functions that will make your video functional and effective for learning. Think about how you consider:
Signalling
Segmenting
Weeding

Matching modality		
When you create the animation, what considerations will you take into account?	Visuals or colours Audio	
When you edit your video, what considerations will you take into account?	Clarity of the voice	
Animation video creation		
Video shot 1	Video shot 2	Video shot 3
Script: Introducing the important component for this big idea like magnets, magnetic field conductor & force	Script: Explaining Fleming left hand rule, and explaining how the conductor will move in the magnetic field	Script: Demonstrating the behviour of the current-carrying conductor in the magnetic field experiencing the force
Technical notes when using Animaker to create	**Technical notes when using Animaker to create**	**Technical notes when using Animaker to create**
When posting or attaching a imported vector, it becomes a background One has to undo and go to image first to post an imported vector	It almost impossible to do grouping and apply smartmove at same time, when all images and vectors are screen.	Voice and background sometimes gets mixed up, when opening the project. You find voices of scene 1 are on scene 5
Technical notes when using Hitfilm express to edit	**Technical notes when using hitfilm express to edit**	**Technical notes when using hitfilm express to edit**
I didn't use this software	I didn't use this software	I didn't use this software

Figure 7.1. CoRe-storyboard of Mr T indicating the planning process for his animation.

The digital-TSPCK intervention began with an online orientation session. This session introduced the teachers to the Big Ideas of electromagnetism, CoRe-storyboards for the purposes of planning animations and the different software that would be used during the intervention. All planning for the animation was noted on the CoRe-storyboards as a working document in planning and creating their animations. Participating teachers were given storyboard templates to complete in order to plan their animation video. Each prompt block required forward thinking from the teacher regarding how they would incorporate the digital-TSPCK components in building the animation video. The prompts on the CoRe-storyboard called for forward thinking first with respect to each TSPCK component curricular saliency (the most important concept to be learned); learner prior knowledge (including common learner misconceptions); what is difficult to teach; representations and the conceptual strategy expanded in the envisaged sequence. In addition, the prompts of the CoRe-storyboard required forward thinking about the technical aspects of the digital software (Animaker and Hitfilm) that would best present the representation while ensuring that there is no unnecessary visuals that contribute to adding extraneous load making it more difficult for the learner to comprehend. Lastly, the prompts of the CoRe-storyboard called for the consideration of CTML components including the use of signalling, dynamic synchronization of audio and visuals and weeding out of aspects that would distract the learner from effective learning. The CoRe-storyboard closes by calling for the teacher to present their envisaged digital scenes, in a sequence with annotations of the technical aspects and CTML principles to be employed.

In the second shot of Mr T's planning drawn from Figure 7.1, he was aiming to display the concept of Fleming's left hand rule, explaining how the conductor will move in the magnetic field. These aspects displayed curricular saliency and representations. He listed that a uniform magnetic field that is prior knowledge, could cause misconceptions therefore he planned to draw uniform magnetic field lines that don't cross each other. He made a point of correctly choosing vectors (images) that would not mislead the learners. The CTML components of weeding, matching modality and segmentation was a general consideration meant to be addressed throughout the animation where he planned to match audio to the visuals in each scene without placing too many distractions in the animation. The analysis of the CoRe showed considerations of TSPCK components for specific concepts, and the CTML components were usually applied to the animation as a whole.

The process of analysis for the CoRe-storyboard involved, much like with the TSPCK maps (Miheso & Mavhunga, 2020), an identification of the components that the teacher decided to incorporate, and the interactions they had with each other. The original TSPCK maps were evolved to include the CTML components to represent the quality of digital-TSPCK as evidence of a teacher's pedagogical transformation of the content based on the three frameworks underpinning digital-TSPCK. Digital functions that were evident in the planning were noted in the CoRe-storyboards for purpose of creating the animation, but was considered as prerequisite standard functionality once a completed animation was created (Akinyemi, in press).

The CTML components were therefore represented as rectangular blocks, where the TSPCK components were presented as circles, see Table 7.3 below.

The identification of the components presented by the teacher in the storyboard was done by an in-depth qualitative analysis method. In this method, each scene is evaluated whether it exhibits the interaction of digital-TSPCK. Scenes that exhibit the presence of digital-TSPCK, are then described, followed by the identification of the components of each construct found present, and how they seem to interact among one another. The identified interacting components were represented in the digital-TSPCK Map in the order in which they appear in the sequence of the planned video. An example of analysis of the CoRe-storyboard is illustrated below. An extract of the scene displaying the presence of digital-TSPCK from the storyboard as described above.

Table 7.3. Storyboard breakdown summary of components of the storyboard for Mr T.

Components visible	Descriptors from storyboard
CS	Sequencing and main concepts to be displayed
RP	Representations used
LP	Common learner misconception
WDT	What is difficult to teach
Segmentation	The delivery of the concept evidently planned as a set of short interrelated videos.
Signalling	Visible highlighting on screen
Weeding	Avoidance of unnecessary destructions, audio or in visuals, that are related to the topic discussed at present.
Matching modality	Audio to match text and visuals in each scene

The storyboard components of digital-TSPCK enable the creation of a digital-TSPCK map exhibiting the components present in the planning of the animation and the specific interactions between the components. The TSPCK components listed in the storyboard would be drawn as circles on the map resting on the label of the teaching topic. The identified CTML components would be placed as squares above the TSPCK circles, overlapping the circles that the CTML component is planned to interact with. Technical aspects noted by the teacher for the creation of the animation is noted on the TSPCK or CTML component it relates to. This map would be compared at a later stage in the study to the digital-TSPCK map created of the created animation itself. Figure 7.2 below shows the digital-TSPCK map for the storyboard of Mr T.

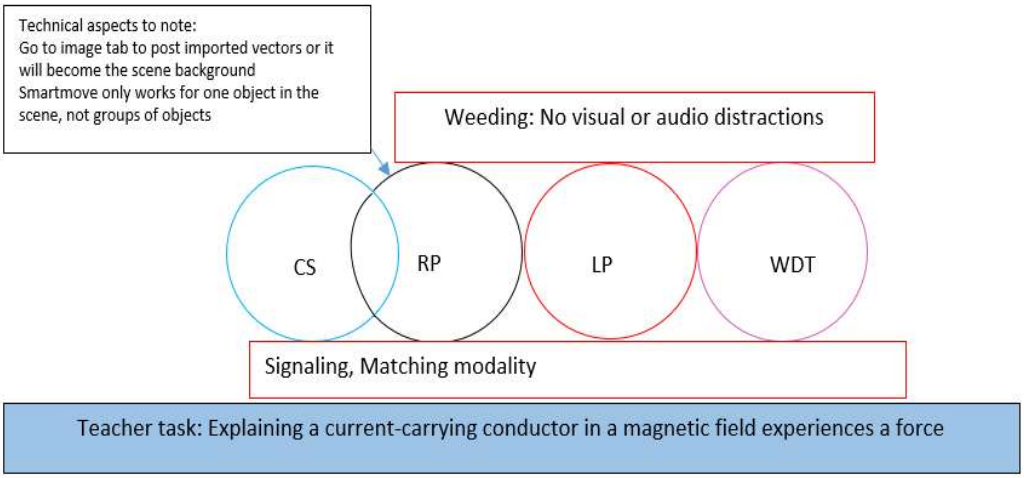


Figure 7.2. Digital-TSPCK map for the storyboard created by Mr T

Looking at the CoRe-storyboard as a whole, the summary of the scenes placed in sequence is the segment of the CoRe-storyboard that is most revealing of the construct interactions. Not all planned scenes were reflecting episodes of digital–TSPCK, the introductory scenes and closing scenes to round off the lessons did not explicitly show evidence of digital-TSPCK. The digital-TSPCK map generated from his storyboard, showed that Mr T had a strong sense of curricular saliency, in terms of the Big idea, important gatekeeping concepts and the sequencing of these concepts to translate into a cohesive, understandable animation. The CoRe-story board TSPCK components like curricular saliency and representations emerged as the components that could only be readily presented in animation format as a text statements and representations that interact with signalling, matching modality and weeding as principles of CTML with .signalling and

matching modality extends across all the TSPCK components as the animation had to draw the viewer's attention to the main concepts, specific parts of the representations at specific times because the teacher wanted to avoid misconceptions and knew what was difficult for them to understand. He also planned to ensure that matching modality was observed for the entire animation to ensure that words, images, sounds and pictures were synchronised. Weeding was noted to span the TSPCK components from the representation of the concept, when the learner would see the concept so that for the animation there would not be any audio or visual distractions drawing the learners attention away from the content to be taught in the animation. The technical aspects he noted in his planning focussed on his attempts to create his representations, therefore he mentioned that certain applications for creating motion would only work on individual items and not groupings, while any shapes needed to be imported as images or they would become the background of the scene.

7.4 Analysis of the created animation video snippets

The created animations were in a format of an animated video. The animation created using an animation software like Animaker, then inserted into a video building software Hitfilm-express to create an animated teaching video. The animated teaching videos were brief in nature (3- 4 min), providing explanations of the specific concept within a topic. Each animation was viewed several times with an additional rater in order to make note of each detail in the sequence. As noted earlier, all visuals, around and content were individually and intentionally placed in the animation before rendering it for use, therefore much care was given to noting the intentions of the details placed in the scenes.

Taking into account that TSPCK consists of five components: Learner prior knowledge, What is difficult to teach, Curricular Saliency, Representations and Conceptual teaching strategies, a TSPCK map would show evidence of, and related interactions between evident components in a teaching episode. In the same way, digital-TSPCK episodes would represent a blending of three frameworks containing the components of TSPCK as well as those of the CTML, namely: segmenting, signalling, weeding, content control, and matching modality and the components of the UNESCO ICT framework, Digital literacy, knowledge deepening and knowledge creation. In the creation of an animation, the technical skills of creating a functional product where there is clear evidence of the transformation of content onto a digital platform, it can be noted that the

technical skills have been applied to create the functional product. Hence a functional animated teaching video was seen as evidence of the third and highest level of digital competence, knowledge creation, without which, an animation would not exist. Therefore digital competence became the 'translucent' foundation on which the digital-TSPCK components were places on the maps.

The animation created by Ms G can be used to show how digital-TSPCK is exhibited in an animation as seen in Figure 7.3.

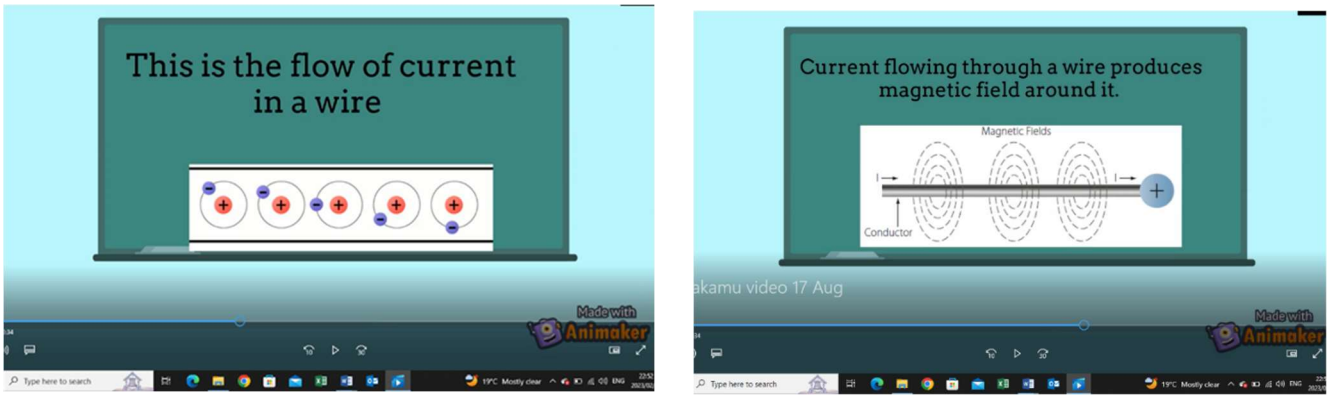


Figure 7.3. Set of images from the animation of Ms G

In this animation Ms G used curricular saliency to sequence main concepts logically. She first showed how current flows in a conductor and then the resulting magnetic field forming around the conductor as a result of the current. This component is interwoven with the representation component as the conductor, flowing charge and resulting magnetic field need to be represented visually in the animation. Furthermore, the components of learner prior knowledge and what is difficult to teach features in the planning and is confirmed by the post-animation interview, but cannot be explicitly seen during the animation itself. These are implicitly intended components. In addition to the TSPCK components, Ms G used CTML components of weeding throughout the animation to prevent visual or auditory distractions across all features of the animation. The components of signalling and matching modality become explicit when the intended content is represented as the animation, therefore, interacting with the representation component. The visual representation of the digital-TSPCK explained in the example above is seen in figure 7.4 below as

a digital TSPCK map showing the type of components and the nature of the interactions as described above.

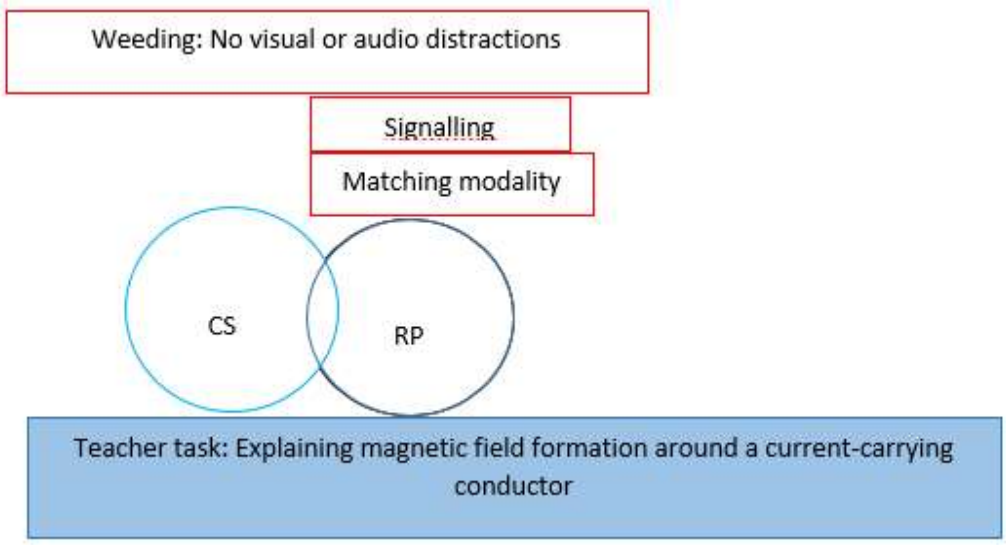
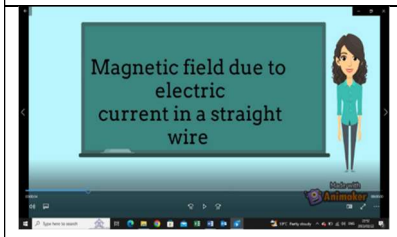
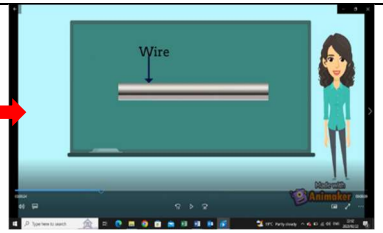
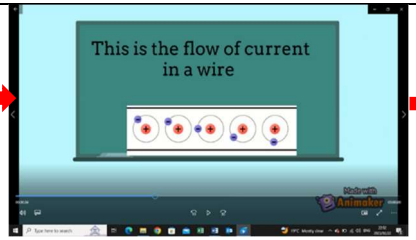
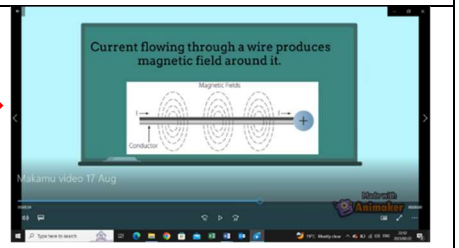


Figure 7.4. Digital-TSPCK map for an animation created by Ms G

Figure 7.4 is a digital-TSPCK map of an animation created to teach a big idea in electromagnetism. The animation fulfils all the technical requirements to show the transformation of the content into an understandable animation and indicated the interaction digital-TSPCK component for the animation. A digital-TSPCK map can therefore be considered a graphical representation of the components of the three frameworks constituting digital-TSPCK and their respective interactions with each other. The created animations were analysed using the soundtrack transcript together with the presented images on the animation in order to identify the components present in the animation as well as the nature of their interactions. Below is an example of animation analysis using the creation by Ms G.

Table 7.4: Overview of Ms G's animation video in screen format shots

			
Scene 1:	Scene 2	Scene 3	Scene 4
"Magnetic field pattern due to electric current in a straight wire." (This heading is spoken and displayed on the screen at the same time. There is a plain blue background which remains unchanged during the animation)	Image on screen disappears "This is our wire" (Image of wire appears, written word "wire" appears with an arrow pointing from the word to the wire)	"This is the flow of current in the wire" (Text appear on the screen synchronized with a verbal sentence and wire image and sub-microscopic representation of the atoms in the wire. The nuclei are stationary and the electrons are moving around the nuclei, but delocalized to move in a resultant path from left to right in the screen.) Image on screen disappears.	"Current flowing through a wire produces magnetic field around it." (Text appear on screen synchronized with the verbal sentence and wire image. The wire has magnetic field lines around it, the direction of the current in the wire is shown with the symbol, I, and arrow. The word 'conductor' is also on the screen with an arrow pointing to the wire.

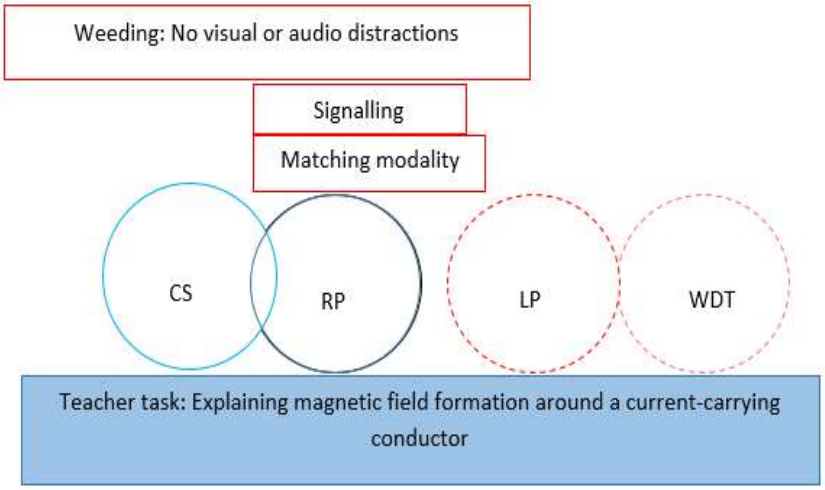


Figure 7.5. Digital-TSPCK map of the animation by Ms G with tacit components included

There is clear evidence in Figure 7.5, the digital-TSPCK map of the animation scenes presented in Table 7.4, of two TSPCK components, Curricular Saliency and Representations interacting throughout the animation to support the explanation of the related concepts. Curricular saliency is evident in the sequencing (from a wire then current in the wire then creation of magnetic field around the wire due to the current) and the main concepts that were displayed. Representations could be noted in the visual aspects created by the teacher- the wire, the atoms, the magnetic field lines which represented the main concepts of the animation. Therefore, these two components were depicted as overlapping in the digital-TSPCK map as their functions are dependent on each other. No distractions were noted and there is evidence of matching modality between visuals, audio and text. Signalling is enhanced by motion. Weeding was applied to the animation to eliminate extraneous information, visuals or sound.

The two components of LP and WDT are represented by dotted lines in the digital-TSPCK map. These two components were not visible by watching the animation itself. After a stimulated recall response interview with Ms G where the aim was to confirm the component identifications made, she was questioned regarding these specific two components which were well represented in her storyboard planning, but could not be seen in the animation. It was noted during the interview that the intended use of the components existed in the animation but were not extrinsically visible, therefore the dotted line representation. During the interview it was noted that some of the components referred to in the storyboard were clearly seen in the animation for example the sequencing and main concepts that were planned to be brought to the learners' attention was also

seen in the animation. Therefore, Curricular saliency featured as a clear component. The following excerpt from the transcript of the stimulated recall interview questioned Ms G regarding the planned components in the storyboard that were not explicitly visible in the animation.

07:11:48	*Researcher*	*What I wasn't able to see is…..the first one is Learner Prior knowledge. So when you had your Learner Prior knowledge in your storyboard, you knew that the learners had to know what a magnetic field was, right?*
07:50:86	*Ms G*	*Ja, ja (yes, yes)*
07:51:08	*Researcher*	*And then also, I'm just checking, I'm reading it for you, you said that your learner prior knowledge, that learners already know that magnetic fields are created by magnets and forms magnetic field patterns. So that is not something that I can physically see in your animation that learners know this, do you understand?*
08:20:54	*Ms G*	*Uh-huh*
08:21:39	*Researcher*	*But when you drew the magnetic field line…….that was because you knew that the learners knew about them before?*
08:50:60	*Ms G*	*Yes*
08:50:63	*Researcher*	*OK. Now the second thing that you said that I can't see on an animation is What is difficult to teach. Now on your storyboard you say what is difficult to teach is that current passes through a conductor. Now if I look at your first attempt at your animation where you had the electrons flowing through and your second attempt which had the beautiful electrons circling the nuclei and being dislocated,*

		is that, is the reason why you changed it, because you realised that it is difficult to teach?
09:35:85	*Ms G*	*Ja, that's why I changed it, and I had to show them the flow of electrons because I think that somewhere I mentioned that electrons they cannot see them with the naked eye, so I had to indicate that on the.. inside the wire.*
10:02:73	*Researcher*	*And then your signalling for that was obviously because you wanted to draw their attention to that difficult concept.*
10:10:92	*Ms G*	*Yes*

Further discussion regarding the nature of the components interaction and visibility will be held in the next chapter.

7.5 Rating the level of digital-TSPCK evident in an animation

Akinyemi (in Press) designed a rubric enabling the measurement of the quality of digital-TSPCK. The rubric described the evidence for a teacher's pedagogical transformation on content in a specific topic on a digital platform using a set of criteria based on the three frameworks underpinning digital-TSPCK (Akinyemi, in press). Digital functionality was considered achieved depending on the operational functional success of the digital product in displaying the content as built by the teacher, and the extent of pedagogical transformation, if present, of the content displayed by teacher in the digital lesson. As a result, producing a functional digital product displaying the digital lesson as intended by the teacher, would be set as a pre-requisite constant reflective of the teacher's digital competence (Akinyemi, in press). Therefore, analysis would focus on the interactions between the TSPCK and CTML components. The presence and the nature of the interactions of the digital-TSPCK components were drawn across three levels of sophistication, namely simple, proficient and sophisticated. Table 7.5 contains the rubric containing the criteria for evaluating the type and nature of interacting digital-TSPCK components and the level of sophistication allocated to the interactions in a digitally created lesson.

Table 7.5. Rubric for digital-TSPCK analysis of digitally produced lessons (Akinyemi, In press)

	Simple	Proficient	Sophisticated
Interactions among TSPCK components	• Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teacher task segment • The TSPCK component interactions may be interwoven or have a linear sequence structural formation. • Both components work together to support an explanation of a single or a pair of concepts that are related.	• Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teacher task segment OR • Evidence of three different TSPCK components interacting, evidently, and distinguishably in a specific teacher task segment, but one component repeating and bringing a different level of explanation that complements the initial emergence. • The TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both. • The three components work together to support an explanation of a single or a pair of concepts that are related	• Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment OR • Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teacher task segment, with one of the components repeated more than once or one of the components bringing different levels of sophistication (e.g., representations used at macro, symbolic and submicroscopic levels. • TSPCK component interactions maybe interwoven or have a linear sequence structural formation or both. • All the TSPCK components work together to support an explanation of a single or a pair of concepts that are related.
Interactions among CTML principles	• There is a distracting visual or text that creates a bit of confusion as it is relevant to the topic as a whole, however not relevant to the specific scene on view. The screen is uncluttered. • The audio simply matches by reading out the texts and/or text on a visual of an easy-to-understand single level of representation used in explaining content.	• There is a subtle distracting element even though not in the focal point of the main scene. The screen is uncluttered. • The audio matches the essence communicated by the texts and the visuals of multiple representations used in explaining content. • There is appropriateness reference to each representation seen through the choice to keep them static and/or in motion at calculated appropriate times. • There is signalling of important features by highlighting key phrases or words with additional pointing (an arrow).	• There is no distraction associated with the displayed texts and visuals and the accompanied audio. The screen is uncluttered and there is no distracting element. • The audio matches the texts and the visuals of simultaneously used multiple representations at macroscopic, symbolic, and sub-microscopic. • There is appropriateness and dynamic reference to each level of representation kept at an appropriate mode (still or motion) in relation to the other. • There is dynamic signalling of important features by highlighting key phrases or words, with audio, texts, and visuals, all matching the purpose and happening all in a synchronized manner. • Signalling in the displayed scenario is enhanced with motion features like zooming in and out of the displayed visual. • There is differentiation in the display of the segmented videos which target different concepts or Big Ideas with the indication of how and where to access them aiming at learners' participation and/or reflection. • There is emphasis on the preferred sequence with rationale provided.
Interactions across components of traditional TSPCK and CTML principles	• There is evidence of weeding having an overall effect on all two different (e.g., CS and RP) interacting TSPCK components. • There is a single CTML principle, matching modality working complementary with each individual TSPCK component e.g., Curricular saliency *(matching audio and text)* and Representation *(matching audio and visuals)*, respectively.	• There is evidence of weeding having an overall effect only on two different interacting TSPCK components, excluding the physically non-visible components of TSPCK (LP) even when present in the episode. • Two different principles of CTML- signalling and matching modality working as a complementary pair with two individual traditional TSPCK components of curricular saliency and representation, respectively.	• There is evidence of weeding having an overall effect on three interacting TSPCK components. However, the effect excludes the physically non-visible TSPCK components (LP and WD) even when present in the episode. • There are multiple groupings (pairs and a trio) of the different principles of CTML working respectively with individual TSPCK components, up to three cases. For example, a trio made up of matching modality, dynamic signalling and content control working as a complementary set with the component of curricular saliency; followed by a pair of matching modality and signalling (static) working with the component of representation and a repeating component of curricular saliency, respectively.

The rubric has three areas of focus on which it bases its functionality criteria upon. Initially the rubric is used to focus on the presence and then interaction between traditional TSPCK components. Secondly digital lessons are analysed for the presence and interactions between CTML components until finally, the rubric distinguishes between levels of interactions between the TSPCK and CTML component interactions to make a complete, educationally functional digital product, which at an operational level defines digital-TSPCK.

Each participants animation, submitted first and second attempts, like Ms G and Mr T, were analysed using the rubric in order to place their digital output at a level of competency according to the digital-TSPCK definition. Although it was not the intention of the study to focus on whether teachers gained a category more or less, with that said, improvement in this field was seen as a bonus, but the aim was to capture and portray evidence, as per definition, pointing to digital-TSPCK manifestations in the digital lessons created by the teachers following the support from the intervention. Furthermore, to determine the nature of the component interactions in a digital-TSPCK.

7.6 Reflections from the WhatsApp group

With the majority of the study conducted online, there existed a need for communication and discussion of the phases participants were working on. This helped them to gain insight into solving some of the minor technical issues they experienced such as where to find new images, or how to set a background so that it does not move with the rest of the scene. Working within a group setting where the other participants experienced similar issues enabled issues for each participant to be addressed quickly and the knowledge was shared to the entire group.

Table 7.6. WhatsApp conversation regarding overcoming technical issues in the animation creation process.

2 July 2022	
Ms. G	 Good day. Please help. I'm trying to create a flow of charges in a conductor but I don't see a shape that I can use to create the conductor. I've tried to use the pencil tool in vector but my lines are not straight.
	 Do we just click export only for exporting? And how do I import things in animaker? I don't see the import button
R	Hi G, you can google images for a conductor, the save on your desktop or image file. Then when you are in animaker you click on images and then there is a download function that will allow you to download the images from your computer Export is only for when you are done and want to submit. The animation will stay on Animaker so that you can work on it again after our next meeting

In Table 7.6, Ms G had been struggling with importing images onto the Animaker file she created for her project as she was only able to locate the export button on the home screen. The texting enabled the researcher to go through the terminology she was looking for (download instead of import) when importing images and when and where to use the export feature.

Therefore, the initial function of the group was communication and assistance in overcoming difficulties in animation creation and was considered to be a part of the facilitation process of animation creation of the intervention. For example, Mr T, Mr M and Ms G intended to use the smart-move function on Animaker to make a group of electrons move across the screen, only to find that the move was to be applied to each item individually. Toward the end of the workshop, reflections were shared on how they experienced the workshop, what they found to be easy or difficult and suggestions for future workshops of the same nature. The feedback gathered from these communications added to the depth at which the reasoning process was operationalised for each participant and was added to their reflections of the workshop and stimulated recall

interviews. Their statements were used to confirm their intentions in the animation creation adding to the reliability within the descriptions within the data analysis. The WhatsApp notes also aided participants as a point of referral if they forgot how to perform a certain technological function or if the group had any suggestions for easier methods to achieve specific technical outcomes. This discussion could therefore be considered a facilitated lesson in the use of the software during the intervention process.

7.7. Interrater reliability

Qualitative studies tend to lend themselves toward a higher level of subjectivity in the interpretation of data. Therefore, in order to maintain the reliability of the findings, measures were put in place to ensure that a manner of standardisation was maintained concerning the results reported on. In this study, two methods were adopted and triangulated to the same data sets to ensure that the intended information that was supplied by the participants was interpreted accurately according to the participant, researcher and an objective, knowledgeable third party.

From the initial data analysis the researcher and another, more qualified researcher, knowledgeable in TSPCK and its extended research analysed the full set of data from one of the four participants. This set the standard of agreement regarding the analysis process and extraction of data accurately according to the tools and frameworks used in this study. Secondly, the findings of the data were shared with the participants for clarity using a stimulated recall interview. This enabled the researcher to confirm the intentions of the participants regarding their use of certain images, motions, items and signals, as well as assist the researcher in clarifying the use of digital-TSPCK components that may not have featured clearly, specifically in the animations.

The following chapter will reveal the findings from the different data set analyses and the interpretations of the findings to reveal possible patterns or trends in the creation of an animation due to the use of the intervention workshop used for this study.

Chapter 8

8: Findings and discussion

The previous chapter elaborated on the different data that were collected during this study and described the qualitative tools used in their analysis. It was further shown what research question responses the analysis of each data set would deliver. In this chapter, emerging findings from the analysis process are presented. The overall aim of this Chapter is to present findings evident of the surfacing digital-TSPCK in the practice of in-service teachers who were exposed to an intervention on digital-TSPCK, in digitally transforming content for creating animations on electromagnetism.

8.1 Introduction

This study employed a qualitative research design using a case study approach. The case in point was an intensive, case study of four (4) practising physical sciences teachers who were exposed to an intervention introducing them to digital-TSPCK, as the teacher knowledge for transforming content knowledge digitally for digital lessons. Common across the 4 in-service teachers was the fact that they all taught the same subject at the same grade level, and had all faced the educational challenges brought on by the COVID-19 pandemic and were aware that they would need to sometimes teach their students remotely. As previously discussed, the intervention workshop focused on pedagogical transformation of content for a digital format of animation. The content of interest were the big ideas of electromagnetism. The data sources received from the participating teachers included: pre-intervention videos, which were used as a baseline assessment of the teacher knowledge they possessed, animation planning digital-TSPCK storyboards, completed animation teaching videos, WhatsApp discussions and stimulated recall interviews. The data collected for this study was to assist in opening windows into the teachers' application of the digital-TSPCK components in the creation and production of their own animation videos.

8.2 Findings from the pre-intervention videos (Baseline Analysis)

As mentioned in Chapter 3, participating teachers were requested to submit videos of their classroom lessons as a baseline impression of the level of TSPCK they exhibited on the topic, as practicing teachers. As alluded earlier, it has been postulated that a teacher cannot have digital-

TSPCK if they did not exhibit TSPCK as the two share fundamental components relating to the pedagogical transformation of content knowledge. In addition, the videos would provide opportunity for evidence of any digital-TSPCK to surface, as the teachers might already have as a skill set as they use technology in their classroom.

Each of the teachers presented a lesson in Physical Sciences, using the technology that they would normally use in their traditional classroom as seen in Figure 8.1. It was possible to identify TSPCK episodes in their submitted videos. TSPCK episodes are segments in the recorded video lesson where two or more TSPCK components are visibly interacting with each other in a complementary manner.

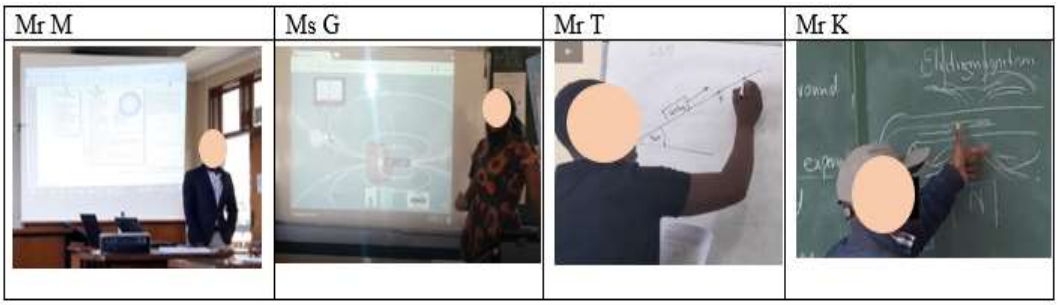


Figure 8.1 Excerpts of the pre-intervention videos

In Figure 8.1 excerpts of the video images were taken from each teacher showing a depiction of their lesson, the topic under discussion and the use of technology in their lessons, if any. It can be seen that Mr. M and Ms. G used projectors during their lessons, but Mr. M used it as a way to show the notes on the screen and teach from it, whereas Ms. G used the projector to show a teaching simulation and an explanatory video during her lesson. Mr T and Mr K wrote on their boards and explained using the representations they drew. It was possible to identify TSPCK episodes in their submitted videos.

The following key was used to depict the TSPCK components drawn in circles.

LP=learner prior knowledge

RP= Representations

WD=what is difficult to teach

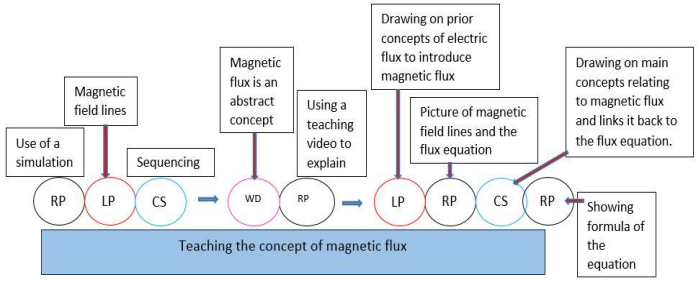
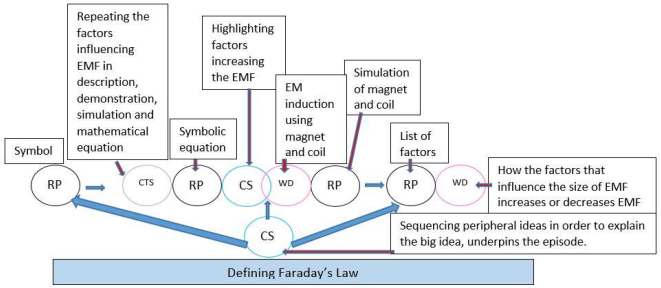
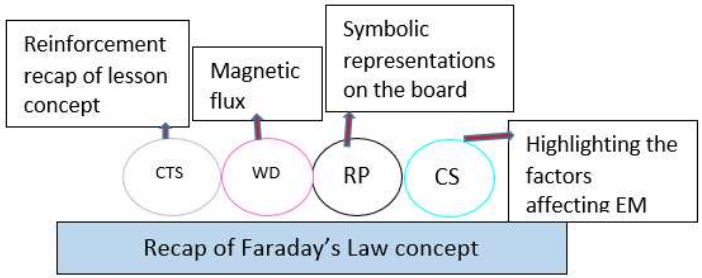
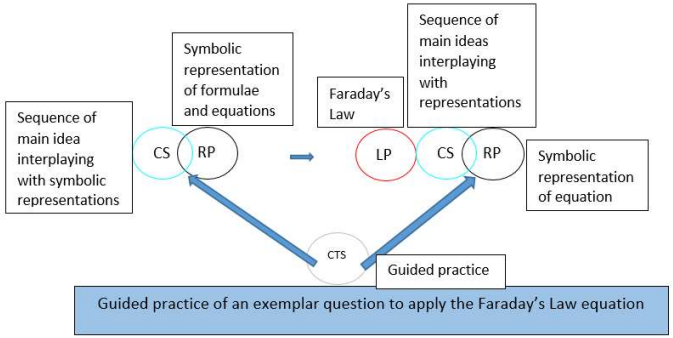
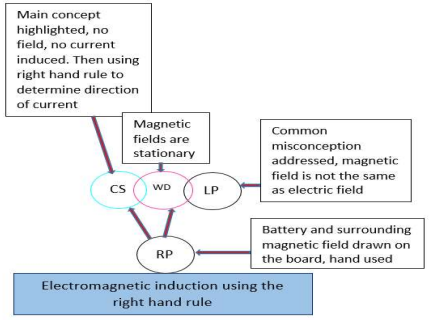
CS=Curricular saliency

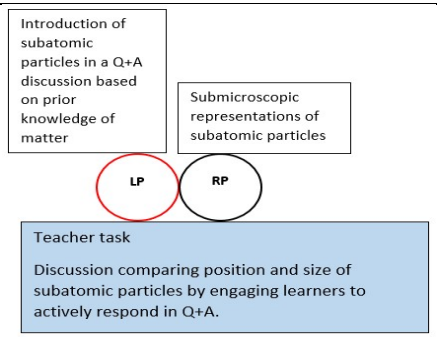
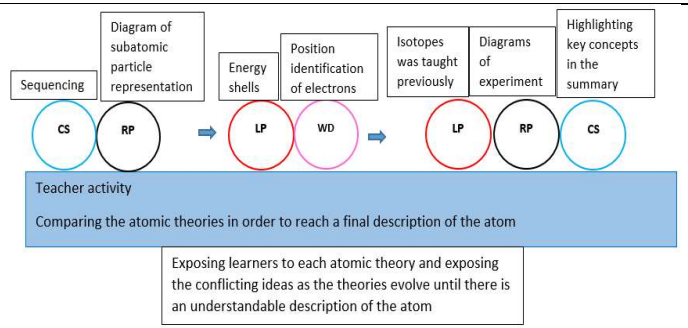
CTS=Conceptual teaching strategy

Teacher task in action

The colourless squares in the maps are brief descriptions of the component identified within a teaching episode. Where component circles were drawn next to each other, the components were visible in the same teaching segment in the given sequence. Where the component circles overlapped with each other, it indicated a more desirable interaction between the components in the identified episode, where evidence of drawing on several components indicates an interactive use of one then another then back to the one etc. The TSPCK episodes were then presented as TSPCK Maps reflecting the identified interacting components, as well as the teacher tasks in which the TSPCK episodes were respectively embedded, as seen in Table 8.1. In a TSPCK Map, the visible components of TSPCK are illustrated in solid circles. Those components implied by the evidence but not visibly seen (for example learner misconceptions) are represented using circles with dotted lines. The specific task that the teacher is doing is explained in a rectangular box that serve as a platform for the circles. Interacting TSPCK components are represented with intersecting circles and an arrow indicates the direction of the sequence in which the interactions occur during a lesson.

Table 8.1 TSPCK maps of pre-intervention videos

Ms. G Lesson on Electromagnetism		
		
Mr K Lesson on electromagnetism		

<table>
<tr>
<td rowspan="2">Mr M
Lesson on particulate nature of matter</td>
<td>
</td>
<td>
</td>
</tr>
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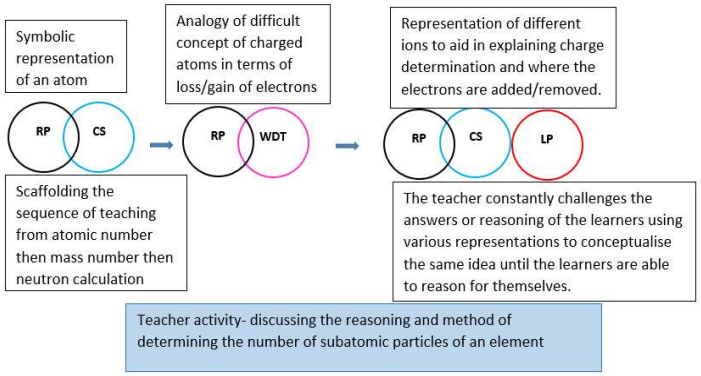
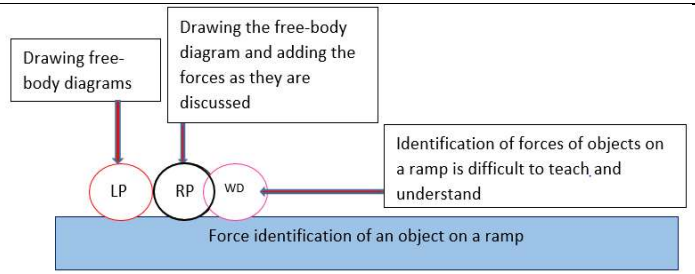
<td>
</td>
<td></td>
</tr>
<tr>
<td>Mr T
Lesson on Newtons Laws</td>
<td>
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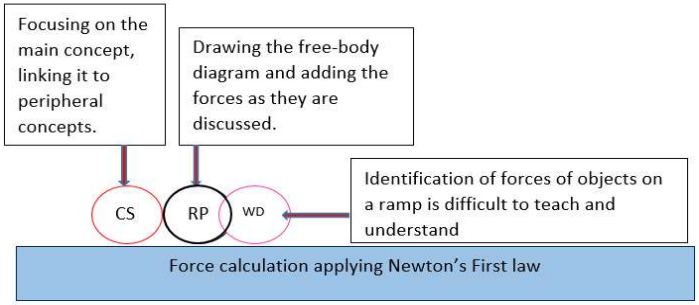
<td>
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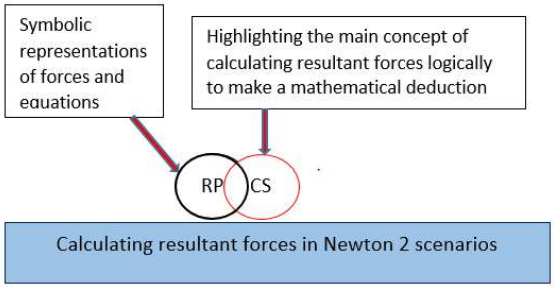
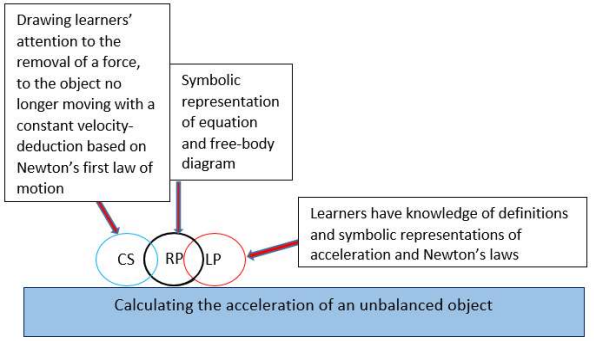

Symbolic representations of forces and equations
Highlighting the main concept of calculating resultant forces logically to make a mathematical deduction
RP
CS
Calculating resultant forces in Newton 2 scenarios


Drawing learners' attention to the removal of a force, to the object no longer moving with a constant velocity- deduction based on Newton's first law of motion
Symbolic representation of equation and free-body diagram
Learners have knowledge of definitions and symbolic representations of acceleration and Newton's laws
CS
RP
LP
Calculating the acceleration of an unbalanced object

Generally, the submitted videos were about 60 minutes long, in excerption of Mr K whose video was the shortest at 4 minutes and 40 seconds. Two of the teachers, Ms G and Mr K, provided recorded videos on electromagnetism, while Mr M, sent through a video on particulate nature of matter and Mr T's video was focused on Newton's Laws of motion. Mr M's video displayed three teaching episodes during his lesson where he was teaching, using the history of the atomic model, to describe the subatomic particles of an atom. He then used this information to teach learners how to determine the number of subatomic particles of neutral atoms and ions from the periodic table. There was evidence of curricular saliency, representations and learner prior knowledge in his episodes. The component interactions were limited to two or three components in a segment. Ms G displayed four teaching episodes teaching Faraday's Law, applying more complex component interactions with a clearly reasoned teaching strategy of using various techniques (simulations, video and question answering) in a repetitive form to reinforce the main ideas in the lesson. Her TSPCK maps indicated a more developed TSPCK component interaction. Mr T's lesson displayed six teaching episodes, mostly derived from each of the exam-type questions on Newton's laws he was teaching the learners to answer. The component interactions were limited to two or three components per segment, which could also be a result of the nature of the lesson (question answering). Mr K exhibited one clear teaching episode. As alluded, his video was the shortest, 4 minutes and 40 seconds, explaining the right hand rule. There was evidence of component interaction dependent on the representation he drew on the board. It was a great concern though that his diagrammatic representation was not neat or accurate, lending much opportunity for the development of misconceptions in terms of representing magnetic field lines. He continued to explain the right hand rule using his left hand, which was another opportunity for confusing the learners. Mr K was not a first year teacher, and had previously taught this subject in a previous year, and recommendations regarding a workshop to upgrade his content knowledge was suggested.

The resulting evidence of the videos indicated that these educators did indeed exhibit the existence of TSPCK albeit in varying levels of proficiency in the specific topics examined. Unfortunately, the analysis of each of the teaching videos did not indicate evidence of digital-TSPCK. The digital equipment used, if at all, was used as a teaching aid to merely change the mode of representation. There was no clear evidence that any of the teachers designed their own learning material to the extent where any digital-TSPCK components were visible. The findings were interesting in

providing a reasonable assumption and baseline to interpret any surfacing evidence of digital-TSPCK post the intervention. The understanding carried forward was that the in-service teachers started the intervention with no knowledge and evidence of digital-TSPCK in their teaching practice.

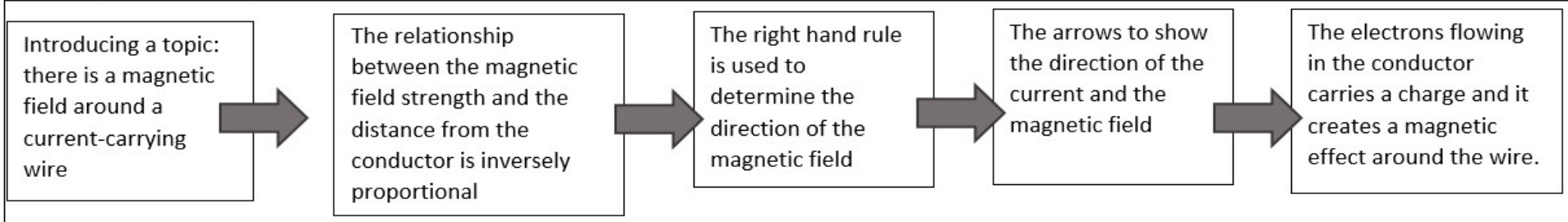
8.3 Findings from the CoRe Storyboards

As alluded in Chapter 3, the idea of CoRe storyboards has been adapted from the original concept of CoRes (Loughran et al., 2004) which portrayed evidence of PCK by reasoning. CoRes are organised through the teaching of the "big ideas" of a topic an element of the TSPCK component of curricular saliency. CoRe storyboards thus followed this structure, and included prompts on all the components of all the constructs making up digital-TSPCK as described in Chapter 4. These are TSPCK, Principles of the Cognitive Load Theory for Multimedia Learning (CTML) and teacher digital competency. For the construct of TSPCK, CoRe storyboard contained components of TSPCK, which are: Curricular Saliency, Learner Prior Knowledge, Representations, What is difficult to teach or understand and Conceptual teaching strategies. For the Cognitive Load Theory, the components were the principles of Cognitive load theory for multimedia learning (CTML), which are: Segmentation, Content control, Signalling, Weeding and Matching modality. Lastly for the Teacher digital competence it was the digital functions needed to build the animation to convey the intended sequence, emphasis and conceptual understanding. Each participating educator completed a CoRe storyboard template with component prompts as part of their planning to design their animations.

Table 8.2 below shows an example from Mr. M who completed his storyboard to animate a lesson showing that a current-carrying conductor produces a magnetic field around it.

Table 8.2. CoRe Storyboard of Mr M in planning his animation

Single Big Idea in the animation video:		**There is a magnetic field around a current carrying conductor**	
What do you intend learners to learn about this Big Idea from the video?	There is a magnetic field around a current-carrying conductor	**What do you consider to be most important to be learnt in this Big Idea?**	The magnetic field produces about the movement of electrons which produces current
Why is it important for learners to know this and how did this inform your rationale in making the video?	Learners will know that moving electrons in a metal carries a charge which results in current flowing.	**Describe the typical learner misconceptions about this Big Idea. How will you address them in this video?**	Learners confuses a magnetic field to/with an electric field.
What concepts need to be in place for learners to engage with this video?	• Moving electrons carry a charge • Static electricity is a result of a build-up of charges (unbalanced charges) which can be transferred.	**What other factors may influence your teaching of this idea when making this video?**	Magnitude of the electric current and the perpendicular distance between the point and the conductor
What else do you know about this Big Idea that you do not want to include in this video, and why.	Triboelectric effect- charging different materials as they come in contact to one another. The needle of a compass is magnetic	**What do you consider easy or difficult to understand about teaching this Big Idea that inspired**	The right hand rule which gives us an indication of the direction of current around a current-carrying
What representations are you going to use in this video for teaching the Big Idea? **Provide a list of the representations (including digital resources) you envisage to use and also describe how they are to be used in each case.**			
Introducing of the topic/big idea through animaker presentation	Digitals used: • A laptop • Projector • Application Animaker Also: * a wire *a compass * chalk + board	• Demonstration using the right-hand rule and magnetic field direction and current in a straight current-carrying conductor • Representing a solenoid's magnetic field lines.	
Provide your teaching sequence below			



In what ways will you ensure that the scene outlined above for your video will help learners to focus on the big idea that you are aiming to teach through this video? Think about, and enlist the technological functions that will make your video functional and effective for learning. Think about how you consider: Signalling, Segmenting, Weeding, Matching modality		
• Adding arrows to indicate the direction of electron's flow • Setting time frame appropriately • Setting the soundtrack to fit with the characters/pictures.		
When you create the animation, what considerations will you take into account?	The time frame must be limited to the information I shouldn't add too many pictures	
When you edit your video, what considerations will you take into account?	The sound must be clear, the electrons must flow smoothly.	
Animation video creation		
Video shot 1	Video shot 2	Video shot 3
Strictly introduction of the main topic	Our goal is to prove the main idea	Electrons flow in a conductor
Script: Mr M's introduction of himself and the topic	Script: There is a magnetic field around a current-carrying conductor.	Script: Electrons to flow smoothly so that no negative idea may ne created.
Technical notes when using Animaker to create	**Technical notes when using Animaker to create**	**Technical notes when using Animaker to create**
1. Click on the new project 2. Select a character and actions of the character 3. paste pictures and move each accordingly (electrons)	1. Click on the new project 2. select the character, then choose actions on the character	N/A
Technical notes when using Hitfilm express to edit	**Technical notes when using hitfilm express to edit**	**Technical notes when using hitfilm express to edit**
1. Select Animaker file to import to the timeline. Type the big idea on the viewer 2. Type on the vierwe magnetic field	1. Select animation file and other files and export 2. On the viewer type magnetic field 3. Do a voice over	1. Select the file to import to the timeline 2. Type magnetic field around a current-crrying conductor 3. Do a voice recording voice.

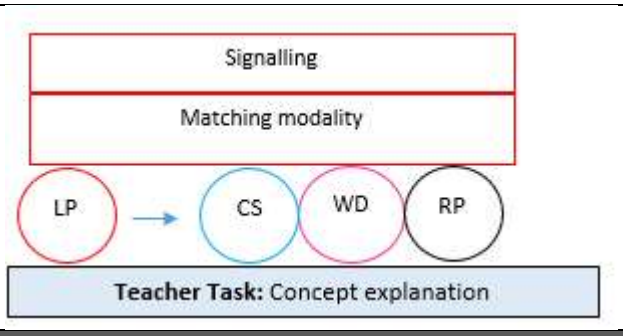
In his planning above, Mr. M has made considerations of TSPCK components by his responses to the prompts on core message to be learned in a Big Idea, for example, he indicated that it is most important for learners to know that it is the movement of electrons in the conductor that produces the magnetic field around the conductor. Clarifying the core conceptual meaning to be learned in an instance is part of curricular saliency. Knowledge of the component curricular saliency further demand clarity of the rationale behind the intended conceptual meaning to be established, and the identification of the pre-concepts needed for laying the foundation for the new intended message. His responses to these prompts reflect the needed acceptable depth to enable discussion. He referred to moving electrons in a metal carrying a charge, which results in current in a conductor. The direction of the magnetic field is also determinable using the right-hand rule. His responses to the above curricular saliency type of prompts read in conjunction with his presented sequence of shots in the direction shown by the arrows, presents evidence of his knowledge of the TSPCK component of curricular saliency. Mr M's depictions of movement of current in a magnetic field are needed to gird his discussion of the intended main concept. His identification of prior knowledge where learners were taught that static electricity is a build-up of charge, and moving electrons carry this charge through a conductor is a flow of current, enables concept progression to the effect of the moving charge resulting in a magnetic field around the conductor. It can be seen in the storyboard that he considered pedagogical (sequencing, portraying key ideas, representations, learner prior knowledge and what is difficult to teach), technical (type of software) as well as multimedia cognition (segmenting, signalling, weeding and matching modality) components in his planning of the animation. Mr. M used the teaching sequence prompt to arrange the order in which concepts would be displayed to the learners in his animation, from his introduction of a magnetic field forming around a current-carrying conductor to the relationship between the magnetic field strength and its distance from the conductor, to the use of the right hand rule for determining the direction of the magnetic field formed. He indicated that learners' prior knowledge may include a misconception of confusing an electric field with a magnetic field. The representations consisted of a conductor showing a sub-microscopic representation of the electrons flowing through the conductor, and a macroscopic representation of the magnetic field lines and the right hand to represent the right hand rule. In terms of technical considerations, he listed the hardware to be used (laptop, projector) and software (Animaker). In the storyboard for technical notes, he described the practical considerations for the use of the software to perform

certain functions, for example when using Animaker to create the animation he noted, “Click on the new project. Select a character and the actions of the character. Paste pictures and move them accordingly (electrons)”. When using Hitfilm express he described file selection for importing onto Hitfilm from Animaker and to type in additional content and perform voice-overs. The consideration of the CTML principles was evident in the storyboard for scene creation. He planned to add arrows to indicate the direction of electron flow (signalling), setting the soundtrack to fit in with the images (matching modality), setting the time frame appropriately (segmenting) and that there should not be too many pictures in the scene and the sound needed to be clear (weeding).

Each educator’s storyboard was analysed to extract the considerations made through content analysis of the responses provided against each of the prompts of specific animation they wanted to create for the big idea of electromagnetism the chose. The similarities and differences between the storyboards were determined by the prompts already available to each educator and the specific idea each educator wanted to portray. The summaries of the storyboards for each educator is shown in Table 8.3 below.

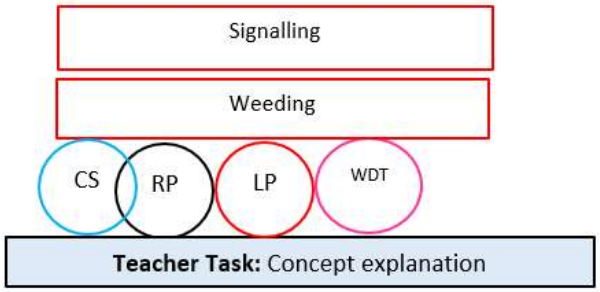
Table 8.3. Comparison of the digital-TSPCK components exhibited in the CoRe Storyboards

Ms. G	
Components visible	Descriptors from storyboard
Learner prior knowledge	Learners already know that magnetic fields are created by magnets and forms a magnetic field pattern.
Curricular saliency	Sequencing of the animation and display of main concepts
What is difficult to teach	When current passes through the conductor. Abstract creation of magnetic field, cannot be seen with the naked eye.
Representations	Must show : Moving electrons Magnetic field Represented by displaying a wire with the above representations to convey the big idea.
Signalling	Show the magnetic field lines, show how the electrons move.
Matching modality	Match script to the magnetic field, electrons when they move.



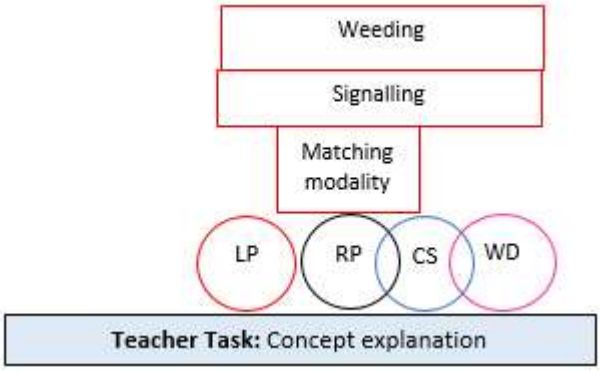
Mr. K	
Components visible	Descriptors from storyboard
CS	The sequence of the animation It is important that the lesson show the main idea of the force and its effect in the magnetic field. The change in current direction also changes the force direction as indicated using the right hand rule of Faraday's law
RP	Moving charge in a conductor. Current flowing in a conductor using charges to present the electrons The current-carrying conductor induces a magnetic field. Field lines appear on wire. The current-carrying conductor then experiences a force in an induced magnetic field. The arrows to show the direction of the current and also reverse direction to also give direction of the force
LP	Learners might have misconceptions that field lines are somehow moving charges. I will have to clarify that only current consist of moving electrons.
WDT	Magnetic field are not moving charges. It The magnetic field lines are showing the direction but they themselves are not moving. I don't want to include arrows because learners will misinterpret the purpose of field lines

	For learners to distinguish between magnetic field lines and the force that is not visible but affect the movement of current carrying conductor.
Segmentation	Video set to be less than 3 minutes
Signalling	Effects taking place around the conductor that cannot be seen with the naked eye The arrows to show the direction of the current and also reverse direction to also give direction of the force.
Weeding	Don't want to include arrows because learners will misinterpret the purpose of field lines.
Matching modality	Not mentioned.

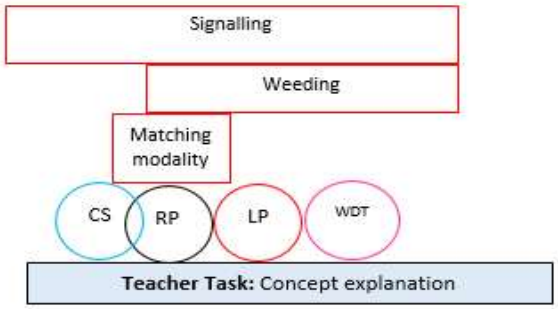


Mr. M	
Visible components	Description from storyboard
Curricular Saliency	Sequencing of concept to be discussed Bring to light the big idea in the animation
Segmenting, weeding, matching modality	Entire animation plan Setting the soundtrack to fit in with the images (matching modality), setting the time frame appropriately (segmenting) and that there should not be too many pictures in the scene and the sound needed to be clear (weeding).

Learner prior knowledge	Charged particles exist in atoms. Magnetic fields exist
Representations , What is Difficult to teach, Signalling	Representation of a magnetic field forming around a conductor. WDT difference between magnetic field and electric field. Shot 1 timing of words appearing. Signalling- use of arrows and movement to show direction of current and magnetic field. RP- electron flow (signalling) in the conductor. WDT electrons must move, and direction maintained to avoid misconceptions. RP- Right hand rule.



Mr. T	
Components visible	Description from storyboard
Curricular saliency	Sequencing of the animation and display of main concepts
Representations Signalling, weeding , matching modality	All images portrayed. Arrows and movement signal attention, weeding for voice clarity Matching modality to match text and visuals in each scene.

Learner Prior knowledge	Uniform magnetic field
What is difficult to teach	Fleming's left hand rule
	

The storyboards of each educator showed some similarities in the components that they used to place the most emphasis in the creation of their animations of the same topic. They most prominently featured components among all the participating educators were Representations (RP), What is difficult to teach (WD), Learner Prior knowledge (LP), Curricular Saliency (CS) signalling, weeding and matching modality and some digital functions.

Interactions among the components of TSPCK were easily identifiable and visible as expected. It was observed empirically, for the first time, across all the digital-TSPCK maps that the CTML principles tend to work in multiples, complementing each other. This is in alignment with the postulation made in Chapter 5. Interactions across components of TSPCK and the principles of CTML were signalled by the written responses from the prompt about the construction of the video shots. Expression such as "*The time frame must be limited to the information, I shouldn't add too many pictures* [Mr M]" is indicative of the consideration for the CTML principle of weeding over the video shots that would have representations (RP) and explanation on magnetic fields (CS). Further expressions indicative of the interactions across the different constructs, included responses pointing to the use of an arrow to emphasize or create a clear understanding of the point of focus or the direction to be noted. This reflected interactions between the CTML component of 'signalling' working together with text or teacher voice that was indicating what was important to understand (curricular saliency). Ms G chose to use representations (RP) of learner prior knowledge (LP) (magnetic fields and electrons) as she noted, "the inability to understand abstract concepts like the movement of electrons (signalling) and magnetic field lines can lead to misconceptions and hinder learner understanding of concepts." Mr T showed how the CTML

principles work complementary to each other as he aimed to prevent learner misconceptions by correctly choosing his vectors (RP), showing the direction of the magnetic field (signalling) and ensuring the audio and voice-over remains clear and in sequence with the images (matching modality). It was noted that the different technological functions mentioned in the CoRe-storyboards under each video shot, were meant to bring forward the intended conceptual emphasis or understanding expressed through TSPCK component responses. This observation of the interactions among components of the same construct and across different constructs in the same lesson segment, confirmed the visibility of digital-TSPCK episodes in the teachers' planning, for example, Ms G expressed focus on learner Prior knowledge of magnetic fields in her planning. She expressed a plan where the learner prior knowledge of magnetic fields was to be represented visibly, and synchronised with her audio statements of explanations. Mr T emphasised in his plan to specifically sequence his main concepts as representations that he intermittently speaks over, hence the CS and RP component overlap in the digital-TSPCK map.

Planning the animation using the CoRe Storyboard guided the educators to familiarise themselves with the both the pedagogical, technological and cognitive aspects to take into account as they envisioned their end-product of an animation teaching video. The storyboard focused their attention on the factors they needed to take into account when designing the animation to ensure that it would be scientifically correct, pedagogically sound and mentally stimulating and not load demanding. With the template as the foundation for the development of their animation as they were not facing the actual execution process of animation making without a pedagogically reasoned vision of what they expected their animation to look like.

Overall, the completed CoRe storyboards, provided promising signals of the surfacing digital-TSPCK, which is teacher knowledge about what considerations are to be made for a successful digital transformation of content knowledge.

8.4 Findings from the built animation teaching videos

The created animation teaching videos (referred to as animations henceforth) were brief in nature (1- 2 min), providing explanations of the specific concept within a topic. Animations take a long time to create, however they can accommodate a large quantity of information owing to the intentional placement of every image or sound. Due to the brief nature of the animations, the component of segmentation (requiring the digital products to be brief to minimize extraneous

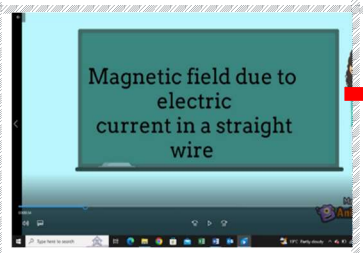
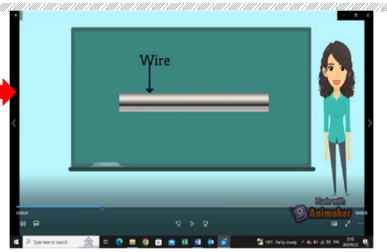
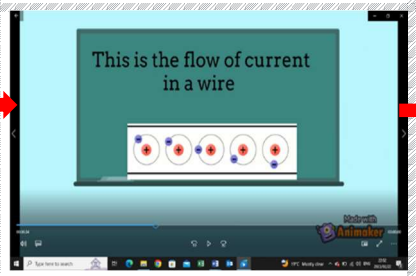
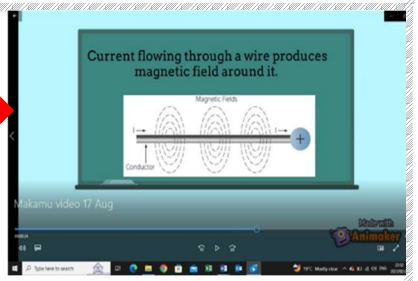
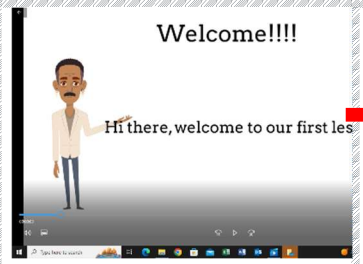
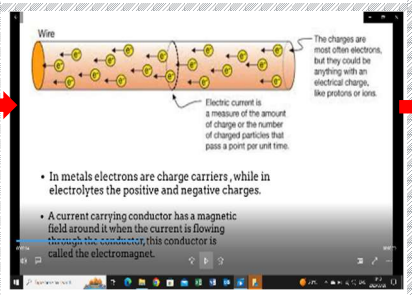
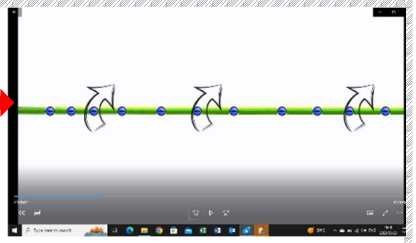
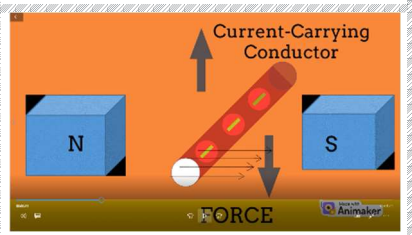
cognitive demand on learners) was considered to be a standard feature for these animations. The animations were analysed using the soundtrack transcript together with the presented images, scene by scene in order to depict the images, signals and synchronicity. Thereafter the components of the constructs found present were identified the nature of their interactions outlined. Presented below first, is the overview of the still shots of the animations presented scene by scene for each of the participating teachers as shown in Table 8.4. This was followed by the mapping of each submitted animation for any surfacing digital-TSPCK. Mr. K did not submit his created animation as he withdrew from the study at this point, allowable by the voluntary nature of participation as accommodated in the ethics protocol.

8.4.1 Emerging patterns from the overview of the created animations

It is important to note that the submitted animation videos were functional, meaning they worked smoothly delivering the intended message from start to finish without glitches. Thus the still scene by scene shots presented in Table 8.4 below, were from the created animation videos that are functional. It is noted that the created animations were similarly addressing the introductory Big Idea of the relationship between a current carrying conductor and the resulting magnetic field. Despite having targeted the same Big Idea, it is noted how each teacher produced a different, and unique set of scenes. While the teacher voices are muted and the motions frozen in the presented still shots, one can observe a few common features signalling the application of the TSPCK and the CTML principles interactively. The following features are noted from Table 8.4:

- The presented scene shots are less cluttered, signalling consideration of the CTML principle of weeding.
- There is an evident effort in using representations at both the macroscopic and sub-microscopic levels. Depending on how these representations have been used in conjunction with voice audio and the choice of motions, there could be component interactions across representations and other components of TSPCK or CTML principles. These will be unpacked in the analysis of the individual animations below.

Table 8.4: An overview of the created animations on electromagnetism - scene by scene.

	Scene 1	Scene 2	Scene 3	Scene 4
Ms G				
Mr M				
Mr T				

8.4.2 Emerging patterns from the individual animation video analysis

(i) Animations by Ms G

Figure 8.2 summarises the animation created by Ms G.

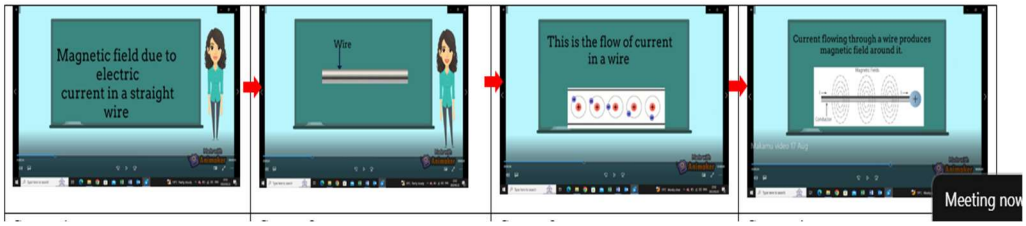


Figure 8.2. Scene-by-scene shots of Ms. G's animation

Ms. G chose to discuss the creation of a magnetic field around a conducting wire. The animation began with an introduction and showed a representation of a wire as we would see it with the naked eye. In that scene, signalling was used in the form of an arrow and label of the wire while a verbalisation of "*This is our wire*" is heard at the same time, an indication of matching modality for the scene. She then changed the scene to show the wire if it were possible to magnify it to the sub-microscopic level. In that scene she depicted a basic representation of atoms in the wire where the nuclei were static and the electrons were circling the nuclei, but dissociated enough so as to form a general movement of delocalised electrons toward the right of the screen as if there were current flowing. The script spoken in the scene, "*This is the flow of current in the wire*" and written text appeared on the screen synchronized with the verbal sentence, indicating signalling and matching modality. Thereafter she reverted back to the macroscopic representation of the wire, indicating the current that was flowing, and the resulting magnetic field around the wire. The direction of the current was depicted by an arrow. There is a clear indication in Figure 8.2 of two TSPCK components, Curricular Saliency and Representations interacting throughout the animation to support the explanation of the related concepts. Curricular saliency is evident in the sequencing (from a macroscopic representation of a wire, wire then current in the wire magnified to show the sub-microscopic particles in the wire, then the creation of magnetic field around the wire due to the current) and the main concepts that were displayed. Representations could be noted in the visual aspects created by the teacher- the wire, the atoms, the magnetic field lines which represented the main concepts of the animation. Therefore, these two components were depicted as overlapping in the digital-TSPCK map as their functions are dependent on each other as was confirmed in the stimulated recall interview. Ms. G noted in her storyboard that learners have a misconception that magnetic fields were only created by magnets, and she would address it with a

representation of the emerging magnetic field lines around the conductor as noted from the storyboard:

"I will address the first misconception by showing the formation of magnetic fields around a current carrying conductor. This will make more sense to learners because in this case a magnet will not be used to demonstrate magnetic field around it".

Therefore learner prior knowledge, although not explicitly visible (represented by dotted lines), interacts with representations as overlapping circles to inform learners of the existence of the magnetic field that formed. The TSPCK component of What is difficult to teach and understand was depicted as a representation. When questioned during the stimulated recall interview, it was mentioned that she had changed the look of the representation in her final version, with reasoning stated as follows:

"Ja, that's why I changed it, and then I had to show them the flow of electrons, because I think that somewhere I mentioned that the electrons they cannot see them with their naked eyes so I had to indicate that on the, inside the wire and draw their attention to it.[Ms. G. extract from stimulated recall interview]"

No distractions were noted, signalling considerations for the weeding principle of CTML. Furthermore, there was evidence of matching modality between visuals, audio and text. This is seen through their synchronization across the entire animation, and the choice of still or mobility of representation to match specific concepts and avoiding misconceptions that the magnetic field is moving. Signalling was achieved using the motion function. Weeding had been applied to the animation to eliminate extraneous information, visuals or sound. The observed multi-construct components and their interactions have been mapped into a digital-TSPCK map as shown in Figure 8.3

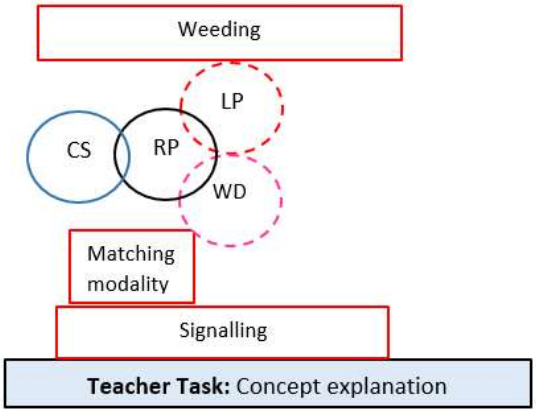


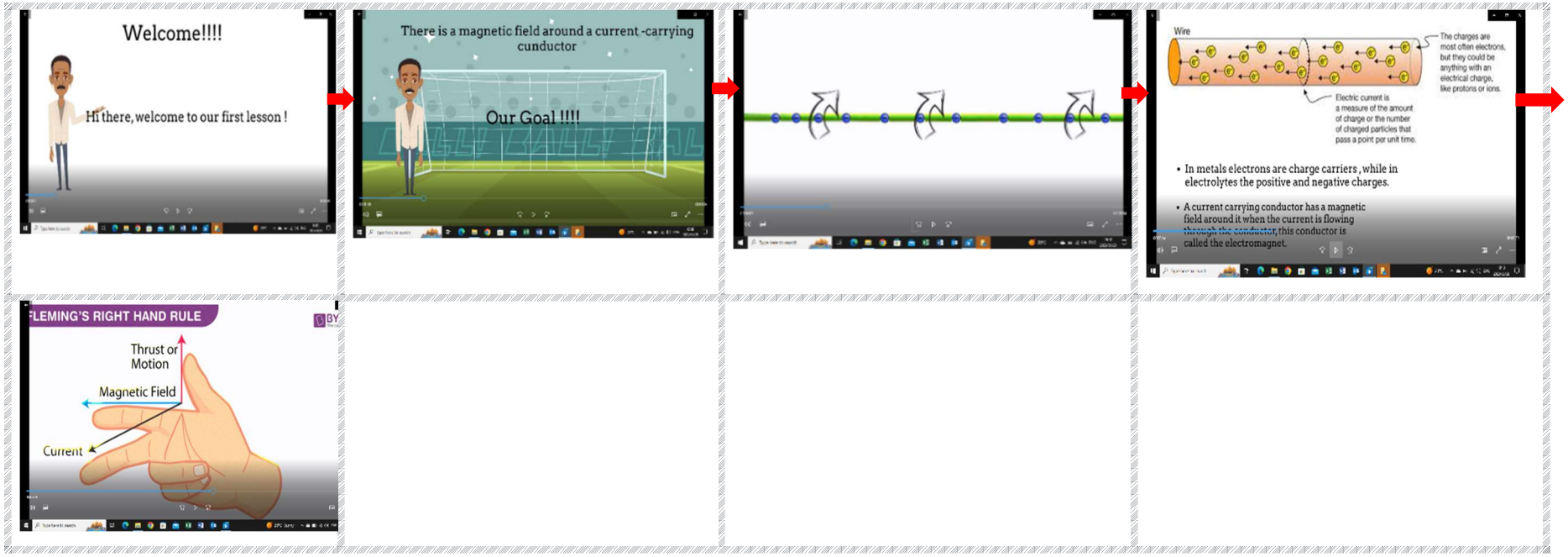
Figure 8.3. Digital-TSPCK map of the animation created by Ms. G.

Figure 8.3 shows a pictorial representation of the interactions of the digital-TSPCK components in the animation explaining how a current-carrying conductor experiences a force in a magnetic field. As alluded earlier, the teacher used representations at multiple levels, sequences logically with endorsing audio and text. This occurrence reflected the interactions of the components of TSPCK, shown in Figure 8.3 as interacting circles between curricular saliency and Representations. Representations also interacts with two other TSPCK components not explicitly visible in the animation, but implied through the planning visible in the storyboard and confirmed by Ms. G in a stimulated recall interview. Furthermore, it is noted that the representations are strengthened by being matched to appropriate audio, text and choice of use of motions or still at specific times. Here we see interactions between the TSPCK component of representation and that of CTML, matching modality. This interaction between the components of different constructs is indicated in Figure 8.3 by a rectangular box placed in contact, directly under the circle of RP to show its selective interaction. This signals the appropriate use of the principle of matching modality specifically with representations. On the other hand, a dynamic interaction was noted as the representations moved, or floated into the screen as the arrows showed direction and drew attention to the concept of forces acting on the conductor, while the teacher signalled to draw learners' attention to these items during the lesson presented. This represented the use of synchronized signalling to endorse teacher explanation over representations with motion used to draw attention to the parts of interest. Here we see the CTML principle of signalling working to strengthen the interaction of the TSPCK components of representations and curricular saliency. This is another construct-construct interaction, slightly different to the 1:1 component seen with matching modality and representations, but now reflecting interactions with the interactions of

TSPCK components. Due to the absence of extraneous words, sounds or images, it was noted that the principles of weeding was observed throughout the animation, that signalling its interactions, working complementary with all the components (of different constructs) present in the animation.

(ii) Animations by Mr. M

Table 8.5 Summary of Mr. M's animation scenes



As depicted in Table 8.5, Mr M began the animation with a welcome and indication of the goal of the lesson. He changed the scene to a representation of a conducting wire on a sub-microscopic level with electrons moving across the screen to the right. As the electrons move from left to right across the screen, he said, "*In this lesson you will learn how the current-carrying conductor produces magnetic field around the conductor*." The way in which the image on the screen matches the verbalisation in the script is an indication of matching modality. Around the conductor there were transparent magnetic field lines depicted as arrows, although they were not labelled. It was assumed as such as this was mentioned in the scene verbally, later confirmed in the stimulated recall interview where Mr. M made the following statement:

"…the electrons are moving in a certain direction, so I was trying to show that around the conductor, there is a magnetic field, as the electrons are moving cause I also mentioned that the…in the conductor electrons are charge carriers. And then, as they are moving, they are carrying a charge in a certain direction. And then as that charge is moving, which is current, are moving throughout the conductor, then around the conductor the magnetic field forms… with the arrows I was trying to show that around the conductor, magnetic field will be produced". [Mr M, extract from a stimulated recall interview].

In the next shot of the animation, the image changed to a static image of a conducting wire with labels describing electrons as charge carriers in the wire. He then changed the scene to show Fleming's right-hand rule with the representation of a hand with matching arrows and labels, describing them to the viewer: "*Let's talk about the right-hand rule. The thumb, second and third finger must be at the right angle to each other.*" There was no further explanation of the purpose of the rule or the labels for each finger. The final scene depicted the right-hand rule applied to the conductor in a magnetic field without a voice over, only the electron was moving through the wire as a signal that there was current in the conductor. The scenes however did not flow smoothly with each other and the link between the first part of the animation (a magnetic field exists around a current carrying conductor) and the link to Fleming's left-hand rule at the end of the animation was not firmly established, therefore the learner would not be able to understand why there was a conceptual jump from the current-carrying conductor to the rule and its purpose. There is evidence in Table 8.5 of two TSPCK components, Curricular Saliency and Representations interacting throughout the animation to support the explanation of the related concepts. Curricular saliency

is evident in the sequencing (from a conducting wire with moving electrons, to the resulting magnetic field around the wire, but there was a tapering down to the application of Fleming's right-hand rule) and the main concepts that were displayed. Representations of the conducting wire, moving electrons, magnetic field, right hand rule, labels of each representation could be noted in the visual aspects created by the teacher. Curricular Saliency and Representations were depicted as overlapping in the digital-TSPCK map due to interacting during the animation. No distractions were noted and there is evidence of matching modality between visuals, audio and text. Signalling is limited to the motion of the electrons and static labels. Weeding had been applied to throughout the animation to eliminate extraneous information, visuals or sound. The analysis of the animation was converted to the digital-TSPCK map depicted in Figure 8.4.

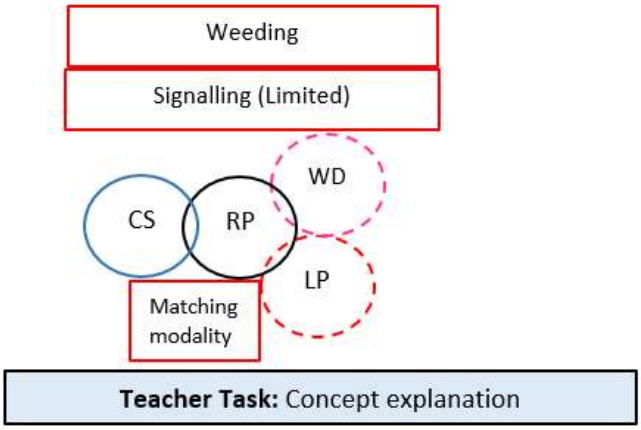


Figure 8.4. Digital-TSPCK map of the animation created by Mr. M

Figure 8.4 shows a pictorial representation of the interactions of the digital-TSPCK components in the animation explaining how a current-carrying conductor experiences a force in a magnetic field. Curricular saliency and representations interact with each other within the TSPCK construct as the main concepts can only be depicted in the animation as a representation, be it an image or a word or symbol. The CTML components of Weeding and Signalling interact complementary across constructs with the TSPCK components of Representations and Curricular Saliency because signalling highlights the main concept depicted by the representation and weeding ensures that the main concept is not obscured by unnecessary images or words. Therefore, in the digital-TSPCK map, the CTML components of signalling and weeding are drawn to span across CS and RP. The CTML boxes touch each other and the TSPCK components as an indication that these interactions are happening at the same time and not sequentially throughout the animation. Representations

are strengthened by the matching modality between audio and visual stimuli in the animation, as a result, the matching modality box was only drawn over the representation component which it was interacting with. The representation of the electrons in the conducting wire moved across the screen, indicated that he used signalling to a limited extent to draw learners' attention to these items during the lesson presented. There were no distracting images, sounds or words in the first four scenes, but there was not much attention given to the representations in scene five and six and it was not clear if these were simply not completed due to lack of time.

(iii) Animations by Mr. T

Mr. T's animation starts with a man greeting and the introduction of the topic. As he talks, the image enlarges to emphasise the topic wording, a form of signalling. In the second scene, the man is gesturing to the topic words as he talks. *"Today's lesson we will be looking at a current-carrying conductor experiencing a force in a magnetic field."* The image starts with a representation of a conductor in a magnetic field. The words on the screen match the script. Wording fades into the screen as the audio plays in sequence to the images, indicating matching modality. There are some cluttering images in the scene of a clock and pot plant and an image of magnetic field lines that were not explained, possibly drawing the viewer's attention away from the topic where Mr T could have been more conscious of the weeding principle. Scene three shows an image of magnet poles with the north and south poles both represented as blue, which risks causing confusion to learners as their prior knowledge the North Pole as red and the South Pole as blue. The current-carrying conductor drops down next to the wording and audio plays at the same time indicating matching modality. *"When a current-carrying conductor is placed in the magnetic field, remember magnetic field is represented by imaginary lines from the North Pole to the South Pole."*

Words on the screen disappear as the labelled force arrows appear (signalling) the written word is placed in the scene with matching audio (matching modality). Moving electrons in the conductor are labelled (signalling). Magnetic field lines appear as the audio refers to it (matching modality) and the writing also matches. Scene four shows the man on the left writing while the narrator talks with an image of a right hand appearing on the right of the screen posed according to Fleming's right hand rule, then arrows appear for each pointed finger with matching written text and audio. The representation of the conductor drops in between the poles of the magnet as the script describes this. Current is shown to pass through the conductor, which moves when it experiences the force.

Signalling and matching modality is noted as the wording and actions occur at the same time. Words on the screen disappear as the labelled force arrows appear the written word is placed in the scene with matching audio. The last scene shows the man saying that the lesson has ended and give an encouragement in words on the screen as he verbally speaks it.

Curricular Saliency and Representations interacted throughout the animation to support the explanation of the related concepts. Curricular saliency was evident in the sequencing (from a wire in a magnetic field to the application of Fleming's left hand rule) and the main concepts that were displayed. Representations could be noted in the visual aspects created by the teacher- the wire, the magnets, the magnetic field lines and left hand which represented the main concepts of the animation. Therefore, these two components were depicted as overlapping in the digital-TSPCK map as their functions are dependent on each other. Minor distractions were noted and there is evidence of matching modality between visuals, audio and text. Signalling is enhanced by motion. The corresponding digital-TSPCK map is pictured below in Figure 8.5.

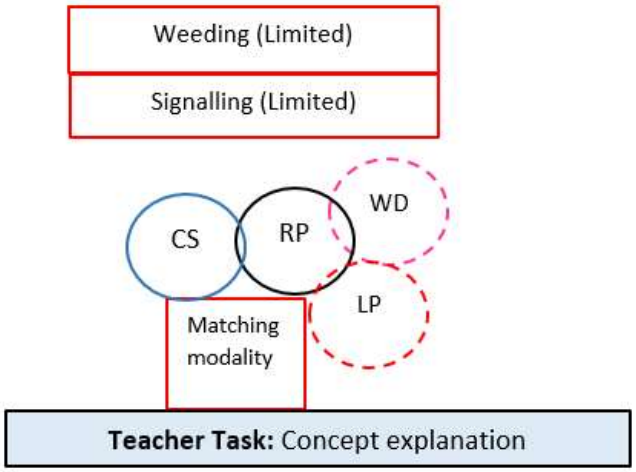


Figure .8.5 Digital-TSPCK map of the animation created by Mr. T

Figure 8.5 shows a pictorial representation of the interactions of the digital-TSPCK components in the animation explaining how a current-carrying conductor experiences a force in a magnetic field. Curricular saliency and representations are depicted as overlapping circles showing component-component interaction within the TSPCK construct as the main concepts can only be depicted on the animation as a representation, be it an image or a word or symbol. Representations are strengthened by the matching modality between audio and visual stimuli in the animation.

Representations of electrons moved across the screen as the arrows showed direction and drew attention to the concept of forces acting on the conductor, hence the teacher signalled on order to draw learners' attention to these main concepts within the topic indicating a construct-construct interaction between the representations of CS and signalling. This is why the CTML box was drawn over all TSPCK components as the interaction occurred between all three components during the lesson presented. The components were drawn overlapping with each other due to their interaction during the animation. LP and WD were seen to be interacting with RP. These TSPCK components were not explicitly visible in the animation itself but Mr T planned to address the learner misconception regarding uniform field lines by representing them accurately in the animation and referring to them verbally in the script. He also noted in the storyboard that the application of Fleming's left hand rule was difficult for learners to understand. The animation contained a representation of the left hand rule, with arrows accompanying the words for each of the fingers while synchronous words were verbalised in order to clarify this difficult concept. Weeding was a limited component due to some scenes showing images like clocks and flower pots that were not discussed or relevant to the topic.

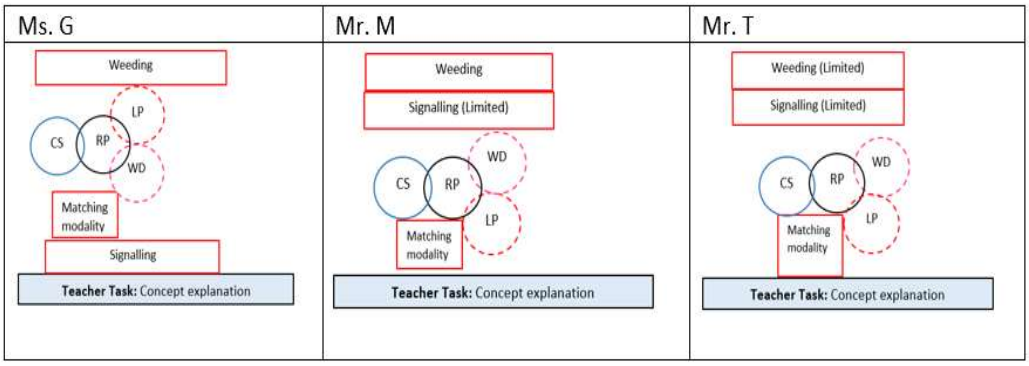
(iv) Summary of the emerging patterns

The emerging nature of the identified digital-TSPCK is summarised below. Mr K withdrew from the study and did not submit his animation, therefore no analysis was available for this comparison. Drawing from the digital-TSPCK maps of the three educators, the TSPCK components of CS end RP feature most prominently. The big idea and the sequencing of these concepts are transformed onto the digital platform as representations in a specific sequence. They are explicitly visible in each animation, for example we see this component interaction in Ms. G's animation where she first represents a wire, then the electrons moving in a wire, then the magnetic field forming around the wire. Each representation lends strength to the concept under discussion and the sequence in which the concept detail is built up enables an understanding of the requirements for the formation of the magnetic field. Less visible components, like LP and WDT become part of the representations that are seen already. As Ms G notes in the storyboard, learners struggle to make sense of abstract concepts like moving charges or magnetic field lines, she incorporated these concepts as representations into the original representation of the wire. To draw attention to the electrons, she creates motion in the scene. It can therefore be noted that there exists interaction

between the components of the TSPCK construct. The CTML components can be seen interacting in multiples, with weeding and signalling engaging across all the TSPCK components, indicating interaction between the components of the two constructs. Matching modality, a component visible when the visual representation, audio and text synchronise in an animation is most commonly associated with the RP component. Stimulated recall interviews confirmed the emergence of the whole map, including the implied components. In his animation, Mr. T represented a current-carrying conductor inside a magnetic field. His representation interacted with the Big Idea leading toward Fleming's left hand rule (CS), but he was aware that learners found the concept of uniform magnetic field difficult, therefore he had the field lines fade into the scene (signalling) and verbally mentioning them when they appear (matching modality).

In the digital-TSPCK maps of the animations created by each educator as seen in Table 8.6, it can be seen that the TSPCK components of Curricular Saliency and Representations interact with each other in order to bring each of their concepts to life on the animation screen.

Table 8.6. Digital-TSPCK maps of the participants' animations.



The main concepts of the big idea, for example electrons moving through a conductor causes a magnetic field to form around the conductor can best delivered to the learners on an animation platform in the form of animated representation. Each of the educators represented this concept, in varying sequences and with differing peripheral concepts. This showed the interaction between the components within the TSPCK construct. Furthermore, the CTML principles emerged to work in multiples, complementary across each other. The most common visible components of the CTML construct were signalling, matching modality and weeding. You may recall that the CTML component of segmenting has been considered a standard constant across all the videos as all met the requirement of being brief (Akinyemi, In press). Signalling took the form of moving electrons

in the conductor for each of the educators, but there were also other applications of signalling. For example, Ms. G used coloured text to accompany the conductor to signal the learners' attention and understanding. Mr. T used arrows that timely appeared when the conductor was placed in between the two poles of a magnet to indicate that the conductor was experiencing a force. Both of these signals assisted to drew direct attention to the specific representation and the text or audio message about the main concept on the screen, therefore it was shown in the digital-TSPCK map as making contact with the interacting TSPCK components of CS and RP. This observation reflected a construct-construct interaction between a CTML principle (signalling) and two TSPCK components in an interaction. Placing all the interactions of the components together in one representation culminated in a digital-TSPCK map for each animation as shown in Table 8.6. Several aspects of the digital-TSPCK maps show similarities across the three educator animations. Firstly, as alluded in Chapter 7, the technological competencies have not been included in the digital-TSPCK maps as it was posited that the fact that a functional animation, delivering the intended message (as seen from planning and the stimulated recall interviews) on a digital platform was created, was sufficient evidence for competency in that construct. Hence it was considered a constant. In the same way, due to the short timeframe of each of the animations, the CTML component of segmentation was considered common across each animation, and not represented in the digital-TSPCK maps. The components of weeding and matching modality were also implemented by each educator but where weeding occurred across the CS and RP interaction to remove extraneous load from the concept as well as the representation, matching modality only interacted with representations. Sound, images (representations) and text were to be synchronised in order to deliver a smooth animation for easy understanding. The only differences to be noted in the digital-TSPCK maps of the three educators is the extent to which the components were applied. Not all the TSPCK component interactions were visible in the completed animations were visible. Learner Prior knowledge (LP) and What is difficult to teach and understand (WD) could not explicitly be seen in the animations, even though a referral back to their CoRe storyboards indicated that the intention to address these two components were indeed present in their animation planning. In order to determine whether the intention translated into the animation, stimulated recall interviews held with the educators addressed this issue and confirmed the component and interactions between components identified by the researcher.

The digital-TSPCK map for Mr. M showed the CS and RP interaction with signalling limited to the moving electrons in the conductor only. Although Mr. M noted on his storyboard that the formation of a magnetic field around a conductor is difficult to teach, this was not evident in the animation. In the stimulated recall interview he noted that the magnetic field he wished to address came out as a representation in his animation, confirming that his intent was the same as in the planning as noted in this excerpt from the stimulated recall interview:

R: But you also knew that it's difficult to teach. So, is there a reason why you made your arrow in a certain direction and the fact that it is see-through and the fact that the electrons seem to pass, that they almost invisible?

M: Yes, um, because as you can see, um the electrons are moving in a certain direction, so I was trying to show that around the conductor, there is a magnetic field, as the electrons are moving cause I also mentioned that the…in the conductor electrons are charge carriers. And then as they are moving, they are carrying a charge in a certain direction. And then as that charge is moving, which is current, are moving throughout the conductor, then around the conductor the magnetic field um will be… with the arrows I was trying to show that around the conductor magnetic field will be produced.

Ms. G's animation showed clear sequencing of the topic with the main concepts of the wire, then a look inside the wire were represented and used the motion of electrons in the conductor, text with arrows pointing to the conductor to signal to the learners. The identified components were confirmed in the stimulated recall interview and she explained how the concepts of WD and LP she indicated in her planning featured in the completed animation as representations and signalling as noted in an excerpt from her interview:

R: The first one I could not see in your animation was Learner Prior Knowledge

G: Ja, I knew that learners already knew about the magnetic fields so I drew them there.

R: Ok

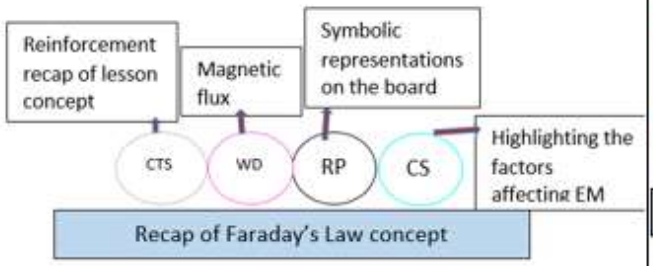
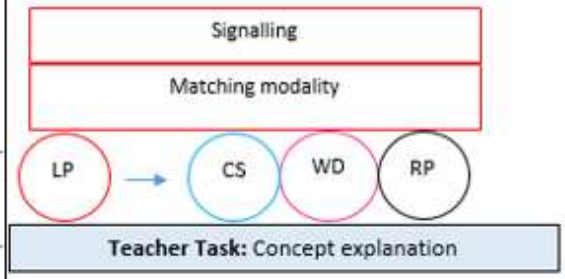
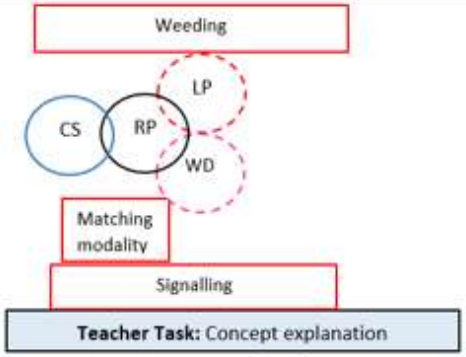
G: Yes

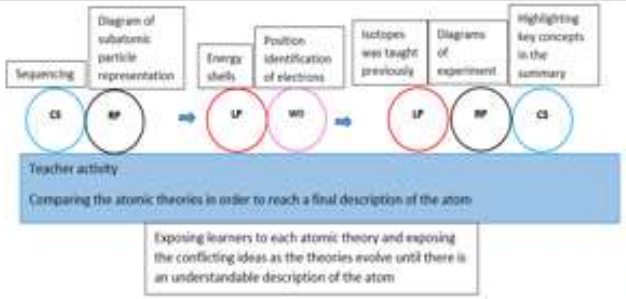
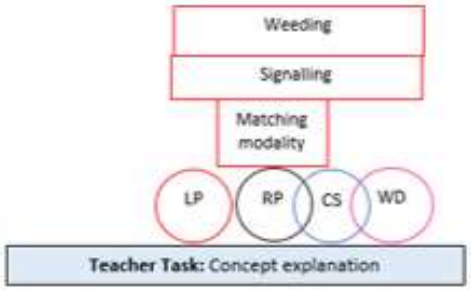
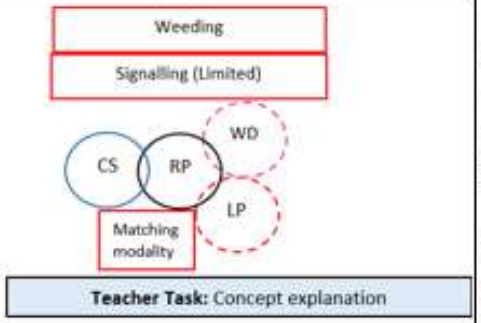
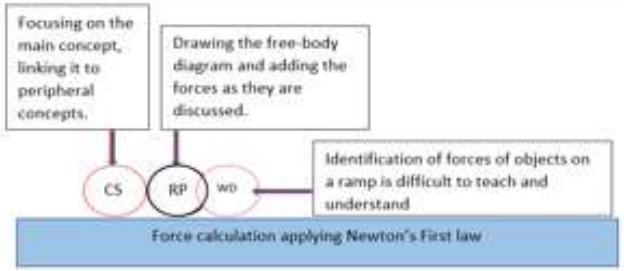
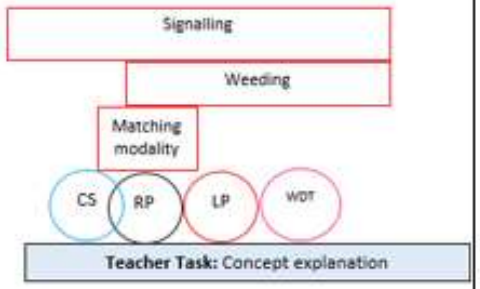
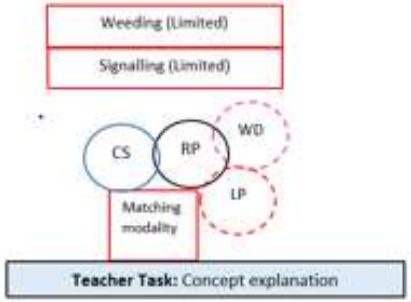
R: *Now the second thing that you said that I can't see on an animation, is what is difficult to teach. Now on your storyboard you say what is difficult to teach is that current passes through a conductor. Now, if I look at your first attempt at your animation, where you has the electrons flowing through and your second attempt which had the beautiful electrons circling the nuclei being dissociated um...is that…is the reason why you changed it, because you realised that it was difficult to teach?*

G: *Ja, that's why I changed it, and then I had to show them the flow of electrons, because I think that somewhere I mentioned that the electrons they cannot see them with their naked eyes so I had to indicate that on the, inside the wire and draw their attention to it.*

In Mr T's animation, signalling was limited to the motion of the electron in the conductor and then at a later stage arrows pointing at the force experienced by the conductor. Mr T also added images of a clock and flowerpot to the background, unrelated to the topic under discussion, limiting the weeding component in his animation. Mr. T was not available for the stimulated recall interview, therefore his digital-TSPCK map components of WD and LP could not be confirmed by him, but if the reasoning process followed by the other two educators was followed, these component were transposed to the animation map from his CoRe storyboard. With the analysis of the pre-intervention videos, CoRe storyboards and submitted animations completed, resulting TSPCK and digital-TSPCK maps were analysed in a comparative process as part of the triangulation of the data to determine and reflect on emerging patterns. Table 8.7 shows the comparison of the maps for each of the participants.

Table 8.7. Traditional TSPCK and Digital-TSPCK maps comparison between storyboard planning and created animations.

TSPCK map of baseline teaching video	Digital TSPCK map in storyboard	Digital-TSPCK map of the animation	Similarities/ Differences
Ms. G			
			**Similarities**: signalling, matching modality, segmenting, curricular saliency and representations. **Differences**: What is difficult to teach (implicit), Learner prior knowledge (implicit), weeding (visible), nature of component interactions.

	Mr. M		
			**Similarities**: weeding, matching modality, curricular saliency, representations. **Differences**: What is difficult to teach (implicit), Learner prior knowledge (implicit), signalling more limited in the animation, nature of component interactions.
	Mr. T		
			**Similarities**: Matching modality, representations, curricular saliency **Differences**: What is difficult to teach (implicit), Learner prior knowledge (implicit), Signalling (limited), weeding (limited), nature of component interactions.

When comparing the digital-TSPCK maps from the CoRe storyboard planning and the completed animations, in Table 8.7, it is clear to see that the shift from planning to animation explicitly exhibited the same components of curricular saliency, representations, signalling, weeding and matching modality. This was a uniform trend for each of the participants. It was also clear to note was that the components of what is difficult to teach, and learner prior knowledge were no longer visible in the animations of any of the educators. Conceptual teaching strategies were not planned for in the CoRe storyboards and were not visible in the animation either. As a result, the components of signalling, matching modality and weeding interacted only with representations as the two other components they interacted with in the storyboard no longer featured in the animation. The trend was identical for each of the educators.

The stimulated recall interviews enabled the implicit, "unseen" components in the animations to be included in the digital-TSPCK maps. However, as they were not explicitly visible, but with evidence implying their considerations, like the decision to have motion then still same representation at different times of the explanations, the components were added to the maps as circles with dotted lines. Comparing the CoRe storyboard maps to the animation maps, it was evident that the components planned for, existed in varying forms in the completed animations. These "invisible' components included in the digital-TSPCK maps of the animations and considered implicitly used component in the creation of the animations.

In summary, both the planning tools and the built digital animation videos, reflect evidence of surfacing digital-TSPCK in the practice of the participating teachers post the intervention. While, the visible interactions among the TSPCK components were limited to two TSPCK component interactions, there is evidence pointing to teacher considerations of other components such as learner prior knowledge (misconceptions) that are hidden but implied by certain subtle teacher decisions and actions that the observer would need to know and pick these up. From the animations, one can see clearly the interactions of the TSPCK components and this includes even those that are implicit (LP and WD). Similar to the CoRe Storyboard, digital-TSPCK in planning, one sees again the CTML principles working in multiples that are complementing each other. Matching modality, weeding and signalling are commonly noted acting across the entire shot for purposes of highlighting the important representations and ensuring synchronisation between audio, visuals and text. When it comes to interactions across the constructs, we see CTML

components interaction with TSPCK components, we also see certain CTML components interacting with certain TSPCK components exclusively, like RP and matching modality, for all three cases. We see that more in the animation than planning.

In planning, all the TSPCK components are explicitly mentioned and can be attributed to the guiding prompts in the CoRe storyboards. Signalling, weeding and matching modality still feature together per digital-TSPCK map, although Ms. G did not explicitly plan for weeding as can be seen in Table 8.7. In the completed animations, the TSPCK components of CS and RP were central to each digital-TSPCK map. Signalling, weeding and matching modality still feature together per digital-TSPCK map, however in the animations of Mr. M and Mr. T, signalling and weeding were limited to certain shots in their animations. Mr. M used signalling to draw attention to the electrons in the conductor by using movement, but subsequent shots were representations, possibly from a book, which were verbally glossed over and did not feature any motion of highlighting of key concepts. With Mr. T, he used signalling well in terms of adding motion to the elections in the conductor, and phasing in the magnetic field lines and forces, he included the force labels to reinforce the verbal referral to the force experienced by the conductor. He was however limited with signalling in subsequent shots where static images were shown with a voice over. He also added images to his shots like flowerpots and clocks to fill the screen, but had no relevance to the topic under discussion, hence risking a higher cognitive load placed on the learner due to the cluttered imagery.

Digital-TSPCK is comprised of a digital functionality construct to enable the transformation of content knowledge onto a digital platform. Once the animation was working, focus on the digital functions that make the animation to work became translucent, hence there was no more focus on the technical aspects, focus was placed on what those representation working together with audio were actually bringing forward. As a result, the existence of a functional teaching animation gave a sense of reference to teacher digital competency being sufficient by linking it to the functionality of the produced digital product. The findings of the digital-TSPCK maps of the animations, and their comparison with the maps of the CoRe storyboards have brought to light new insights regarding digital-TSPCK. Not only were the inter- and intra-construct component interactions forming specific interaction patterns, but following the trajectory of the educators have provided insights too. In the pre-intervention videos, there was evidence of TSPCK, but unfortunately, no

evidence of digital-TSPCK was noted. As the educators progressed to completing their CoRe storyboards, evidence of elements of digital-TSPCK were noted, and the findings of the educators' animations showed a greater emergence of the construct of digital-TSPCK, giving insight into the component interactions and the nature of these interactions.

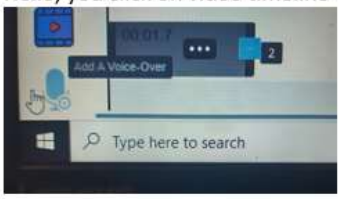
As mentioned in Chapter 7, the CTML component of segmenting was considered a standard constant across all the videos as all met the requirement of being brief. These interactions were confirmed through the stimulated recall interviews, strengthening the evidence toward establishing the surfacing of digital-TSPCK in the digital enactment of a science lesson (electromagnetism). As alluded earlier, the technological competencies have not been included in the digital-TSPCK maps as their individual presence was translucent, inferred from the functionality of the created digital output – animation teaching video snippet.

8.5 Reflections from WhatsApp groups and the stimulated interviews.

Reflections from the WhatsApp group

The WhatsApp group was established to maintain contact with all the participants during the intervention as it began as a virtual intervention due to COVID restrictions. The group also served as a platform where educators could ask clarity seeking questions as they progressed with their animation creation. Table 8.8 shows excerpts from the WhatsApp conversation where Ms G asked questions regarding the technical issues faced when attempting to create a conductor as a background image that allows electrons to move through it.

Table 8.8. Excerpt from the WhatsApp group for the intervention participants

2 July 2022	
Ms. G	 Good day. Please help. I'm trying to create a flow of charges in a conductor but I don't see a shape that I can use to create the conductor. I've tried to use the pencil tool in vector but my lines are not straight.
	 Do we just click export only for exporting? And how do I import things in animaker? I don't see the import button
R	Hi G, you can google images for a conductor, the save on your desktop or image file. Then when you are in animaker you click on images and then there is a download function that will allow you to download the images from your computer Export is only for when you are done and want to submit. The animation will stay on Animaker so that you can work on it again after our next meeting
5 July 2022	
Ms. G	Hello. How to add an audio on the animation?
	 Hello, you click on video timeline  Then go to the bottom of the screen where the scene timeline is

On the WhatsApp group educators were able to ask questions regarding the solving of technical issues in the creation of their animations as seen in Table 8.8, with solutions provided by the researcher. As Ms. G was the only participant asking animation-related questions on the group, it

enabled any other educator to also learn about the solving of technical issues they did not know about, empowering them to try using more features of the software in their own animations.

Reflections from the stimulated recall interviews.

Verification of the component analysis occurred through a stimulated interview of each participant in order to determine firstly, whether the identified components in their storyboards and animations matched their intentions. Secondly, the stimulated interview afforded the opportunity to ask questions regarding the use of the components that were not explicitly evident in the animation.

Confirmation of identified components took the form of the researcher telling the educator how they interpreted the component interactions in the animation and the educators confirmed or explained their intention of their component interactions as discussed in the findings of the digital-TSPCK maps. The interviews highlighted that the participants still had the intentions to display the components, but they did not exhibit in the animations as clearly as signalling or representations. As a result, the digital-TSPCK maps were modified to include the components that were intrinsically part of the animation, but not directly visible to the viewer. These stimulated interviews provided a measure of validity to the digital-TSPCK maps that were created, as they agreed to the representation of the components, but added depth to the maps with insight into the intention of the participant to address issues of avoiding misconceptions and what is difficult to teach. Mr M confirmed that the two components that were not explicit on the animation were still intended and came out more in representation choices. An additional benefit derived from the reflective interviews and notes from the stimulated recall interviews was the insight shared by the educators regarding their experiences during the intervention and recommendations regarding the administration of the intervention. Mr M noted that:

"I honestly learnt that there are various ways that we can impart knowledge unto our learners, and something that is visually so, it makes it easier, attractive and makes it, makes learning easier because learners will be um, ok they will now, concept of moving electrons in a conductor, though it's not maybe shown in the way I wanted to, but they can clearly see that electrons are moving definitely in a conductor. And then it's easier and also the audio part of this whole planning was to instil that information to them that electrons are moving in a current carrying conductor and so forth. So I have learnt that there are better ways, or OTHER ways in which we can instil knowledge in our learners. And I have also learnt that, I didn't know much about animation. I was just

thinking about those cartoons you see, and I didn't think of it in a way that we can bring it into our physics curriculum and assist learners. So I have definitely learnt a lot. And with the app as well save and store the information [excerpt from stimulated recall interview Mr. M]"

Mr. M mentioned that he definitely felt more empowered, and wanted to continue and grow from it, using it in the future and different ways of teaching in the future. When asked if he had any suggestions regarding improvements to the workshop in the future, he said that the workshop was amazing, he really enjoyed it, but that allowing participants to present their findings to each other would allow them to learn from each other as well

Ms. G reflected the following as response on the WhatsApp group:

I have learnt that Animaker is a software that can promote visual learning and I did not know Animaker before the workshop, now I know how to use it to create 2D animations for learning. Secondly, I have learnt that you can use text to speech option as an alternative to recording your own voice if you want to. To me teaching with Animaker promotes more of visualisation learning. That is a pedagogy I am willing to implement in my teaching because it can help learners to remember and understand complex concepts. It also caters for different learning styles for different learners since there's audio in it, images and arrows.

There's one question that is missing here, What was difficult? Getting the electrons to move properly. They either moved very fast or too slow, it was a struggle. [excerpt from WhatsApp group conversation Ms. G]

Her suggested improvement to the workshop entailed lengthening the period in which the workshop took place as there were certain technical skills that took more time to master than was catered for. The interactions held with the educators at the beginning of the intervention were focused on the solving of technical issues regarding the creation of the animation. Towards the end of the intervention, educators became more reflective and noted how they could apply the new competency in other topics of their teaching. They also mentioned suggestions for the improvement of the intervention, which included lengthening the amount of time available to create their animations to allowing participants the opportunity to present their animations to each other in an attempt to learn from each other's opinions and suggestions for improvement. These suggestions open a possibility for improved teacher intervention programmes in the future.

8.6 Summary Conclusion

In this chapter, we presented the findings that came from various data sources about windows into the surfacing digital-TSPCK of the participating teachers. When we looked at the baseline teaching videos, findings indicated that the teachers, while they had TSPCK in the teaching of their topics, they exhibited no digital-TSPCK. In their planning, using the CoRe storyboard, there was evidence of surfacing digital-TSPCK, shown in how they planned these TSPCK components in conjunction with their sequencing and their articulation of what digital functionality they would need to realise these shots. From the animations, we started to see the enacted digital-TSPCK, where they had functional animated videos that were able to show us visible interactions by TSPCK components, interactions among CTML principles and interactions across the constructs. Additionally we were able to see the nature of the interactions across constructs, most visible were the RP and matching modality interactions. Signalling and weeding were able to interact across any TSPCK components that was there but matching modality was selectively more visible interacting with the representation component of TSPCK. These interactions were confirmed through the stimulated recall interviews, and it was often noted that the nature of the questions and the queries that were coming from the teachers tended to shift from technical functionality, how to use the technology to reflections on how they experienced the intervention and its possible applications in their teaching careers.

There are emerging digital-TSPCK episodes in the practise of the teachers following the intervention where initially none was noted. Given the work in Table 8.7 where the digital-TSPCK episodes were summarised from the CoRe which reflected the planning of their animations and from their enactment of the created animations of the participating educators, there is evidence of surfacing digital-TSPCK episodes, and analysis of these episodes answer the research question of this study:

What would teacher professional knowledge for effectively teaching a science topic digitally entail?

In answering this question, analysis of the way in which surfacing digital-TSPCK manifests itself through the practising teachers' development of their teaching animations is shown in Figure 8.6.

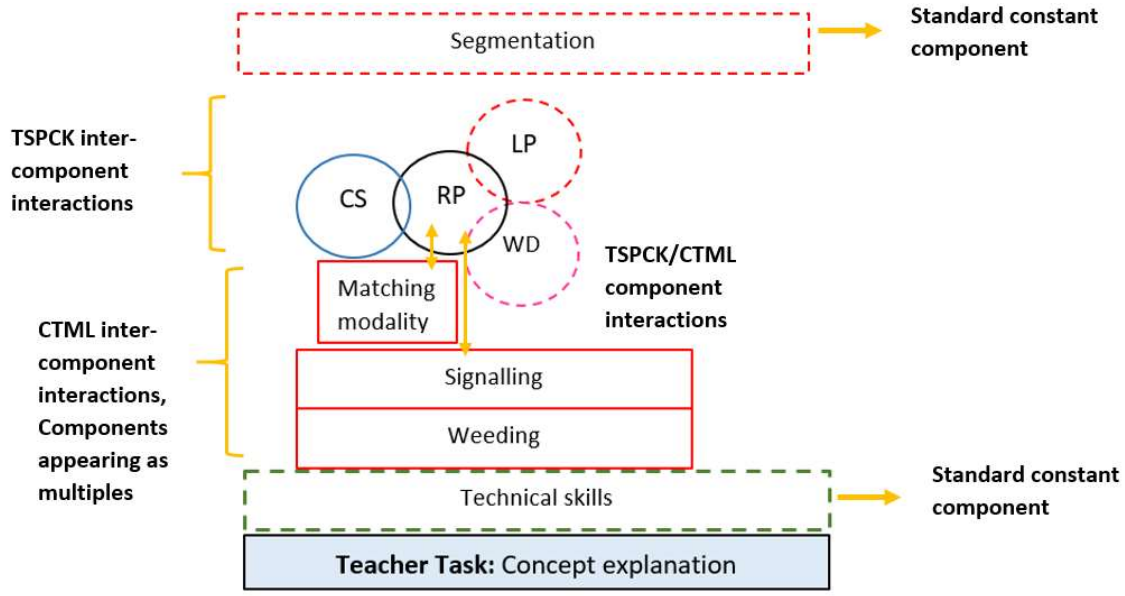


Figure 8.6 Interactions between components in a digital-TSPCK map

There was evidence of component interaction between components within a construct, for example CS and RP, but also between components across the two constructs. It was visible with each educator's CoRe that signalling was most often seen to be interacting with RP while weeding and matching modality interacted across all the TSPCK components.

Looking closely at the episodes of digital-TSPCK, we start to get a sense of their nature, what they look like, how they are manifesting and how the different interactions appear in pictorial representations of the digital-TSPCK construct. We are seeing interactions among individual constructs that are making up digital-TSPCK, but we also see interactions across the constructs of TSPCK and CTML, where some of the interactions are consistently found across all the educators' digital-TSPCK maps (CS-RP).

These interactions prove that different properties, features or trends influence the interactions among components we see them with both TSPCK and CTML giving a clear indication that there is more balance when CTML components are working in multiples rather than individually, the same way that there is depth when there are multiple interactions between TSPCK components.

In summary, the findings of the analysis process discussed in this chapter with the aim to identify how digital-TSPCK manifests in the development of animation videos and what the nature of the component interactions are, answered the research questions of the study. The holistic approach

of triangulating multiple sets of qualitative data, including the comments made by the participants after analysis to confirm findings in stimulated recall interviews, elevates the trustworthiness of the findings made from the data. It can be concluded that an intervention program with practising physical sciences teachers can develop their digital-TSPCK as was seen emerging in this study provided they already have TSPCK knowledge. The construct of digital-TSPCK consists of an interaction of three constructs namely technical knowledge, TSPCK and CTML. The nature of the technical knowledge is assumed as a default knowledge if the product is a functional teaching animation. Digital-TSPCK manifests in an animation as variable interaction types between the components within the individual constructs and interactions between the components from each construct in order to produce an animation, which shows the pedagogical transformation of a science topic on a digital platform.

Chapter 9

9: Discussions and implications

This chapter renders a summary of the findings of this study inferred from the presentations in the previous chapters. Here the premise of a newly defined theoretical construct that enables practicing science teachers to pedagogically transform content of a science topic onto a digital animation platform, is corroborated by empirical findings providing supported responses to the research question asked in this study. The chapter begins with an overview summary of the study and its goal. This is followed by a reflection on contributions to new knowledge emanating from the synthesis of the findings. The salient features of the key findings pointing to the emergence of digital-TSPCK in the practice of the participating teachers are unpacked. These findings are then linked to formulated responses against research questions. The efficiency of the research design employed in the study is reviewed highlighting lessons learned. The study concludes with implications of the findings and recommendations for teacher development.

9.1 Overview of the study

This study began by pointing-out the growing insufficiency of traditional teacher education pedagogies for the preparation of a science teachers for a digital society, particularly for the teaching and learning over digital platforms. The value derived from tested and widely accepted theoretical construct of Pedagogical Content Knowledge (PCK) as defining the teacher professional knowledge for teaching science effectively is first acknowledged (Shulman, 1986). At the heart of PCK, is the key benefit of knowledge and competence that enables the teacher to pedagogically transform their own understanding of content into forms that are accessible and understandable by learners. This benefit of PCK is timeless. PCK is more valued when considered in specific topics of science, as the kind of teacher knowledge that aims to transform the content knowledge of the specific topic (Abell, 2008). At a topic level, that kind of knowledge has been termed Topic Specific PCK (TSPCK) (Mavhunga & Rollnick, 2013). However, the experience of social disruptions in recent times by diverse factors (pandemic, energy supply, wars, etc) has seen the increasing migration of education, including the teaching of science, to digital platforms for remote learning. This conversion of teaching in the digital realm came to ensure continuity in the

teaching and learning process but it opened a plethora of other issues, like equity, access to technology and teacher skills to create suitable digital outputs reflective of the value derived from traditional TSPCK. One major factor that was brought into question was the preparedness of teachers to import the pedagogies they know as effective from their traditional practice for application in the digital teaching platforms. This has created an explicit demand for a new kind of teacher knowledge (Cherner & Fegely, 2017). In this study, a concern was raised regarding the teacher knowledge required to teach science in the digital realm rather than the traditional classroom. In the digital realm, content is digitised and formatted into digital outputs such as teaching videos. The teachability of the digitized content, contained in the digital outputs, is now hidden in the 'technological know-how' of building a digital lesson rather than the technology being used in the traditional lesson. For asynchronous teaching contexts, the created digital output represents a digital lesson. The challenge them arises from enabling the importation of the tried and tested teacher knowledge (PCK/TSPCK) to pedagogically transform content digitally into version understandable by learners, and digitally build it into formats such as teaching videos, teaching animation videos and much more, in recognition of best practices for multimedia learning. The description of such kind of teacher knowledge in the literature was lacking, and thus the major gap addressed in this study through the main research question:

What would teacher professional knowledge for effectively teaching a science topic digitally entail?

This research question was pinned to a topic on electromagnetism as one of the topics considered difficult and abstract (Dori & Belcher, 2003). It was further unpacked through the following sub-questions:

- How could teacher professional knowledge for effective pedagogical tranformation of content in the digital realm of teaching and learning be conceptualized?

- How does the conceptualized teacher knowledge manifest in the planning for and teaching of electromagnetism digitally when animation teaching videos are used as a digital output?

This study therefore aimed to answer these research questions and the discussion below reflects on insight drawn from the findings.

The first part of the presented reflections and discussions is based on the process followed to develop a theoretical argument for a refined conceptual teacher knowledge that would respond to the new need of enabling pedagogical transformation of content in the digital realm of teaching and learning. It was postulated that such teacher knowledge would be distinct from traditional TSPCK. A qualitative literature meta-synthesis (Thunder, 2016) enabled the establishment of the needed argument leading to a model of teacher knowledge for the digital realm.

The second part of the reflections are based on revealing the manifestation of the newly conceptualized teacher knowledge construct in the teaching practice of the participating in-service science teachers. For the needed insight, a purposefully designed intervention reflective of the newly conceptualized construct was needed. The reflections below unpacks the pedagogical considerations behind the structure of the intervention. This is followed by the discussions of the identified evidence of the surfacing refined teacher knowledge in the planning for building a digital lesson and the enactment through animation teaching video as a digital output. The evidence of the newly refined construct was considered as episodes with a unit of analysis being the segment reflecting the moment containing the intact sophisticated interactions of the constituent conceptual frameworks of the refined construct. These reflections are then linked to contributions of new knowledge in the body of literature and my conclusions.

The concluding part of this chapter reflects on the theoretical framework through the lens of the qualitative research design to discuss the method used, trustworthiness of the process and findings, including the limitations of the study.

9.2 Insights pointing to new knowledge contributions.

The findings of my study contribute towards addressing the gap about the teacher's knowledge appropriate for teaching a science topic digitally through three major findings. Firstly, they provide a conceptual argument defining refined teacher knowledge called digital-TSPCK. The conceptual argument is visualized through a corresponding schematic model of digital-TSPCK. Secondly, they provide empirical evidence of the construct's existence as per the definition, through the visible emergence of this construct in the teaching practice (planning and enactment) of the participating teachers, which builds towards the validity of the construct. Thirdly, the findings reveal the structural nature of digital-TSPCK reflected in the sophisticated visible interactions across the components of the frameworks encompassing digital-TSPCK.

9.2.1 Conceptualizing a refined conceptual framework for teaching science digitally

It is important to note that this first finding was a quest for a refined teacher professional knowledge conceptual framework. The search began by acknowledging the value of pedagogical transformation of content as a consistent benefit derived from the frameworks of PCK and TSPCK as a discipline-specific pedagogies. For the process of conceptualization, the TSPCK components were considered foundational as resource from which pedagogical transformation of content knowledge emerges. The components include Learner prior knowledge, Curricular saliency, Representations, What is difficult to teach and Conceptual teaching strategies. The TSPCK conceptual framework continued as a resource for teacher knowledge from the content teachability perspective. However, besides the pedagogical transformation of content knowledge, the need for new teacher competencies associated with digitalization technology as well as the understanding of learning on a multimedia platform were glaring. A qualitative literature review was conducted on literature having relevance to the factors mentioned above according to the methodology noted by Thunder (2016). A qualitative meta-synthesis suited the nature of this phase of the study as a wide selection of studies were interpreted for a deeper understanding of the components of constructs that would add value and a deeper understanding of the new type of teacher knowledge required to produce transformed content digitally. Initially studies of TPACK were included in the collection and analysis of literature, being a popular framework among researchers, but the UNESCO ICT framework provided principles more salient to the needs of the framework in this study. The key difference was the focus of this study on the digitalization of a science lesson vs. use of technology in a traditional science classroom as offered by the TPACK framework. With consideration to the fact that teachers would be expected to design their own digital lessons, in doing so, they would need to seamlessly draw on digital functions across different levels of sophistication (from digital literacy to creating digital content). The UNESCO ICT framework suited this application for its guidance for educators in progressively gaining technological skills that enabled digital literacy, knowledge deepening and knowledge creation. It was therefore pedagogically reasonable, to consider the amalgamation of this ICT framework with the TSPCK framework as discussed in Chapter 5. In addition to the argued amalgamation, there was a need to include a conceptual framework drawn from a learning theory into the description of teacher knowledge. This needed to be a learning theory sentient to the digital realm of learning. The Cognitive Theory for Multimedia Learning (CTML) (Mayer, 2014a) was found appropriate for its

directive in guiding the process of building digital content in a manner that leads to a balance of cognitive loads for the learner who engages with the content in the absence of a teacher. The basic premise of the multimedia principle is that learning occurs with greater intensity when words and pictures are presented together than from words alone (Mayer, 2014a). Mayer (2014a) however pointed out that for effective learning; a link was needed to the mechanisms of the working of the mind. A focal point to the factors influencing effective learning on a digital platform included the following principles: Segmentation, Content control, Weeding, Matching modality and Signalling as discussed in Chapter 5. Blending the CTML into the TSPCK- UNESCO teacher ICT Framework amalgam, holistically addressed the teacher considerations to be made when building a digital lesson with discipline topics. The process of blending these three conceptual frameworks, and the provided rationale constituted the conceptual argument for a refined conceptual framework called digital-TSPCK. Digital-TSPCK was presented pictorially as shown in the recalled Figure 5.5., presented in Chapter 5.

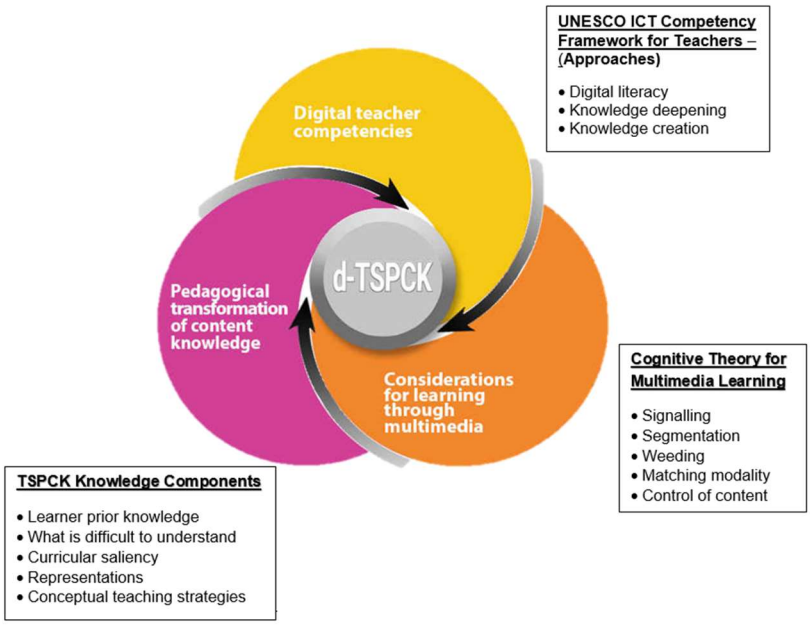


Figure 5.4 An illustrative model of digital-TSPCK

In Figure 5.4, we see the contributing components of each conceptual framework toward the final digital-TSPCK construct. Through the literature meta-synthesis, a definition of digital-TSPCK emerged as the kind of teacher knowledge that enables pedagogical transformation of abstract content knowledge digitally, as well as its packaging in a digital output such as animations teaching

video for an effective learning experience by learners over digital platforms. The conceptualization of digital-TSPCK, is the first major finding from this study contributing to new knowledge in the science education literature.

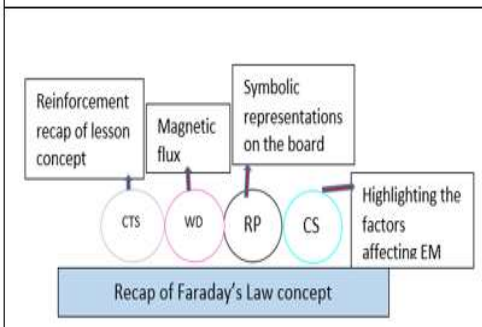
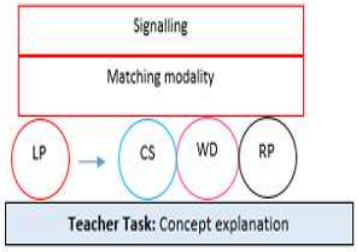
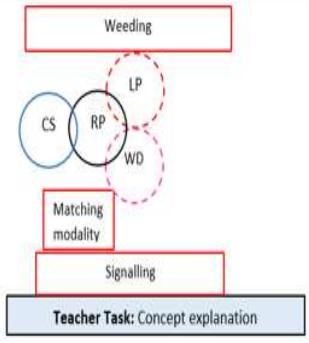
9.2.2 Empirical evidence pointing to surfacing digital-TSPCK in the teachers' planning and teaching electromagnetism digitally.

The second major finding was the collated evidence pointing to surfacing digital-TSPCK in the teaching practice of the participating teachers. This study developed an intervention to expose practicing physical science teachers to digital-TSPCK in the topic of electromagnetism. The structure of the intervention was based on the newly conceptualized argument forwarded as digital-TSPCK (finding one, above). Key to this conceptual argument is the understanding that the teacher knowledge for teaching science in the digital realm is a refined version. It is reflective of the sophisticated blending of existing and widely tested conceptual frameworks that are still powerful in their own individual use. They are now working together in complex but seamless interactions to bring forth digitalized powerful teaching. The base of this blend remained to be the pedagogical transformation of the topic delivered consistently from the traditional TSPCK construct. However, for an effective practice in the digital realm, a blending of TSPCK with additional teachers knowledge constructs, 'teacher digital competence', and a learning theory for multimedia, 'CTML' are required. The intervention began by collecting data that helped to establish a baseline information about the teachers' knowledge of TSPCK (due to experience) and potential digital-TSPCK in the topic of the intervention, electromagnetism. An essential feature of the intervention was the integration of the discussion of the individual TSPCK components and their internal interactions, alongside the activities supporting the development of the participating teachers' digital competence to create an animation video. Here teacher digital competence surfaced as a tool visualizing the intended TSPCK component interactions manifesting in the created teacher explanations of concepts within the Big Ideas of electromagnetism. For example, when each of the TSPCK components were introduced, the participating teachers had to apply their understanding in developing an explanation blurb in electromagnetism applying the learned TSPCK component and its interaction with another TSPCK component. The said explanation blurb once discussed and feedback input effected, would be built into a digital animation video snippet using a purposeful software, Animaker. This allowed the learning of the digital functions of the Animaker software in reference to the pedagogically transformed explanation blurb as the

rationale – the why a certain digital function is needed, and at what point in the sequence of the visual shots. These cycles of simultaneously creating pedagogically sound explanations and creating corresponding animations, we collated using a CoRe storyboard. The CoRe storyboard is a valuable tool to portray the teachers' pedagogical reasoning adapted from the original tool the CoRe, commonly used in planning PCK rich traditional lessons. In this study, the CoRe storyboard assisted to place structure in the collation of the considerations made in the planning towards building-up a digital lesson on electromagnetism. The CoRe storyboards doubled-up as both a tool for capturing the considerations made in generating teacher explanations as explained above, as well a tool portraying the surfacing digital-TSPCK in the planning for building an animated teaching video.

The findings from the three sets of data analyzed in Chapter 9: (i) the baseline teaching video, (ii) the planning as reflected through the CoRe storyboards and (iii) the created animated video snippets showed evidence of surfacing digital-TSPCK as influenced by the intervention. The evidence was presented pictorially as TSPCK and Digital-TSPCK maps in Table 8.7.

Table 8.7 Traditional TSPCK and Digital-TSPCK maps comparison between storyboard planning and created animations. (Segment)

TSPCK map of baseline teaching video	Digital TSPCK map in storyboard	Digital-TSPCK map of the animation
Ms. G		
		

Recalling the evidence of the maps presented in Table 8.7, a few observations pointing such evidence were made as listed in Chapter 8. These were:

i. There is a clear visible difference across the three sets of data Maps. The key difference is the absence of CTML principles and the digitization of the content in the TSPCK Maps of the baseline self-recorded videos, as compared to those from both the planning (CoRe storyboards) and the built animated teaching video snippets. This difference pointed to the confirmation of only traditional TSPCK being present in the self-recorded videos. Evidence for traditional TSPCK was evident through the presence of component interactions, which were consistent with the observations from previous studies (Mavhunga & van der Merwe, 2020) and (Mazibe, Coetzee, et al., 2020). While this finding was not surprising, it however proved the difference between the kind of teacher knowledge evident in a video of a recorded traditional class teaching as traditional TSPCK, and that reflective in a purposely built video for a digital lesson, called digital-TSPCK.

ii. Across the digital-TSPCK maps from planning (seen in CoRe storyboards) and the enactment (seen in the built animation video snippets), the contributions from all three component conceptual frameworks encompassing digital-TSPCK as per the conceptual argument, were visible. It is interesting to note the emerging role played by the component of 'teacher's digital competence' in the built animated video snippets. When viewing a functional animated video snippet, the absence of attention drawn to the technology or the digital function used to create the content was striking. Focus seemed to shift to the hearing, the seeing and making sense of what both these channels are bringing forth. The technology used became translucent bringing forth the visualized teachers' efforts in presenting a logical and pedagogically sound explanation. Here we see technology being used beyond digitizing the content into an animation video format, but playing a role of bringing to light the component interactions across traditional TSPCK and the CTML principles, as well as the interactions within each of these conceptual frameworks. In so doing, technology brought to view the entire pedagogical transformation process of content knowledge into the digital mode. This included also revealing the wisdom behind teachers' choices of the mode of the chosen discipline-specific representations i.e. whether they were static or dynamic, the synchronization of events, the quantity of information shared at a time, and the appropriateness of the sequence of the discussions. Thus, the critical role of technology in the case of digital-TSPCK appeared to be, to translate and bring to view the complex transactions of component interactions of traditional TSPCK and the CTML principles. Teachers, who can affect these interactions in a digital setting, show the ability to import their traditional TSPCK knowledge with consciousness of learner

cognitive load demands when learning through multimedia. The observed evidence of the surfacing digital-TSPCK in the teachers' planning and the digital enactment through animation video snippets, albeit qualitative in nature, points to the existence (*validity*) of the newly conceptualized teacher knowledge construct of digital-TSPCK. Furthermore, this finding further provided the rationale behind the observation that while traditional TSPCK is needed for effecting the desirable pedagogical content transformation as postulated, it is not enough by itself to enable the building of proficient digital lessons in a science topic.

9.2.3. The nature of the interactions of digital-TSPCK

The third major finding contributing to new knowledge to the body of the science teacher education literature is the observed visible nature of the component interactions within the digital-TSPCK construct. Drawing from the digital-TSPCK maps of the three teachers, the nature of the interaction components within the digital-TSPCK construct were found to be as follows:

i. Clear evidence of the TSPCK components interacting with each other in a teaching animation was observed, see Table 8.7. Given the nature of the medium used, the TSPCK components of CS end RP are explicitly visible in each animation. These components were commonly seen in the teachers' enactment in science traditional classrooms (Mavhunga & van der Merwe, 2020). The big idea and the sequencing of these concepts are transformed onto the digital platform as representations in a specific sequence.

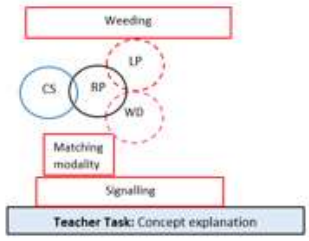
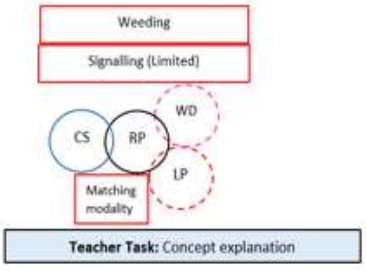
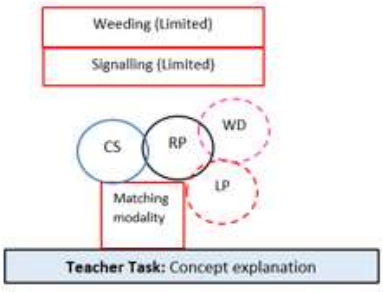
Components implicitly present but not visible in watching the animation, like LP and WD could be inferred from the visualizations. These components were explicitly visible in the planning of the animation and catered for in the creation of the animation. The teachers in the stimulated recall interviews further confirmed them. However, by virtue of their nature they were not explicitly noted in the final animated product but inferred. For example, teachers do speak explicitly about students' misconceptions but act and explain in ways that avoids or mitigate them. Similar trends of implicit component interactions are reported in the literature such as Akinyemi & Mavhunga (In press). The confirmation of these common patterns in which traditional TSPCK component interact, indicates the refined construct of digital-TSPCK, having successfully enabled the desirable exportation of the tested and widely accepted construct of TSPCK from the teacher

practices from the traditional classroom realm into the digital realm. This means teachers could enter the digital era of practicing teaching, with confidence of the relevance of their traditional professional knowledge (of what works for pedagogical transformation of content) as they learn and acquire new competences to blend with their professional knowledge.

ii. The CTML principles were seen interacting in a digital-TSPCK episode among themselves in multiples and in complementary to one another, rather than working singly, see Table 8.6. No case was observed of a single CTML principle in action by itself. This observation confirmed a postulate made in the description of the CTML, that like for TSPCK component interactions, a better balance of the cognitive load is to be derived from the overall interaction effect of the principles.

Two distinct patterns in which the CTML principles interacted across with TSPCK principles. The first pattern, as could be seen in the recalled example of Table 8.6, from Chapter 8 (included below) refers to cases when specific CTML principles appeared to interact with every single TSPCK component present in an identified episode of digital-TSPCK.

Table 8.6: Emerging digital-TSPCK Maps from the created animations

Ms. G digital-TSPCK Map	Mr. M digital-TSPCK Map	Mr. T digital-TSPCK Map
		

The principle of 'weeding' had a visible effect in promoting the visibility of all kinds of interactions demonstrated in an episode, evident through the teacher's consideration to place no content or sound or text that would destruct the intended video's visual and message to be derived. Examples of this were seen in all the teachers' digital-TSPCK maps drawn from the identified episodes of digital-TSPCK in the video. The second pattern observed is that certain principles of

CTML seem to work in pairs with only specific TSPCK components. 'Matching modality', a component visible when the visual representation, audio and text are synchronised, or when decisions about the mode of a discipline representation is used (what moves or is still when) was most commonly associated with the RP component. Furthermore, the CTML principle of 'signalling' was most common visible component at work to bring to the fore elements of the TSPCK component of 'curricular saliency'. Let us recall that the component of curricular saliency refers to endorsement of the most important, the core concepts vs. peripheral concepts at calculated moments in a lesson. It also refers to pedagogical sound sequencing and the delivery of the needed prior knowledge. 'Signalling' was seen to work complementary bringing the elements of component of curricular saliency to the fore. 'Signalling' further worked in a pair with the principle of 'matching modality' in interacting with the component of representations. As mentioned in Chapter 8, the CTML component of segmenting was considered a standard constant across all the videos as all met the requirement of being brief.

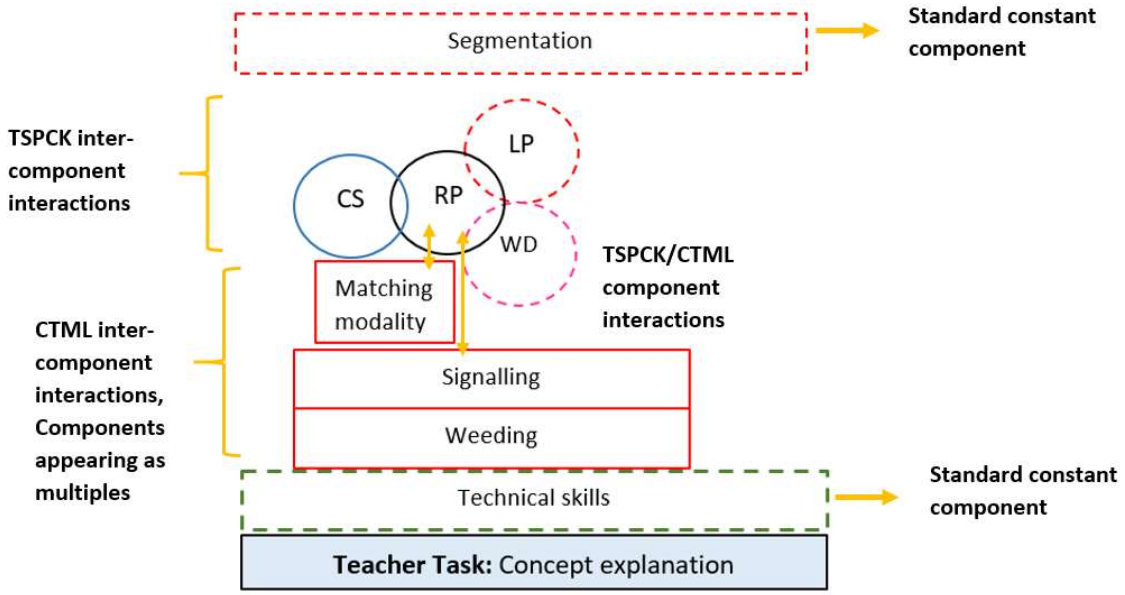


Figure 8.6 Interactions between components in a digital-TSPCK map

These interactions were confirmed through the stimulated recall interviews, strengthening the evidence toward establishing the surfacing of digital-TSPCK in the digital enactment of a science lesson (electromagnetism). As alluded earlier, the technological competencies have not been included in the digital-TSPCK maps as their individual presence was translucent, inferred from the functionality of the created digital output – an animation teaching video snippet.

The presented emerging understanding of the nature of digital-TSPCK component interactions is new. It is crucial in helping teacher education educators develop insight of the complex interactions that are demanding more emphasis. Furthermore, it provides science education researchers with important insight on what component interactions of these conceptual frameworks are visible and which are not in enactment, and yet present in another realm such as that of planning. Such insight is crucial when developing tools and instruments to capture digital-TSPCK. This finding offers both a practical way (intervention) for stimulating the development of teachers' digital-TSPCK in their practice, as well as shedding light into the structure of the complex component interactions across the interacting constructs.

9.3 Summary of the research questions

As the main aim of the study was to respond to the need for teacher knowledge that enables the pedagogical transformation of content on a digital platform, the research questions were structured to enable this. The conceptualization of such teacher professional knowledge, and the capturing of its emerging manifestation in the teaching practice of the participating science teachers was powerful in signalling validity of the newly refined conceptual framework. The analysis of the collected data have provided direct findings enabling responses to the individual sub-questions and ultimately to the main research question. Following are the formulated questions:

Sub-research question 1: *How could teacher professional knowledge for effective pedagogical transformation of content in the digital realm of teaching and learning be conceptualized?*

Response:

Digital-Topic Specific Content Knowledge (digital-TSPCK) has been conceptualized as the refined conceptual framework defining teacher professional knowledge for teaching science topics in the digitally. Digital-TSPCK is a complex blend of powerful teacher knowledge and student learning conceptual frameworks enabling pedagogical transformation of content knowledge and its digitization into powerful digital lessons optimized for learner understanding in the digital realm. The constituent blending conceptual frameworks are three constructs, namely TSPCK, UNESCO ICT Framework and the Cognitive theory of multimedia learning (CTML). Figure 5.5, presents a schematic illustration of the digital-TSPCK model.

Sub-research question 2: *How does the conceptualized teacher knowledge manifest in the planning for, and teaching of electromagnetism digitally using animation-teaching videos as a digital output?*

Response:

Digital-TSPCK manifested with a component structure as defined by the conceptual argument presented in phase 1 of this study. It was found distinguishable from the traditional-TSPCK and from any of the constituent conceptual frameworks on teacher knowledge, by the visible presence of the complex interactions among the components of the constituent three conceptual frameworks, and across them. These component interactions reflected a unique role of the constituent component of 'teacher digital competency' as the enabler of digitization and more importantly as the revealer of the sophisticated ways in which the interactions within and across the other two constituent conceptual frameworks (traditional TSPCK-CTML principles) looked like.

While the next listed observation was not generated in response to a specific sub-research question, it was however an important finding that enriched the response to this second sub-research question. The manifestation of the digital-TSPCK construct, revealed an interesting nature and behaviour of the component interactions. These included the nature in which the CTML principles interacted within themselves and across with TSPCK components. CTML were found to work in multiples and in complementary to one another to bring about the desired cognitive load balance. Furthermore, they were found to interact across with TSPCK components in distinct two patterns: (i) totally inclusive (segmenting and weeding) and (ii) some that worked in preferential mode with specific TSPCK components (e.g. matching modality (CTML) with representations (TSPCK)).

Overall, the responses provided above provide a response to the main research question, which was formulated as: ***What would teacher professional knowledge for effectively teaching a science topic digitally entail?***

Response:

Teacher professional knowledge for effectively teaching a science topic digitally requires teachers to be supported in acquiring a uniquely refined conceptual construct called digital-TSPCK. Acquiring digital-TSPCK would mean the creation of opportunities for teachers to develop traditional TSPCK in the topic(s) of interests, as well as the digital competence that enables pedagogical transformation of content digitally in cognisant of pedagogical principles for multimedia learning.

9.4 Reflections on the methodological process.

With the intention to define a new teacher knowledge for teaching science on a digital platform and to examine the nature of this knowledge fully, a qualitative research design was followed in two parts. The first part was the conceptualization of the construct using a literature meta-synthesis and the second part was the empirical intervention held with practising science teachers to empower them to create their own pedagogically reasoned animations, thereby providing an opportunity to examine for any emerging evidence of digital-TSPCK. The reflections on the effectiveness of the methodological design in soliciting responses to the research questions are an empirical view of digital-TSPCK are shared below.

9.4.1 Developing a conceptual argument through reflections on the literature meta-synthesis

In this study, the development of the conceptualized digital-TSPCK construct employed a qualitative literature meta-synthesis. This approach was instrumental in the interpretation of literature collected based on the clearly specified, exhaustive set of search criteria (Finlayson & Dixon, 2008) discussed in Chapter 4. Given the iterative nature of the meta-synthesis, data was collected and interpreted as part of a sequential multiphase design (Creswell & Garrett, 2008) where qualitative data was collected and informed the subsequent research stage. It was as a result of this process that the initial intention to use the TPACK construct had shown a gap in the considerations of the alone learner who receives content in a digital format through the digital teaching and learning platforms. Further collection and analysis of literature revealed what the knowledge of digital-TSPCK needs to be able to do in order to help our teachers develop the competencies to use technology and consider the learner in ways that are appropriate for multimedia and still be able to pedagogically transform content knowledge. Although there is no hard rule on the minimum number of articles required for the meta-synthesis (Leary & Walker, 2018), the most amenable approach to eliminate bias and overlooked opportunities still remains in an approach of inclusivity (Sandelowski & Barroso, 2006). In this study the specification for inclusion of digital technology as an intergral component of the mix of knowledge that yielded pedagogical transformation and learning theories grounded in digital learning were of high interest. Given the vast array of constructs and volume of available, structuring the studies according to the aim of the study allowed for the emergence of patterns in the components salient to the needs of the study. From these emerging patterns, the need to include an additional aspect of learning

theory within a digital field became clear and through discussions with my supervisor and the accompanying research team, the literature search for learning with multimedia was included to mould the construct of digital-TSPCK. From that search, the CTML construct proved to add the final theoretical aspect involving the mental assimilation of digitally formatted knowledge by learners (Mayer, 2014a) exposed to lessons like science animations. The sharing of the findings with a reference team of specialists in the TSPCK field added validity to the findings from the literature and credibility to the salient components captured, resulting in a multi-faceted, holistic construct known as digital-TSPCK. Furthermore, the presentation of the findings from the literature search to communities of practice like the Paser conference in 2023 and on-going PCK Talks forum provided authentic constructive critiques of the construct and recommendations for refining the most salient components of the constibuting constructs into a working definition and the formation of a credible model. Thus, the employed qualitative design proved to be most optimal for the purpose.

9.4.2 Reflections on the intervention and its structure.

The intervention process was initiated as the second part in the conceptualization of a valid argument for the existence of the digital-TSPCK construct (Kane, 2012). The intervention was structured to have opportunities for observing the planning and creation of the digital-TSPCK animations on electromagnetism by the in-service teachers. The observations provided the empirical evidence of the emergence of digital-TSPCK given that the baseline showed that at first none was observed. Furthermore, the observations revealed for the first time the complex interactions within and across the components of the different constructs making up digital-TSPCK.

The intervention process was formulated to teach the theory behind digital-TSPCK simultaneously with the digital competence to digitally execute the explanation digitally as an animation. The adoption of the concurrent and integrated approach was a revision from the initial plan to teach in a linear format, where the theory of the construct would be first, and then allowing the teachers to put this knowledge into practise as they created their animations. Because of the intervention following an in-practice learning of theory together with technological skills, teachers were able to make informed decisions regarding their use of the technical applications of the Animaker program. The unique approach of linking explanation blurbs to the digital competences on the home screen of the Animaker tutorial seemed to have helped provide significant rationale behind

why certain digital features were required and how to determine the best timing in the sequence to use them.

The intervention was initially performed online due to the Covid-19 restrictions preventing face-to-face contact with participants, but as the study progressed, the restrictions were lifted and the participants were able to gather for formal sessions of the animation creation process. The orientation of the intervention and resource packs for creating the animation, as shown in addendum I, was placed on a shared google drive file enabling access to all resources as the online meetings continued. Participants therefore had constant access to resources as they were working on their animations away from the group setting. A WhatsApp group provided an additional platform allowing insight into the development of teachers' digital-TSPCK where questions regarding the application of technical features would be shared with the participants. With the lifting of the COVID restrictions, there was a request by participants for face-to-face sessions to complete their animations. These sessions allowed each animation to be designed with support during the process from myself and the other participants enhancing their learning experience. The intervention was therefore rich in the variety of data that was collected, allowing for example, triangulation of data in one of the data sets to confirm findings of the emerging patterns in others. The peer rating of the resultant data sets after the analysis process further enhanced research rigour and post-intervention structured recall interviews held with the teachers as discussed in Chapter 7. The participants provided online data in the form of electronically submitted videos and storyboards, discussions regarding the process in the form of WhatsApp group communications, face-to-face meetings to work on animations and one-on-one interviews. The analysis of the data gathered showed the emergence of digital-TSPCK in terms of the nature of the construct, its interacting components within and across constructs and its relationship to traditional TSPCK. Chapter 7 described the manner in which the gathered data sets were analysed while chapter 8 reported on the emerging patterns as findings from the analyses. With this study following a qualitative research design, several pitfalls in the research design had to be overcome with appropriate methodology in analysis and reporting if the trustworthiness and credibility of the findings were to maintain while minimising the possibility of researcher bias infuencing the study negatively (Johnson et al., 2020).

Four data sets were collected for this study: the pre-intervention video of classroom teaching, CoRe storyboards planning the animation, created animated videos and post-intervention stimulated

recall interviews. Each data set contributed to making sense of the nature of digital-TSPCK within the context of the intervention from the four participating individuals. Data analysis was performed with the aim of maintaining the trustworthiness and integrity of the data, the resulting findings and the process as a whole. Standards of rigour were maintained according to selected analysis practices as described by Johnson et al. (2020). A clear audit trail was kept, as noted in the annexures to ensure that the information gathered did not lose its sequence and that information from each participant was not lost. Secondly, findings from the analysed data were reviewed by other researchers with experience in the same field, confirming the findings and emerging patterns. Thirdly, with the use of stimulated recall interviews, the participants themselves were asked to confirm findings or provide clarity on implicit component interactions of the analysed data. Finally the findings from the CoRe storyboard, created animation and stimulated recall interviews were triangulated to create a set of emerging findings regarding the nature of digital-TSPCK, validated by the multiple data sources creating the findings as noted by Creswell and Miller (2000).

Keeping in mind the interpretive epistemology of this study, each data source adds to the multifaceted description of the emerging knowledge of digital-TSPCK emerging in each teacher, with clear overlapping areas of agreement within the data sources per teacher and within the group as a whole. Initially there was no explicit evidence of digital-TSPCK present in any of the participating teachers, but after the intervention, each teacher showed some level of digital-TSPCK development. With Ms. G., for example, her development was visible across the abovementioned data sources as well as the WhatsApp group where she was the most frequent user of the platform.

9.5 Limitations and recommendations

Within every study, there are opportunities to generate new knowledge confined to the parameters set by the research questions and the research design. There are also limitations to each study from the nature of the methodology and findings. This study is no different. Online barriers were experienced by the teachers who struggled to access online meetings because of load shedding and they had difficulties in applying the technical knowledge discussed in the online interventions while the meeting was in progress, hence the request for face-to-face meetings once COVID restrictions were lifted. Secondly, as a qualitative interpretive study, where the views of the participants drive the data produced, the reality presented in the data is an expression of each participant's version of reality as a social construct (Gray, 2021). Although much effort was made

in this study to establish coherence between the views of the participants and the observations and inferences of the researcher, the findings are still contextualised within this specific case study (Johnson et al., 2020). This study's findings can therefore not be generalised, but still offer insights into the nature of digital-TSPCK as a replicable study with a larger group in the future. The nature of the component interactions from the participating teachers shared similarities. Specific components, for example signalling and matching modality interacted specifically with Representations while Representations interacted with Curricular saliency as one function, hence the merged components in each map. Although the nature of the interactions can mostly be justified by the purpose of creating the animation on the same digital platform, a question arises whether these interactions would appear the same if teachers were designing animations on different topics in the science curriculum. Future studies using more target groups among more science topics could enrich the empirical findings of this study.

9.6 Implications of findings and recommendations

Observation of practising science teachers in their planning and creation of the digital-TSPCK animations on electromagnetism provided the empirical evidence for this study. It revealed the emergence of digital-TSPCK in the teachers where at first none was observed. Data analysis showed, for the first time, the complex interactions between the components of the constructs making up digital-TSPCK.

The findings from this study provide a view of an emerging body of teacher knowledge that enables teachers to design and create their own science teaching animations that encompasses all three constructs in the digital-TSPCK construct. In the South African context, teachers would no longer need to rely on internet-based content that was developed by software creators who might not have a teaching background or knowledge of pedagogy. Neither would they need to develop content based on international curricula where parts of the content need to be edited to conform to the content and sequence of the South African CAPS curriculum. From these findings, it can be recommended that teacher preparation programs could include the creation of digital content using the digital-TSPCK construct. In-service teachers could attend skill enhancement workshops, as performed in the intervention in this study, to build their digital-TSPCK while they are in the field of teaching. Further extensions of the study could include a study of the development of digital-TSPCK in pre-service teachers as they develop their TSPCK. Finally, the

effect of teachers' gain in digital-TSPCK on learner performance could prove valuable in the search for improving the quality of science education in South Africa.

9.7 Conclusion

This study began as search for a possible solution for teachers who, as a result of disruptions the COVID-19 lockdown, were separated from their learners for several months but still needed to find a way to instruct them. Teachers were thrust into the digital world with limited expertise of what teaching on a digital platform would entail, limited technical skills and this was complicated by the lack of a comprehensive guiding framework for teaching on digital platforms.

The abovementioned factors prompted a search of a refined theoretical construct to assist teachers retain agility in teaching science in digital formats and over digital teaching platforms. While, much progress had been made in the field of science teacher education since Shulman (1986) introduced the special amalgamation of content and pedagogy known as PCK and its grainsize TSPCK, both constructs were designed for traditional classrooms and less for creating effective digital lessons. The findings from this study shared the conceptualization of a refined version, digital-TSPCK. Digital-TSPCK while building on the foundation of TSPCK, is extended for suitability for the digital world, through its affordance to offer teachers an opportunity to develop digital competence across several levels of sophistication (literacy, knowledge deepening and content creation). It further extends from TSPCK, by offering teachers the means to consider the learning by learners on digital platforms. The principles of cognitive theory for learning through multimedia (Mayer, 2014a) helps teachers to strive for a balance of the cognitive load students face when learning on multimedia. The evidence for emerging digital-TSPCK in the teachers planning and created animation, is indicative of the new type of teacher knowledge that could contribute to the empowerment of teachers to be the creators of their own digital content through sound pedagogical, technical and cognitive-based reasoning theory. Furthermore, the intervention provides teacher educators with a base process for developing teachers who are confident of both their content and their teaching of the content in the digital realm. What is also comforting is that digital-TSPCK retains the widely tested value derived from pedagogical transformation of content and pedagogical reasoning derived from PCK (Carlson & Daehler, 2019)and the related grainsize of TSPCK (Mavhunga & Rollnick, 2013). For the science education literature, digital-TSPCK

offers a possible refinement of the RCM model of PCK, to now include a version describing the digital realm of teaching. The study has shown that digital-TSPCK is a theoretical construct. It has both a conceptual argument defining it purposefully for digital lessons, and empirically, it has be shown to be visible as per definition in the teachers' planning and created animation teaching video snippets.

9.8 Further Research

Drawing from the limitations of this study, it is recommended that larger studies be conducted in more physics and chemistry topics to determine whether the nature of the component interactions remain the same from one topic to another and to strengthen the validity of the digital-TSPCK construct. Changes to the participants to include comparisons between practising and pre-service teachers could further enhance teacher education programmes to better equip the next generation of teachers to begin teaching with an advantage on digital platforms.

The technical aspects of the digital-TSPCK construct were considered as functional by default if a functioning animation was produced by the teacher. It may be considered for future research to measure the levels at which the digital competencies are displayed in the process during the phases of learning the animation creation as a synchronous study to the intervention held with practicing teachers to develop their digital-TSPCK.

The implications of these findings could inform future professional development programmes of pre-service educators and practising educators who need a theoretical construct from which to apply the technical, learning and pedagogical knowledge required to create digital learning materials of their own. This kind of teacher knowledge could empower educators to adapt to the global change in education in line with the 4th industrial revolution. In the context of the South African education system, as we have learnt to overcome the technology gap in education during the Covid-19 lockdown, there could arise future situations where the educator and learner are separated from each other and the classroom atmosphere. As a result, educators who develop pedagogically sound, information rich educational animations that are cheap to download and distribute, will be able to enhance the learning experience of their learners, improving understanding of concepts in the animations. The benefit for learners will be that they will gain access to higher quality resources when away from their educators and will also be able to review the animations multiple times for revision and study purposes.

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Addenda

Addendum A- Ethics Clearance

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Van der Merwe

CLEARANCE CERTIFICATE	PROTOCOL NUMBER: H20/04/24
PROJECT TITLE	The conceptualization and validation of digital-Topic Specific Pedagogical Content Knowledge for electromagnetism
INVESTIGATOR(S)	Mrs D Van der Merwe
SCHOOL/DEPARTMENT	Education'
DATE CONSIDERED	24 April 2020
DECISION OF THE COMMITTEE	Approved Permission letters are required before data collection can commence Risk level: Minimal
EXPIRY DATE	28 July 2023
DATE 29 July 2020	CHAIRPERSON _____ (Professor J Knight)

cc: Supervisor : Professor E Mavhunga

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. I agree to completion of a yearly progress report.

_____ Signature

_____/_____/_____ Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Addendum B- GDE research approval letter

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

8/4/4/1/2

GDE RESEARCH APPROVAL LETTER

Date:	07 September 2020
Validity of Research Approval:	04 February 2020 – 30 September 2020 2019/588
Name of Researcher:	Van der Merwe D
Address of Researcher:	32 Pigeon Street
	Elspark
	Germiston
Telephone Number:	0722072144
Email address:	Vdmerwe.denise@gmail.com
Research Topic:	The conceptualisation and validation of digital-Topic Specific Pedagogical Content Knowledge for electromagnetism
Type of qualification	PHD
Number and type of schools:	7 Secondary School
District/s/HO	Ekurhuleni South

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

09/09/2020

The following conditions apply to GDE research. The researcher may proceed with the above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

1. *Letter that would indicate that the said researcher/s has/have been granted permission from the Gauteng Department of Education to conduct the research study.*

Making education a societal priority

Office of the Director: Education Research and Knowledge Management
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za

Addendum C- Participant information sheet



PARTICIPANT INFORMATION SHEET

Study title: The Conceptualization and validation of digital-Topic Specific Pedagogical Content Knowledge for electromagnetism

Dear Science Educator
My name is Denise van der Merwe and I am a PhD in Science Education student in the School of Education at the University of the Witwatersrand in Johannesburg.

I am doing research on science teacher knowledge for teaching with technology. Research is a process used in seeking new knowledge. In this study the focus is on teachers' use of technology in their science lessons and the reasons why they choose their specific methods.

You are invited to take part in a research study. In order to determine how you teach using technology, you will be observed in your classroom as you teach for three lessons. A video recording device will be set up by you in your class, aimed at your teaching space, and will make video recordings of your lesson during the teaching period. The recordings will be sent to me electronically and will only be viewed by myself and my supervisor for coding of practice purposes, with data gathered filed under a pseudonym.

Your name and the name of your school will be kept confidential at all times and in all academic writing about the study. Your individual privacy will be maintained in all published and written data resulting from the study. All research data will be destroyed after 3 years after completion of the project.

You will not be advantaged or disadvantaged in any way. Your participation is voluntary, so you can withdraw your permission at any time during this project without any penalty. There are no foreseeable risks in participating and you will not be paid for this study. However, you may benefit from the reflections you may have on the topic.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email Shaun.Schoeman@wits.ac.za

Thank you for reading this Participant Information Sheet.

Date:_____

Yours sincerely,



SIGNATURE

NAME: Denise van der Merwe
ADDRESS: Wits School of Education. University of the Witwatersrand. Johannesburg.
EMAIL: 769102students@wits.ac.za TELEPHONE NUMBER: 072 207 2144

Addendum D- Permission from schools to conduct research



University of the Witwatersrand,
School of Education

The Principal

Dear Sir/Madam,

Re: Permission to conduct research at _____.

My name is Denise van der Merwe.

I am a full time Physical Sciences teacher with 21 years teaching experience.

I am studying part-time for a PhD degree in the School of Education at the University of the Witwatersrand. I am seeking permission to do research at your school.

I am conducting research on the reasoning of Physical Science teachers to use technology to teach electromagnetism. Electromagnetism is a complex, abstract topic in the grade 11 syllabus and its presentation to learners could be more effective if the appropriate technology is used during teaching. Knowledge of the components of pedagogically reasoned teaching with technology could empower in-service and pre-service teachers to design and present lessons more attuned to educating our learners to prepare them for the 4th industrial revolution. As your school offers Physical Sciences with the resources to use technology in the teaching process, it would be most suitable to search for components of teaching with technology.

The research will entail collecting data from grade 10 and 11 Physical Sciences educators when they teach the topic of Electromagnetism. Educators from your school are invited to participate in this study. If they agree, they will be asked to make video recordings of themselves and the resources they use during the lesson of Electromagnetism as per their normal teaching schedule. These recordings would be sent to me electronically, eliminating contact with the school premises and people. Follow-up interviews or discussions regarding the video recordings would take place via zoom meetings or similar platforms which will be recorded for analysis. These meetings would take place after school at the convenience of the educator and would last about 45 minutes.
Participants will be asked to give their written or verbal consent before the research begins. Their responses will be treated confidentially, and identities (their names and the name of the

organisation) will be anonymous unless otherwise expressly indicated. Individual privacy will be maintained in all published and written data resulting from the study.

The results will be communicated in my research dissertation.

The research participants will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this project without any penalty. There are no foreseeable risks in participating in this study. The participants will not be paid for this study.

All research data will be destroyed after a period of three years.

I therefore request permission in writing to conduct my research at your organisation. The permission letter should be on your organisation's headed paper, signed and dated, and specifically referring to myself by name and the title of my study.

Please let me know if you require any further information. I look forward to your response as soon as is convenient.

Yours sincerely,



_____
Denise van der Merwe

Denise van der Merwe
Contact number: 072 207 2144
769102students@wits.ac.za

Supervisor's name: Prof. Elizabeth Mavhunga
Wits contact number: (011) 717-3734
Wits email address: Elizabeth.Mavhunga@wits.ac.za

Addendum E- Teacher consent form for video recording and questioning



University of the Witwatersrand,
School of Education

The Principal

Dear Sir/Madam,

Re: Permission to conduct research at _____.

My name is Denise van der Merwe.

I am a full time Physical Sciences teacher with 21 years teaching experience.
I am studying part-time for a PhD degree in the School of Education at the University of the Witwatersrand. I am seeking permission to do research at your school.

I am conducting research on the reasoning of Physical Science teachers to use technology to teach electromagnetism. Electromagnetism is a complex, abstract topic in the grade 11 syllabus and its presentation to learners could be more effective if the appropriate technology is used during teaching. Knowledge of the components of pedagogically reasoned teaching with technology could empower in-service and pre-service teachers to design and present lessons more attuned to educating our learners to prepare them for the 4th industrial revolution. As your school offers Physical Sciences with the resources to use technology in the teaching process, it would be most suitable to search for components of teaching with technology.

The research will entail collecting data from grade 10 and 11 Physical Sciences educators when they teach the topic of Electromagnetism. Educators from your school are invited to participate in this study. If they agree, they will be asked to make video recordings of themselves and the resources they use during the lesson of Electromagnetism as per their normal teaching schedule. These recordings would be sent to me electronically, eliminating contact with the school premises and people. Follow-up interviews or discussions regarding the video recordings would take place via zoom meetings or similar platforms which will be recorded for analysis. These meetings would take place after school at the convenience of the educator and would last about 45 minutes.
Participants will be asked to give their written or verbal consent before the research begins. Their responses will be treated confidentially, and identities (their names and the name of the

organisation) will be anonymous unless otherwise expressly indicated. Individual privacy will be maintained in all published and written data resulting from the study.

The results will be communicated in my research dissertation.

The research participants will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this project without any penalty. There are no foreseeable risks in participating in this study. The participants will not be paid for this study.

All research data will be destroyed after a period of three years.

I therefore request permission in writing to conduct my research at your organisation. The permission letter should be on your organisation's headed paper, signed and dated, and specifically referring to myself by name and the title of my study.

Please let me know if you require any further information. I look forward to your response as soon as is convenient.

Yours sincerely,



_____
Denise van der Merwe

Denise van der Merwe
Contact number: 072 207 2144
769102students@wits.ac.za

Supervisor's name: Prof. Elizabeth Mavhunga
Wits contact number: (011) 717-3734
Wits email address: Elizabeth.Mavhunga@wits.ac.za

Addendum F- Teacher consent form for workshop



Teacher Consent Form for workshop

Please complete this form if you agree to participate in my research project called:

The Conceptualization and validation of digital-Topic Specific Pedagogical Content Knowledge for electromagnetism

I, _____, agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

Permission for participating in the online workshop and answering questionnaire

I agree to participate in the workshop activities requested for this study YES/NO

I agree that the questionnaire answers can be used for this study only. YES/NO

I agree that the researcher may use anonymous quotes in her research report YES/NO

I agree to answer questions based on the workshop. YES/NO

I know that Denise van der Merwe will keep my information confidential and safe and that my name and the name of my school will not be revealed. YES/NO

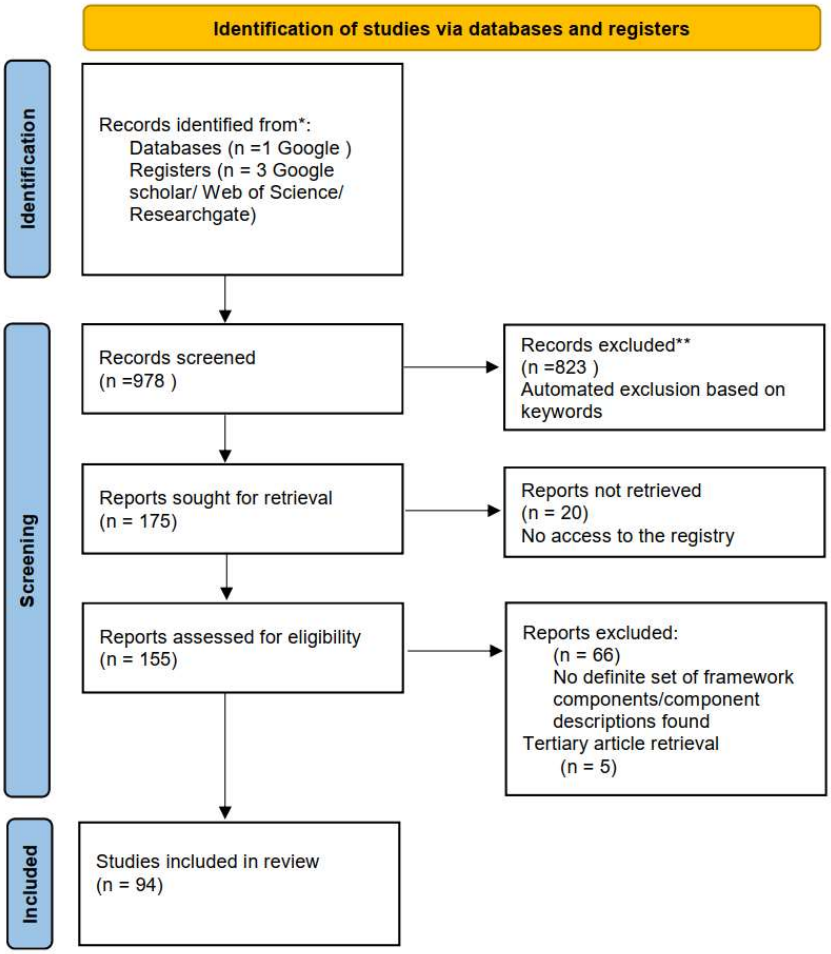
I know that I can withdraw from the study at any time. YES/NO

I know that all the data collected during this study will be destroyed within 3 years after completion of the project. YES/NO

Sign_____ Date_____

Addendum G- Article analysis audit trail for literature meta-synthesis

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only



Adapted From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Summary of Literature sifting - Literature meta-synthesis

Data Source				Limits				Duplicates Results				
Database	Vendor	Date searched	Database update	English only?	Time Period Searched	Publication types	Other Limits	Items found	Excluded-Primary	Excluded-Secondary	Included Tertiary	New
Google/Web of Science	Elsevier/Taylor and Francis/ Researchgate/ EBSCO	2019	2 023	Yes	5 yrs	Journal articles/books/ newspapers/ Academic dissertations/ conference proceedings	Keywords: TSPCK, Topic Specific Pedagogical Content Knowledge, Teaching with technology, tools, rubrics, digital competency	978	823	66	5	94

	Items found	Excluded	Excluded	Included	New
Totals	978	823	66	5	94

Article analysis list for Literature meta-synthesis audit trail	
	List of articles in Literature meta-synthesis primary analysis (155 articles)
1	A'tiah Sakinah Abdul Rahman, R., & Harun, N. S. R. (2018). Tesl Pre-Service Teachers' Tpack: A Review. *International Journal of Academic Research in Business and Social Sciences*, *8*(2), 795-804.
2	Abbitt, J. T. (2011). Measuring technological pedagogical content knowledge in preservice teacher education: A review of current methods and instruments. *Journal of Research on Technology in Education*, *43*(4), 281-300.
3	Adipat, S. Developing Technological Pedagogical Content Knowledge (TPACK) through Technology-Enhanced Content and Language-Integrated Learning (T-CLIL) Instruction. *Educ Inf Technol* (2021). https://doi.org/10.1007/s10639-021-10648-3
4	Agyei, D. D., & Keengwe, J. (2014). Using technology pedagogical content knowledge development to enhance learning outcomes. *Education and Information Technologies*, *19*(1), 155-171.
5	Agyei, D., & Voogt, J. (2011, March). Determining Teachers' TPACK through observations and self-report data. In *Society for Information Technology & Teacher Education International Conference* (pp. 2314-2319). Association for the Advancement of Computing in Education (AACE).
6	Akinyemi, O. S. (2016). *Pre-service Teachers' Development of Topic Specific PCK in Kinematics and Transferability of PCK Competence to a New Physics Topic* (Doctoral dissertation, University of the Witwatersrand, Faculty of Science, School of Science Education).
7	Akinyemi, O. S. (2020). *Exploring the development of pre-service teachers' Topic Specific PCK and its influence on learner outcomes* (Doctoral dissertation).
8	Ali, C., & Agyei, D. (2016). Preservice teachers' technological, pedagogical andcontent knowledge in utilizing the Merrill's first principles in solving polynomials. Merit Research Journal of Education and Review. 4(10). 133-142.
9	Altun, T., & Akyildiz, S. (2017). INVESTIGATING STUDENT TEACHERS'TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE (TPACK) LEVELS BASED ON SOME VARIABLES. *European Journal of Education Studies*.
10	Alzahrani, A., & Cheon, J. (2015, March). The Effects Of Instructors' Technological Pedagogical And Content Knowledge (TPACK) On Online Courses. In *Society for Information Technology & Teacher Education International Conference* (pp. 3044-3049). Association for the Advancement of Computing in Education (AACE).
11	Angeli, C., & Valanides, N. (2013). Introduction to special issue: Technological pedagogical content knowledge. *Journal of Educational Computing Research*, *48*(2), 123-126.
12	Ansari, I. (**2015**). Technological Pedagogical Content Knowledge (TPACK): An Emerging Research and Development Tools for Technology Integrated Science Teaching-learning.
13	Ansong-Gyimah, K. (2017). *Creating an online tool for assessing the readiness of teacher training colleges in developing countries to implement the UNESCO ICT competency framework for teachers: A design and development study* Virginia Tech].
14	Avdeeva, S., Zaichkina, O., Nikulicheva, N., & Khapaeva, S. (2016). Framework for Assessing the ICT Competency in Teachers up to the Requirements of" Teacher" Occupational Standard. *International Journal of Environmental and Science Education, 11*(18), 10971-10985.

15	Azam, S. (2020). An Inquiry Into Personal Pedagogical Content Knowledge of Science Teachers: Stories of Teaching Electricity. *Journal of the Canadian Association for Curriculum Studies*, *18*(1).
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Addendum H- Transcripts from pre-intervention videos

Transcript from Mr D lesson: 1 section submitted only.

D: lets talk about electrostatics in two dimensions. We already talked about one(**LP**) dimensional now we are going to talk about 2 dimensional and then (**CS**)we proceed to talk about the electric field strength and then we solve questions and then we revise for the final examination. Look at the example on the board**(R).** We have determined the resultant force on B, (points) that is charge B, this is charge A and charge C. (**CTS**)

Transcript from Mr M lesson



M: If I may ask, what knowledge do you have about matter? What are we referring to? Or, what makes up matter?(**LP**)

M: In grade 8 you learnt that matter is everything that occupies space. This desk is what we call matter, is that right?(**LP**)

L: Yes

M: yes. So if all matter occupies space and has mass, but what makes up matter?

M: you said something there?

L: Atoms

M: Atoms. Ok, so if matter is made up of atoms, it means that atoms are the smallest building blocks of matter. So if you think about it, and break a certain object into pieces, you cut it into half, then you take that half and cut into half again, and cut it again and so forth, at the end you are going to have a so-called 'uncuttable piece' where like, something that you cannot cut anymore. (**R**)

Refers to the slide on the screen from the projector where a list of scientists are displayed.

So I am just going to go through the scientists that discovered certain things like J. J. Thompson. He discovered the electrons. It is the plum pudding model to elaborate that he found some spots, or (**R**)negative particles on the metal, alright, and those he called electrons, alright? So I just want to show this slide to you, structured from science clinic. Oh it's a pdf from science clinic that was given. There are others like James Chadwick that discovered the neutrons. Finding the nucleus and inside one he found a charge ok it's the protons, and there are many more scientists that I want us to look at.

Oh this is very slow (working with the laptop)

Ok so now what we need to know is the electrons are having a certain charge, they are negatively charged and they are found outside the nucleus. So within the nucleus which is positively charged …why is the nucleus positively charged?

L: no response

M: Because the nucleus has one charge inside. A positive charge, the charge of the …protons. Ok, and what about the neutrons within the nucleus? What is their charge? (**CTS**)

L: no charge

M: There is no charge, ok? They are neutral, so if the protons are positive, and the neutrons are neutral, and both protons and neutrons are found within the nucleus, then the only dominant charge will be the charge that exists within the nucleus, which is the positive charge.

So protons are positive, neutrons are?

L: Neutral

M: Neutral, so where are the electrons? Electrons are outside the nucleus. Around the nucleus. They are orbiting, ok? So they orbit the nucleus, they move around the nucleus. Just like the planets orbiting the sun. Now, their charge is negative. And they have very less mass, they are less in mass as compared to the nucleus as a whole. The heaviest part of the atom is on its nucleus, at its centre. (**R**)

So I just want us to have a look at page 38 (shows page 38 on the screen). Can you all clearly see there? (**visual adjustment for learners)**

L; No

M: Ok, let me try to make it 75. You still can't see there?(enlarges print again) Alright can you see now?

L: Yes

M; Ok, so the first one is J.J. Thompson….06:07 . They say he used cathode ray tube to show that there are small negative particles, alright, inside the atom. He called them electrons. Electrons are found in all atoms, it means that regardless of which atoms is it, it must have electrons and then, what did he say again? He said that they have the same charge and mass no matter what substance they are coming from. It doesn't matter where the electron is coming from, it will have the same charge and mass, OK?

So he used the currant bun, also known as the plum pudding model to explain the negative electrons that are found inside the solid positive mass. OK so as you can see here, um, it says electrons are negative part of the positive solid mass.

So now you can see Niels Bohr.

OK, so J. J. Thomson discovered the electrons and Niels Bohr explains how the electrons are moving, OK?

So in terms of how they orbit the nucleus, remember they are outside the nucleus, electrons travel around the nucleus.

There let me just move this a little bit and then make it 100 again.

OK, so electrons travel around the nucleus in circular definite paths called orbits, like the planets orbiting the sun.

Alright, orbits around the sun. each orbit has a certain energy, right, and electrons in the same orbital has the same energy, so it means those that are in the same level, they have the same energy. So now he also said that the ones having a large amount of energy they must be far away from the nucleus OK? The further it orbits from the nucleus, the higher the energy it has. And also electrons can jump from one orbit to another, OK? Now depending on the amount of energy that it's gained, it might move from the lowest to the highest level of energy. Now if they drop from the highest orbit to the lowest, OK orbital, from the highest to the lowest it means that it has lost energy, OK. Now OK, Now when an electron moves to the highest energy level it gains energy. You can all see then and you are familiar with the energy shells. As you can see the K, L, M they are the alphabet and the letters are increasing as we move away further away from the nucleus OK.

You can see the electrons paired. We are going to talk about the orbitals, right? So an orbital is simply, let me say, a region where there is the most probability of you finding an electron, because it's impossible to say electrons are there or electrons have been there so you only find out through the orbitals, we use orbitals, this is a probability of us finding an electron in that atom in that shape OK?

09:44

M: so now let's go to another one which is Schrödinger. Schrödinger he says it is impossible, it is not possible to find an exact position of an electron OK? So it's not possible to find the exact position, to say electron is right there. So only the most probable regions where electrons move.

So where they normally move we can estimate and say OK these electrons are somewhere there because we know they are going to move around there. So he says the regions inside of an atom where the electrons are likely to be found are called the orbitals OK.

So we are going to talk about the orbitals a bit later on if we have time. Now another artist, no let's go down, there is James Chadwick, the one I spoke about, he discovered the neutrons. And what did he say? Neutrons are within the nucleus and they have no charge and their mass is almost the same as the mass of the protons and neutrons are found inside the nucleus, OK.

And where are protons found?

L: Inside the nucleus.

M: Inside, Neh? OK and the electrons? Where are they found?

L: Outside

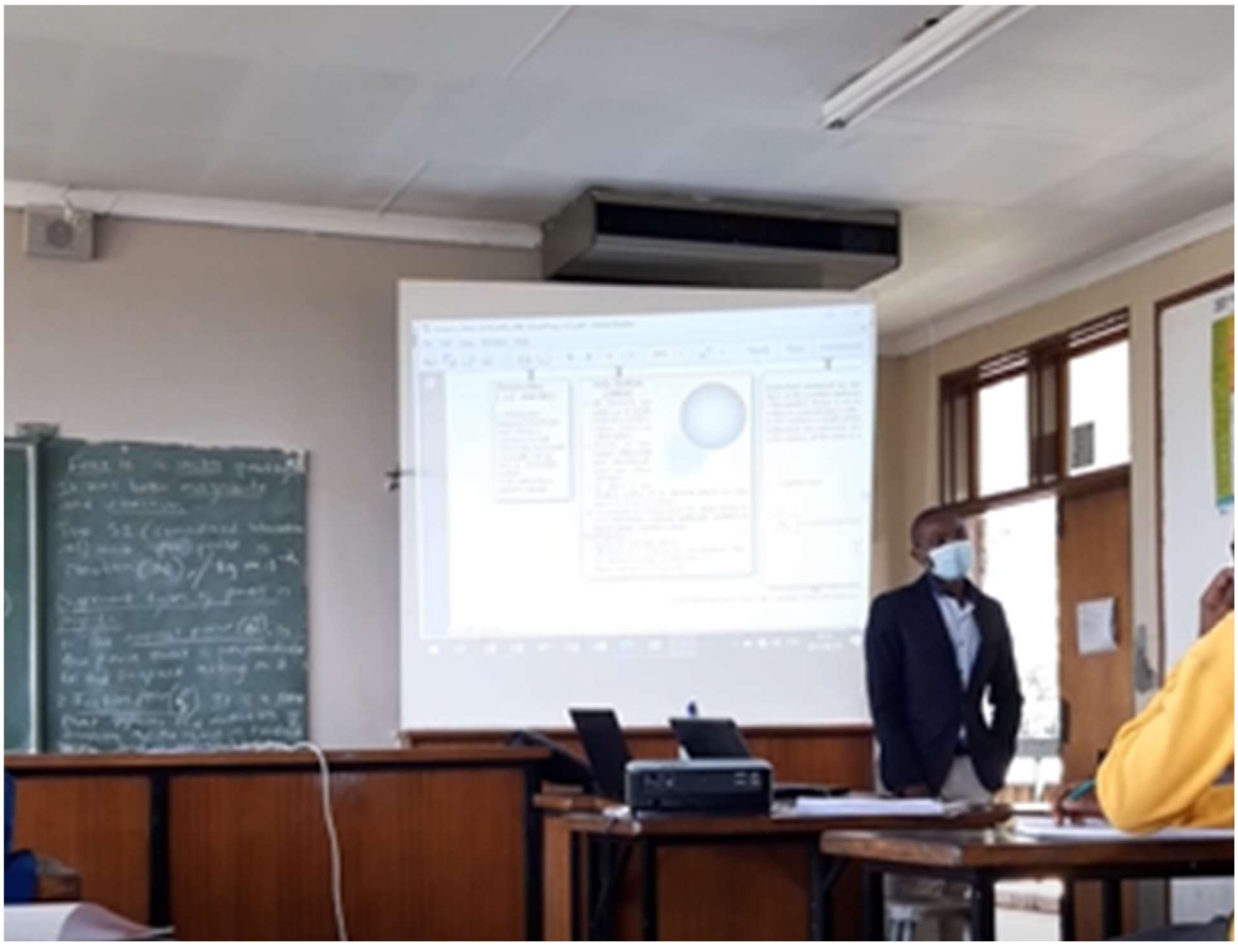
Around the nucleus

M: OK, and which one has the more mass? Is it the nucleus or the many electrons outside the nucleus?

L: The Nucleus.

M: It's the nucleus. Electrons are very light OK? Let's go down to another artist again. Sorry scientist, not artist.

OK now let's look at going a bit up these. Democritus discovered the atom, he talked about cutting a substance in half.



11:59

You cut it into half and eventually you cannot cut it anymore. Alright he says suppose you kept cutting a substance in half repeatedly, eventually you will have an uncuttable particle so you won't be able to cut anymore and he called these particles atoms. These are the smallest parts of atoms that take part in a chemical reaction. They are so small we cannot break them any further or cut them further no matter what method you use. . OK, so that's Democritus. Then you have another one, John Dalton. Now what did John Dalton say? He spoke about, he said all elements are made up of small indestructible particles, solid spheres called atoms, atoms of the same elements are identical in same size, meaning same shape, OK. That's what he said. Then he said the atom is the smallest particle of an element which can take part in a chemical reaction. OK, so it's the smallest part of matter that also takes part in a chemical reaction.

13:17

Now he says compounds are formed when atoms of two or more elements combine with one another, you know that these are different atoms, so now if they come together they make up a compound, alright?

So now he says if they come together and meet up in fixed whole numbers or ratios.

13:40

Now there is some dispute about his discoveries. OK. So now we are going to find out also that atoms are not solid spheres alright? As he said, and secondly all atoms of an element are not identical. OK, and then there are different isotopes OK

14:00

So you learnt about isotopes, these are elements of the same atomic number OK, and then atoms consist of sub-particles, when we talk about sub-particles we are talking about what makes up particles. We are talking about protons, we are talking about neutrons, both are found within the nucleus and the one that is outside the nucleus is the electrons. OK so now you can see there are some shortcomings there (points on screen-Dalton). So his theory was, uh, disputed there and then so OK, now let's look at another one. (Sequencing bad)

Ok. This one we call Ernest Rutherford. OK, now this one used a foil, a gold foil to show that every part, let me say atom, every matter will have some spaces there. OK. So you are going to have some spaces between the nucleus and the electrons OK. So now he used the alpha source or beam of light to shine through a metal foil, alright? And then what happens is there were some rays that went straight like this one (points at a ray on the screen) undeflected alpha particles and others were deflected, right, so as you can see here (new diagram) this is a solid nucleus and then what happens there? It's the rays are passing between the nucleus. OK so then the other one you can see the ray with the whole atom, its deflecting because of the solid nucleus at the centre. OK and then if read the Rutherford experiment in which he shone a beam of alpha particles towards a sheet of thin gold, most of the, OK, most of the particles continued in a straight line but some were deflected in the tubes, that the positive charges are not evenly distributed as suggested by Thomson. OK.

And then the positives are found in the centre of the atom, so you remember Thomson said that the atom is metal or solid spheres and then the electrons are all around the metal, so this one is saying,

16:59

No, the positive is at the centre of the atom, it's not evenly distributed as Thomson was saying OK. It's in the nucleus and the mass is concentrated in the nucleus so the whole mass of the atom is in the nucleus. Now the nucleus is a large mass that can deflect the alpha particles so these have deflections because of the mass at the centre so that causes them to move in a different direction. The nucleus is small compared to the atom because most of the particles passed undisturbed through the gold foil.

17:33

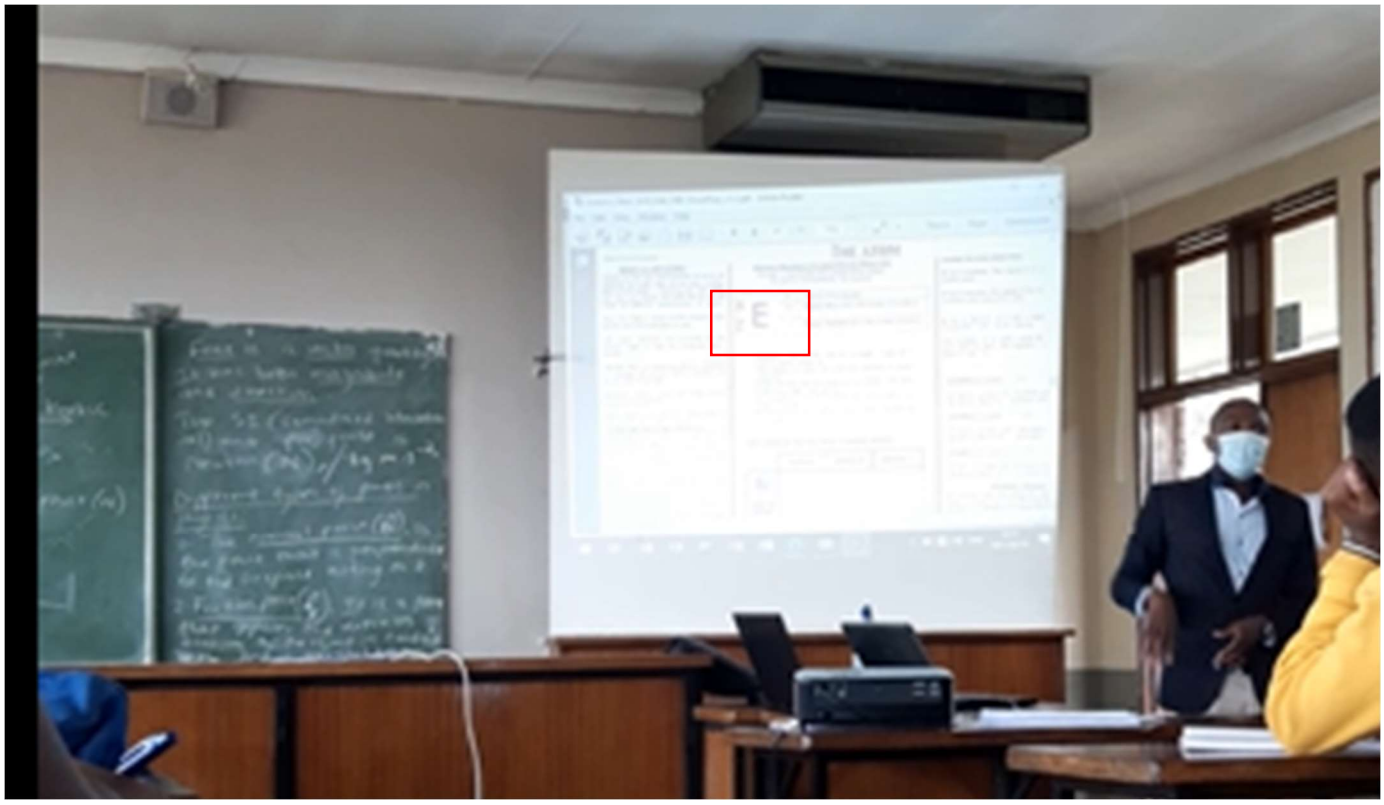
Alright. And then the electrons are extremely small and far from the nucleus who makes up practically the whole mass of atoms, so the electrons are very small. So they determine the volume of the atom.

OK. Now the volume of the atom is 10000 times greater than the volume of the nucleus. So it's greater than the volume of the nucleus…

18:02

because the nucleus is the solid part of the centre, alright and then the electrons make up, remember the space outside, so outside the nucleus, that space is the volume, that is where the electrons are orbiting the nucleus. So the atom is mostly empty space. OK, so you have empty space that allows the alpha particles, the beam of light, to pass through them. OK now let's take a look at another one OK. (moves PDF on screen) basically we covered every scientist then. But I want us to look at the atom on it's own, OK?

18:50



The atom is represented by a symbol $\frac{z}{a}$ E. OK so maybe we are talking about Lithium, you must have a symbol, represented by the E, there, the symbol of an element OK. So when we represent the symbol of the element Lithium, its Li, then E will represent Li. And a will represent the atomic mass OK and then which we also call the number of nucleons, nucleons meaning the protons and the neutrons in the nucleus makes up the nucleons, the mass of the nucleus. Ok besides the atomic number OK for example you know Hydrogen's atomic number 1, Magnesium is atomic number 12, calcium and so forth. Now that atomic number tells you the number of protons.

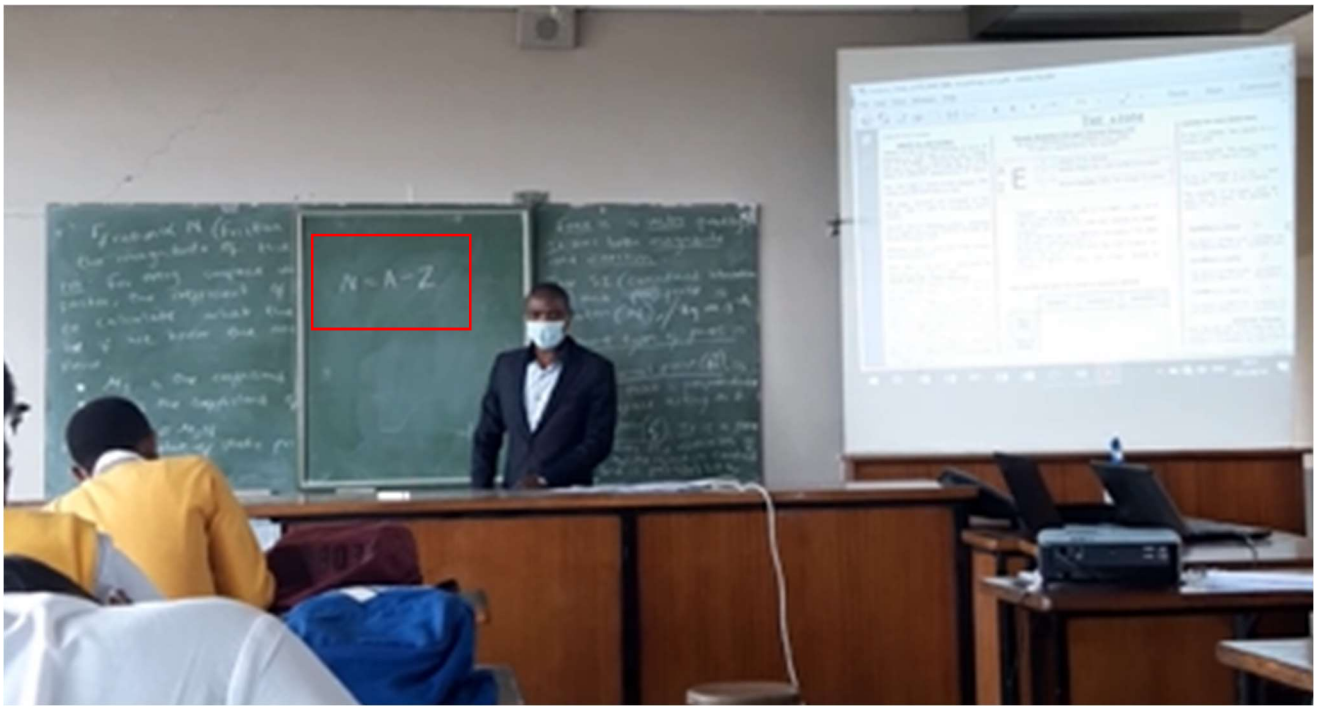
19:42

OK now if you know the number of protons in the nucleus and you know the mass number of the element.

20:00

Can't you find the number of neutrons? You can, isn't it? Now how are you going to find the number of neutrons? OK you are going to use, remember you have a and z there OK. To find the atomic number, I mean the mass number you need to add the number of protons and neutrons. Now if you want to find the number of neutrons what do you do? You subtract the protons from the atomic mass, OK? So n represents the number of neutrons, so if you're looking for the number of neutrons, n, then what are you supposed to do?

20:38



We are looking for N (cleans the board and starts writing) OK, so n is going to be a minus z (writes n = A – Z)

OK and then do you know what this is the number of?

Learner: Neutrons



M: Neutrons (writes the word above the symbol on the board)

And then it's the atomic (writes) atomic mass. And then this is the atomic number neh? (writes) which represents the number of protons (writes)

21:29

OK, now tell me if I'M saying that the element is neutral, OK, what does it mean? It is neutral. Remember when we are talking about neutral we are talking about balanced charges OK? Then what does it mean? It means that the positives are equal to the …

Learner: Negative

M: Negative. For every neutral atom. So you say this Lithium is neutral and Lithium is atomic number three, it means it has how many protons?

Learner: Three

M: How many electrons?

Learners: Three

M: Because its neutral, alright? But now if we say if Lithium ion for example what does it mean?

Draws symbolic representation of Li^{+}

It means what?

Learner: Positive ion

M: it's a positive ion. It has lost one electron OK. Remember electrons are negatively charged neh? If you gain an electron you become more negative.

22:43

M: OK. I made this example with negative friends, you are not going to listen to your parents, but get rid of those negative friends then your life is going to shine positively alright. So now electrons are negatively charged, those in group 1, remember when you talk about the periodic table are going to do what? To? Lose one electron, alright? Those in group 2, 2 electrons. So the ability of giving more than 1 electron and those in group 7 will receive that 1 electron and those in group 6 will receive those 2 electrons OK.

23:22

Why? To fulfil the octet rule: the octet rule says that all atoms must at least have eight electrons in their outer shell, OK. So now they are sharing these electrons to at least fulfil the octet rule.

23:38



OK now if this one (points to Lithium on the board) we say its Lithium plus. What does this mean? It has lost an….?

Learner: Electron

M: Electron, because it is positively charges, isn't it? Alright. If it has lost an electron, what is the atomic number of Lithium? Atomic number is Z. it is….?

Learner: 3

M: Do you all agree?

Learners: Yes

M: It is going to be 3. Lithium is atomic number 3. It means that is has 3 protons. Can that be changed?

L: No

M: No, remember atomic number represents the number of protons. Can you change the atomic number?

L: No

M; And say now Lithium is no longer 2 because it lost an electron. It is now changed to 2. Is that possible?

L: No

M; No, so it will remain the protons 3, so if its neutral it will be 3 protons and 3 electrons. Now it has a charge (points to Li^+) this charge tells you it is now a lithium cation, it is positive, it's a cation. If it is negative its an anion, like chlorine-draws symbolic representation of chlorine ion- this is a chlorine ion, but it's a chlorine anion because of the excess negative charge. OK now, so now its supposed to have three protons and three electrons if its neutral, but now its lost an electron. How many electrons does it have now?

L: 2

M; Two electrons, do you all agree?

L: Yes

M: Yes, very good. But now, how many neutrons will it have now? Neutrons is atomic mass subtracted atomic number

L: 4

M: How many? How many neutrons will it have? (draws on board n = A – Z and speaks the words of the symbols). OK so what is the atomic mass?

L: 2

M: The atomic mass is 2. Atomic mass is made up of protons and…

L: neutrons

M: Neutrons. OK so the atomic mass is 2, its for Lithium.

Do you all say that?

L: No

M: No?

OK, let's start with the normal Lithium. This is the normal Lithium (points to the board and the equation n = A – Z)

26:20

How many nucleons does it have?

L: 3

M: 3? OK, how did you find 3? What is the atomic mass for Lithium?

L: Vague answer

M: remember on the Periodic Table (Draws the symbol for LI as seen on the Periodic Table) You are going to have the symbol there, you will have the atomic number at the bottom, sorry on top, and the atomic mass at the bottom. If I'm asking for the atomic mass, I am looking for that (points at atomic mass). OK, what is the atomic mass?



L: 7

M: 7. OK. Can you change the mass of an atom? Of an element? Can you change it?

L: You can't change it.

26:49

M: You can't change it. OK and what is the number of protons there?

L: 3

M: It's atomic number….

L: 3

M: (underlines 3) and so you are going to have…

L: 4

M: 4. OK. So you are going to have 4 neutrons.

27:13

You are going to have 3 protons and then the atomic mass is going to be 7 (showing counting with fingers) How many electrons are you going to have then? For that LI. That neutral element.

L: 3

M: 3, very good. So the number of electrons, does it contribute to the mass number in the nucleus? In the nucleus.

L: No

M: It doesn't. OK so the mass number consists of protons and neutrons. And the electrons are very light but they are outside the nucleus. Now they give us the volume of the atom. OK? Now we are going to have 4 neutrons and 3 protons, if you add them together you are going to get 7 which is the atomic mass. Did we have any electrons on that equation? How do you tell how many electrons are there? You are going to tell by the…

L: (vague)

M: By the charge, alright. Is it neutral or is it not neutral? If it's neutral, same number of protons, same number of electrons. OK, if it's not neutral its negative like chlorine, let's say, let me write this down.

Chlorine has an atomic number of 17. How many protons does it have? Remember protons is shown by the atomic number. Number of protons is the atomic number, so if it has 17 protons, how many electrons does it have?

L: 18

M: 18 electrons. Very good. Why? Because I said if you have negative friends you gain negativity, your lif is influenced in a negative way. So this one has gained one electron, OK so that charge tells you the number of electrons that it has gained. So it is only 1 negative, so it gained 1 electron, right? So it's gonna have 17 protons, 18 electrons OK. So its mass is around 35, 34.5 somewhere there alright.

29:46

M: So if we were to look at another different one, look at Mg^{2+}. Mg^{2+} how many protons does it have? Atomic number for Magnesium is 12. How many protons?

L: 12

M: 12 protons. Mg^{2+} how many electrons?

L: 14

M: 14 electrons? Oh OK. So this one (points at Cl^{-}) you say is negative and we are adding electrons and now I gave you another charge and said

L: (whispers) 10



M: (starts with new representation on the board) Now I am saying Mg^{2+} How many protons does it have?

L: 12

M: 12. How many electrons does it have?

L: 10

M: 10. How did you get to 10?

L: we subtracted

M: If you have more negative- chlorine has an extra electron, your life will be faced negatively. If you lose negative friends, your life becomes more positive. OK. So these are electrons alright? Now, now magnesium has lost how many electrons?

31:07

L: 2

M: 2. Why did it lose 2 and not 3?

L: because it is 2 positive.

M: Because it is 2 positive. OK but remember. Which electrons can be lost? The ones on the valence electrons. So the valence electrons can be lost. The electrons on the outer shell of the atom. Ok which represents the group number. Group 1 has the valency of 1, Group 2 has the valency of 2.

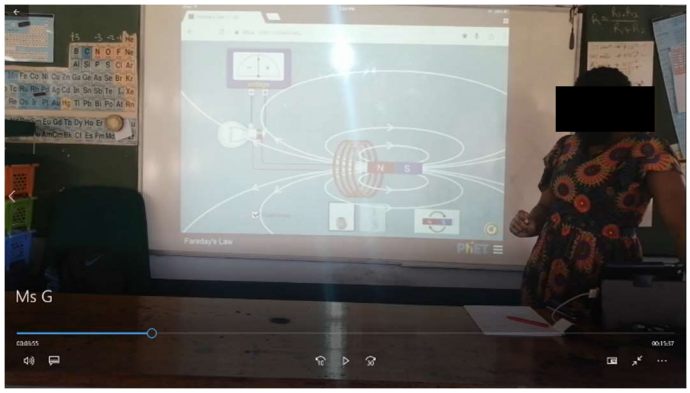
Ends 31:51

Transcript from Ms G lesson

G: Good afternoon everyone.

L: Good afternoon

G: so today we will be looking at Faraday's Law. So I'm gonna use this simulation to explain the basis of Faraday's Law.



So in the simulation I have a magnet and I have a coil which is connected to the light bulb and the voltmeter. So if I move the magnet into the coil, there are two things that are happening. Firstly the bulb glows and then also you are going to see the deflection in the voltmeter. So as we know around a magnet we have magnetic field lines, let me just show you the magnetic field lines. So now we have the magnetic field lines, OK, but first for us to understand Faraday's Law there are terms that we need to understand.

The first one is magnetic flux. So what do we mean by magnetic flux?

So magnetic flux is the measure of the field, of the magnetic field that are moving through the coil, so that's the first term. But then I will have a video that will explain more on the magnetic flux, let me just play it.

Goes over to the video on the whiteboard.

Video transcript:

Now let's look at magnetic flux. So flux in general: well we've already seen the concept of electric flux (LPK) and magnetic flux is really the same sort of concept.

And again that was a measure of the flow through the surface, in this case it's the flow of magnetic field lines through a surface, and so you can think of it kind of like in this picture. If I've got a particular surface I've got some field lines going though it and I want to measure that. Now that magnetic flux is going to depend on three factors:

It's going to depend on the field strength. Remember that the field strength is represented by the density of the arrows, so the stronger the field is, the more arrows you've got more closely packed together representing those field lines.

Then we've got the area. If your surface has more area, you're going to have more flow going through it than if you've got a smaller area.

Then we talk about the angle of the surface. Depending on how the surface is tilted you could have more or less field lines going through that surface.

We can wrap all of these concepts up with a single equation that says the flux is equal to BA Cosine Ɵ.

Video stops.

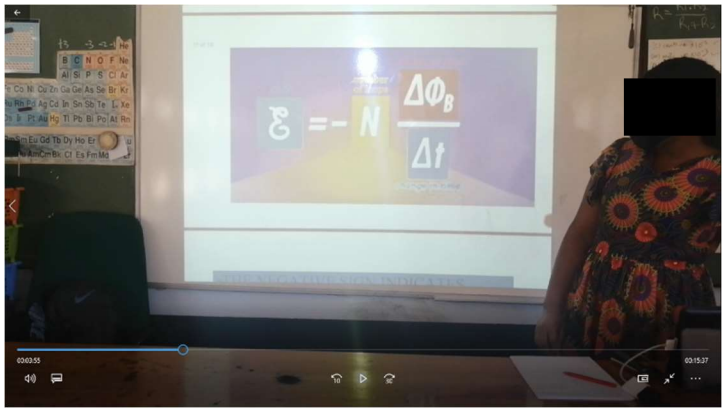
Ms G: OK so now that's it. Now we understand the magnetic flux. So I am going back to the simulation.

Puts on the PHET simulation

So in this simulation, so we now understand the change in magnetic flux, so the change in magnetic flux here, if I change the magnetic flux, see there is movement (moves the magnet into the coil) the light bulb will light up and then we have the voltage there, so the voltmeter will deflect to show that there is voltage. So now I want to explain Faraday's Law. So Faraday's Law is represented by an equation, let me just go, let me just go and open my slides so that you can see Faraday's law equation.

(Opens the powerpoint presentation)

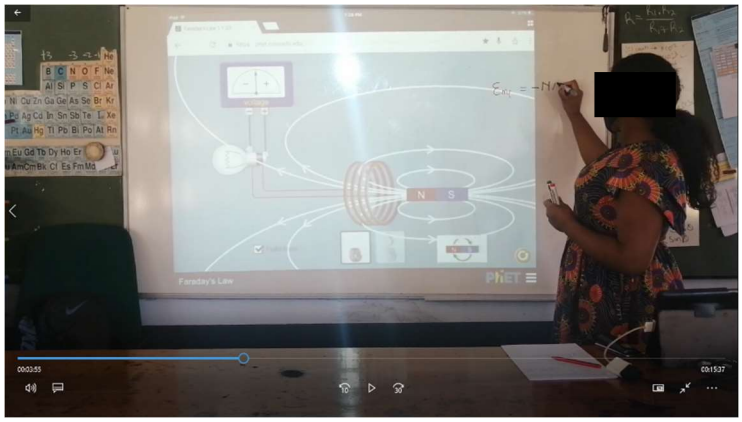
So Faraday's Law is presented by this equation:



So the ε is the induced emf and then we have the number of loops, and then we have the change in magnetic flux (points at the symbol $\Delta\Phi_B$)- so this is the symbol for change in magnetic flux, that's the magnetic flux, this is the Greek symbol, they call it phi, over delta t.

So you can see the emf there it depends on the number of turns and also the magnetic flux. But then it's important to know that in the Faraday's law we have the negative sign, so the negative sign it indicates that the current induced and the magnetic field they resist the change in the magnetic flux.

So we have the emf that is directly proportional to the change in magnetic flux. So let me go back to the simulation



(writes a formula on the whiteboard over the simulation)

So here, you know your Faraday's law is emf, that's the mathematical expression, so it's, uh, it's emf is equal to the number of turns, change in magnetic flux over change in time. So the emf there is directly proportional to- let's go back to the equation again (Back to the powerpoint presentation)

So here's the equation

So the emf is directly proportional to the change in magnetic flux and indirectly proportional to the change in time.

(scrolling up the slides to the definition of Faraday's law)

So I just want us to look at the law. So Faraday's Law states that: (Reads off from the slide)

That the magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor.

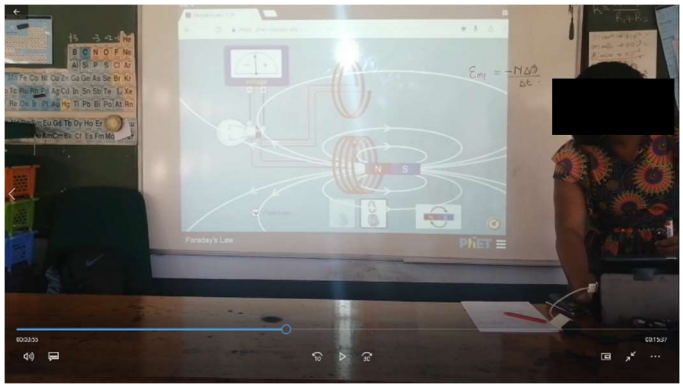
(as she reads each concept eg emf, she points to the symbol on the formula on the right)

So that is the law.

(returns to the simulation screen)

And then, so now you know that if you move the magnet toward the coil, we are going to induce the current in the coil (on the simulation she moves the magnet back and forth to aid the verbal explanation) which will create the, which will induce the emf.

So now the value of the emf is, it depends on the number of turns. So now I have the turns here (points to the coil in the simulation) nut then let me just add more turns, OK (adds another solenoid to the circuit with less turns than the one already on the screen- both solenoids are visible)



So now I have 4 this side and I have two there (points each time) So now as I move in the magnet (magnet is moved back and forth in the large solenoid) you see the light.

So let me now move the first one (small solenoid) where I have 2 loops, so you see now when I move the magnet (moves magnet back and forth) you see the light. But then when I move it here where I have more, you see the difference? OK, so now the emf that is induced, it depends on the number of loops and then it also depends on OK let's just look at this: OK if I put my magnet in there (large solenoid) if the magnet is stationary, you see there is no change in flux, if there is no change in flux there will be no emf produced or any other current produced, so we only going to have the current when there is a change in the magnetic flux, so as you can see when I am moving it (moving the magnet back and forth) there is current produced (light bulb glows) and then if I'm not moving it, then there won't be any current induced. Also you can see that the needle on the voltmeter- so if I move in the magnet it will, uh, it will move to the, you see, if I move to the coil it moves to the other side, but then now when I move it back, it now deflects to the opposite side. And then to increase the value of the emf that is induced I have to use stronger magnets so I can increase the strength of the magnet, and then I can also, if I move the magnet slowly, check the current, but then if I move it faster, see? So there's a difference in the amount of emf that is being induced.

(Refers back to Faraday's Law Definition slide)

So the Faraday's Law of electromagnetic induction states that (reads off from the slide) The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor.

And then what we have checked on the simulation is this, ways of increasing the induced emf

(goes to the next slide)

Heading: 'Increasing the induced EMF'

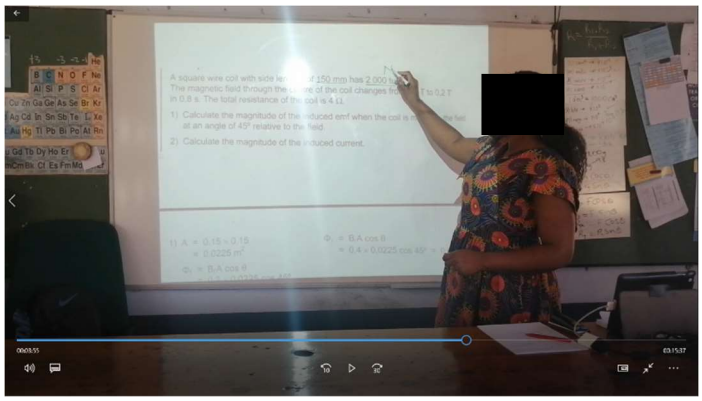
(cleans the white board of the previous formula that was written on the board)

So the first way of increasing the induced emf is to increase the rate of change of magnetic flux i.e. by decreasing the time it takes to change the flux and then we can also increase, OK, by increasing the speed of the movement of the magnet (pointing to each factor). But then also we have realized that when you increase the number of loops in the coil we can also increase the emf that is induced and there also I have mentioned that if we use a stronger magnet then we gonna have more emf that is induced.

And then it is also important to notice that you can also increase the surface area of the loops and then lastly to increase the change of flux by changing the angle from a minimum of zero to a maximum of 90°.

So that is Faraday's Law (Time: 12:19)

So the Faraday's Law can help us to, it can help us to calculate the value of the induced emf. So let's look at this example



So OK, this example it says (she reads the question out loud and explains and underlines keywords as she reads)

A square wire coil with side lengths of 150mm has 2000 turns. So you know we have 150mm (underlines it) and then you have to convert it to meters and we have our number of turns (underlines it and writes the symbol N on top). So number of turns is 2000 and then the magnetic field through the centre of the coil changes from 0T to 0,2T in 0,8s. The total resistance of the coil is 4Ω.

So the first question asks to calculate the magnitude of the induced emf, so you are looking for emf (underlines emf) when the coil is moved into the field at an angle of 45° (underlines 45°). Now the coil is moved at an angle of 45° relative to the field. That is the first question. So in answering that question, trust me, we have to calculate the area of the square wire and then when we're done with the area we must also calculate the change in magnetic flux (underlines the two magnetic field values) because the emf equation (begins writing the formula on the board) it's emf is equal to –N, change in your magnetic flux over the change in time. So we do have the delta time and we do have the number of turns but we don't have the magnetic flux.

(moves the presentation upwards to reveal the answers)

So firstly we are going to find the area. So in finding the area (rubs out any previous marks made on the board) we have to convert the millimeters first, so you're going to have 0,15 multiplied

with 0,15 then your area will be this (points at answer of 0,0225m^2). And then how are we going to calculate the magnetic flux?

We are going to start with the final magnetic flux (points at formula) this is your Φ final= $B_f A \cos Θ$, magnetic field, which is your area cos your angle and then you know the final flux was 0,2T and the area is, we calculated the area (points at the value on the board) and then cos of an angle, and you know that the angle is what? 45° from our data. And then this (points) is our answer in Weber. And then we also have the initial magnetic flux and then we have our B, we have our A and cos of and angle (points to each value on the board) and then B_i we know was 0,4 multiplied by 0,0225cos of 45 then we have our initial magnetic flux in Weber.

And then, now we can say (draws a square around the formula $\Delta\Phi = \Phi_f - \Phi_i$) the change in magnetic flux which is the final flux minus the initial, if you put your numbers, your final minus your initial the answer will be this answer (circles answer on the board) in Weber.

And then we can use our Ohm's law, sorry our Faraday's Law. So now we can use our Faraday's Law. So it's the induced emf equals to negative N over delta phi over delta t (points to each value on the board). So N it's negative 2000 and we have our change in magnetic flux which is then our 0,8 (points) and then over 0,8 (points) and then our emf will be (points at answer) so that's how we use the Ohm's Law equation.

And then the second question was:

Calculate the magnitude of the induced current. So now you can see that the Faraday's Law can help us to calculate the induced, the induced emf and also the induced current. But then in the induced current we are going to use our Ohm's Law. So I equals to V over R (points at symbols in the equation). We calculated our induced emf which is 8 over R (points at the 4) we got our R from our scenario and then the current is 2A. but now in finding the direction of the current we use Lenz's Law. So (scrolls to the definition of Lenz's Law and points as she reads) Lenz's Law states that the magnetic field generated by the induced current will be in the direction opposite to the change in magnetic flux, but then we are not going to dwell much on that.

So let's just recap.

So we started by magnetic flux

So we know that the magnetic flux is the measure of the magnetic field, we've seen that in the video so it is the measure of the magnetic field running through a loop of wire and then it is represented by this symbol (points to the appropriate symbol on the board) phi B. and then we said it depends on three factors, I'm sure you've noticed that from the video (points at the formula). So it depends on the magnetic field strength. It depends on the area of the loop and then it also depends on the angle.

So now if we combine the three factors (scrolls down to new formula) we get that equation for calculating the magnetic flux. Magnetic flux if BAcos of an angle. (scrolls down to Units of magnetic flux). Yes we measure the magnetic flux in tesla meters squared which is equivalent to webers.

So yes, that's it.

Thank you.

Transcript from Mr T Lesson

00:00

Mr T: Alright, OK, good morning once again, OK let's quickly look again at the questions we have done yesterday and see how best we were supposed to respond to these questions. I'm starting with questions number 1, um, I don't think that there is anyone who had any challenges with question 1.

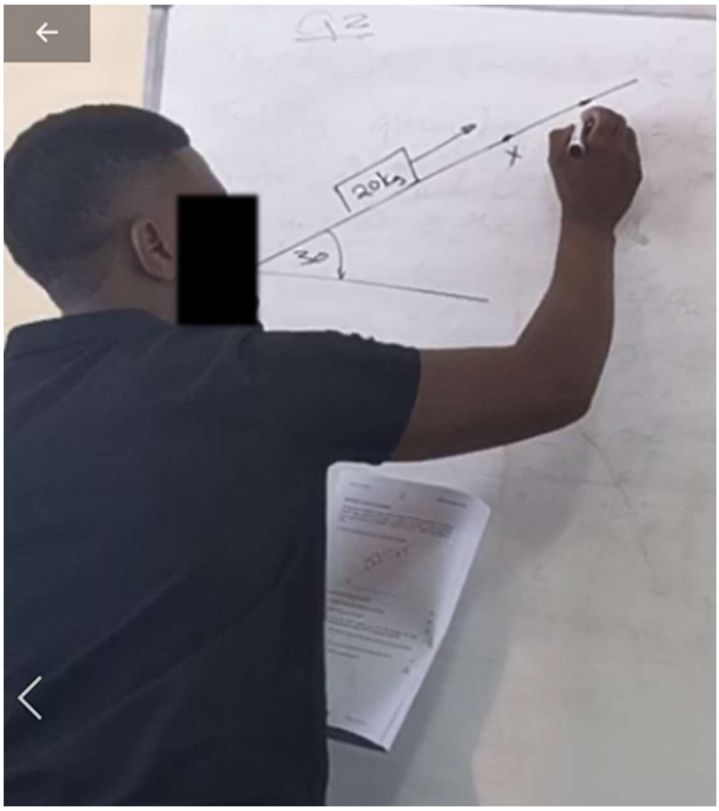
(learner silence)

So I won't focus on question number 1 and we will start with question number 2 since there was no-one who had any challenges with question number 1.

Right, unless if there was a challenge with question 1? But if there's none we move on to question number 2.

01:08

Right, question number 2, um, it's forces so it reads as follows: It says that a 20kg block is placed on a rough surface inclined at 30° to the horizontal and a constant force F acting parallel to the surface is applied on the block so that the block moves up the incline at a constant velocity of $2m.s^{-1}$. now it says that refer to the diagram below, OK so it's question 2, let's try…. For question 2 the diagram below (starts drawing it on the board) it looks like this (draws the RP)



Right so that is the diagram below. Right you need to read the statement as many times as you need so that you understand what is being said in the statement before you try to answer the question. You must read the statement and understand what has been said. Right, I'm going to read one more time for the last time.

03:40

Re-reads the question.

04:06

Now it says that a constant frictional force, kinetic frictional force of 8N acts on the block so there is the diagram on the board. But the first statement, the first question here it says that, this is 2.1 it says state Newton's First Lao of Motion in words. So what does Newton's first law says? So what does it say?

04:34

Learner: An object will remain at rest or continue moving at a constant velocity unless it is acted on by an external resultant force.

Mr T: Right, correct. I don't think there is anyone that does not know this principle, I think we are familiar with that, so, you must also familiarize yourselves with all the laws from the first to the Universal gravitational, now number 2, it says that, 2.2 draw a labelled free-body diagram for the block and here the mark allocation is very important. We draw a free-body diagram. How do we go about that?

Most of us find, I don't think we heard the word and there were some cases that were very concerning when you doing that and there are cases that are very concerning for people.

05:54

Right, first of all we are told that this block it moves on a rough, um, on a rough surface, therefore it has friction and it moves up the slope, it moves up the slope so now (starts to draw free-body diagram as he talks) to draw the free-body diagram it's OK you can make an example of a slope, but since they said it's a free-body diagram, so how do you draw a free-body diagram? Remember that the box itself, the object must be made by a dot because it is a free-body diagram. So now we know there is a force acting on it causing F so that will be the Force applied. (draws on the board as he talks)

06:33

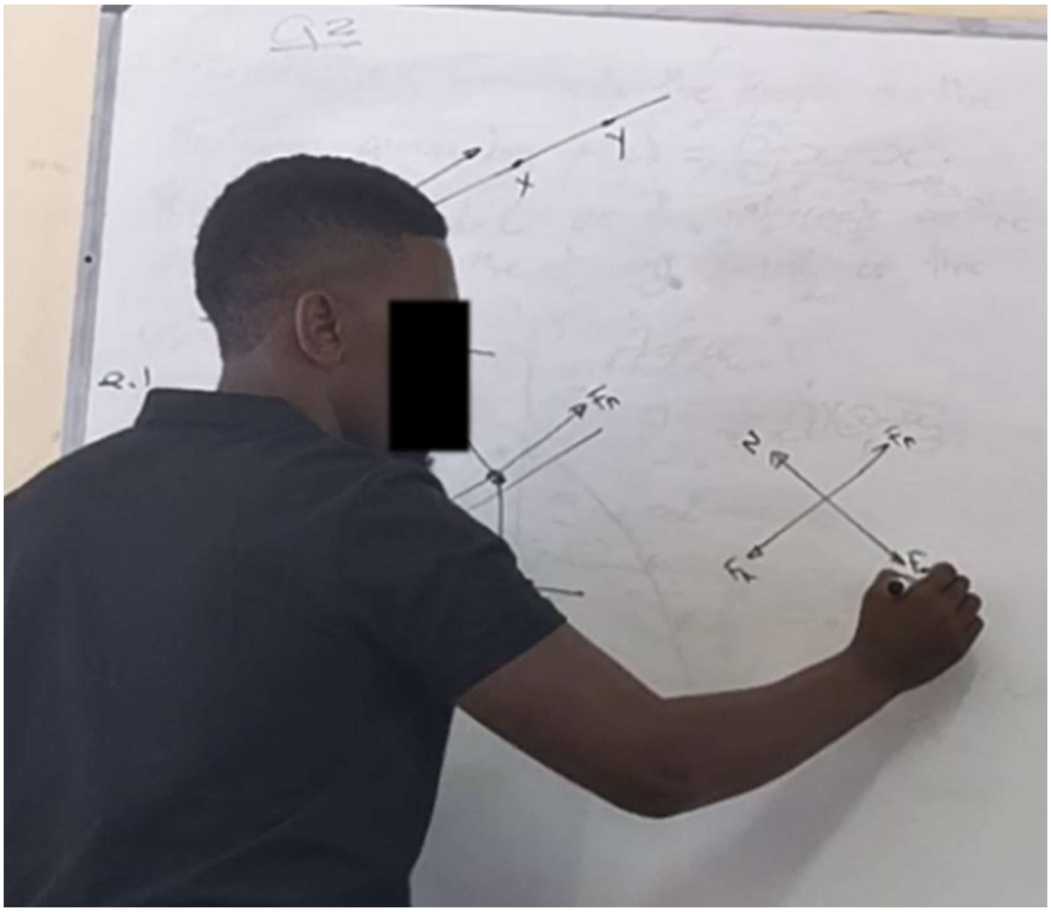
And we were told that since it moves up and on a rough surface it means that it experiences friction and friction will be in which direction?

Learner: Down

Mr T: It will be down the slope in this direction, friction. So it means that F parallel will be somewhere here. Right, so what other forces do we have?

Learners: A normal force, Gravitational force (other indistinct voices)

Mr T: Since again it has a mass (points at the object, circles the mass) so it could put it as a vertical force which is acting vertically downward. Fg is vertically downward. We don't have a case where you have Fg in this direction (shows perpendicular to the ramp). Fg is vertically downward, we don't have a case whereby you have Fg in this direction unless if they are talking about the component of Fg which is Fg perpendicular therefore you can put it there, it's OK. Fg is always downward. It pulls everything down toward the centre of the earth so now next one will be what? Since it moves on the surface it would experience also a normal force. Normal force is always perpendicular to the surface, then it's going to be somewhere here (draws forces and labels them as he talks)



So this is your four marks basically. This would be your four marks. Right, the other thing you also need to be aware of, if you decided to draw the components of Fg, you don't have to draw Fg at all.

Learner: What if we draw them both? (assumed-muffled)

Mr T: We subtract marks, we deduct marks for that, why do you do such? We don't give full marks for that, we subtract instead of adding marks. So if you decide to do the other one, you decide to use FG parallel and FG perpendicular, it's OK, there's no problem. The normal force is still here, then this side you have Fg perpendicular and on this side you will have Fg parallel that's it. So you cannot include here Fg, once you include Fg you lose marks. So you should avoid such, because these two they are equal.

Right, the question now, question number 2.3, question number 2.3 says calculate the magnitude of the force F. The force applied which is this one (points) this one. What is this force equals to? So since they have said on 1, define Newton's first law, so we know that in this case we don"t have an acceleration because the words at the top says that this object is moving at a constant velocity. So we know that all the forces which are acting here, they are equal, they are in equilibrium.

Teacher-learner interaction in vernacular, teacher moving around the class.

Mr T: Right, so OK, as we were saying, um, this it's moving with a constant velocity, so if it has a constant velocity there is no acceleration here. So it means that, it also means what? These forces that are acting here they are in equilibrium. The forces that are pulling up are equal to the forces that are pulling down. Right now, how are we going to calculate force F? so you should, yes you can write Fnet again. So Fnet is going to be equal to what?

11:00

It's equal to ma (draws symbolic representation on the board) and we know that Fnet is equal to what? The…

Learners and Mr T: sum of all the forces.

Mr T: So now what we're going to do, I normally prefer you to use this diagram here (he points to the diagram with the Fg components) because all these forces here they are perpendicular to each other. This one is perpendicular to this one, this one is perpendicular to this one (pointing), so they opposites to each other so you can use this one.

11:28

But the movement is in this direction so therefore what you can do, this direction (up the ramp) you can take it as positive, that means our force F is in the positive, the rest of the forces that are acting downwards are negative.

So we have F is equals to Fk minus Fg parallel is equals to ma

And from there, we are looking for this force (shows F)

So Fk is equals to what? And I think it was mentioned in the statement. Fk is equals to?

Learner: 18

Mr T: 18. Fg parallel is equals to what?

(teacher + learners): is equals to mgsin30°

Mr T: mg, the mass of the object is going to be..

Learner: 20

Mr T: 20x9,8xsin30° (filling in the equation on the board) Θ is going to be the angle of the slope and the mass is equals to 20x0 because it moves with a constant velocity. So now you're going to work all this out and we're going to solve this piece first. Now when you simplify this, how much do you get? 18

….-18-20 multiplied by that, how much does it give you?

It will give you minus…?

Learner: 116

Mr T: (writes F-116=0), so now what do you do?

Learner: Transpose it.

Mr T: Transpose this (116) to the other side. Therefore F will be equal to…

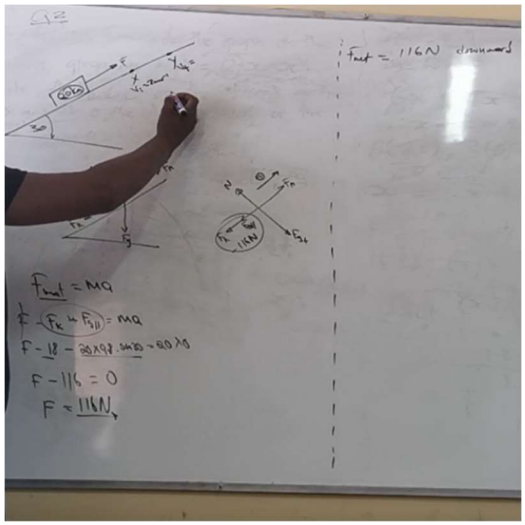
Learner: 116

13:22

Mr T: 116 N

So that's how you get 2.3

Right. Now the next question says that, the next statement says this: Force F is removed when the block reaches point X. so when the block, it reaches point X here (points to the diagram on the board) the force applied is removed, is removed. So take note now therefore the, so the sum of these two forces (circles Fk and Fg//)



The sum of these two forces (points at the forces on the mathematical equation) negative, it gave us negative, it gave us how much?

Learner: 116

Mr T: 116N and with 18 it gives us (points at 18). So this one (shows F) is now removed, and in this case, yes -116 it was equal to +116N, they were equal, but now you've removed that force and you are only left with 2 forces now.

So now they are saying here, on point X, that it happened at point X, so they are saying that the block continues to move up the surface and comes to rest, it comes to rest momentarily on point Y.

So now what you need to check now, remember the question there- assume that, assume, that the kinetic frictional force acting on the block remains the same at 18N, it is the same, it is still 18. So definitely if it remains the same, the mass of the body does not change, so that means then Fparallel is to be the same, so that's why I am saying that these two they will be the same. OK now they say write down the net force now acting on the block as it moves from X to Y. These are the sum of the forces here, it will be what? The sum of the forces is what?

Learner: (calling out indistinctively)

Mr T: Fnet will be equal to these two (circles Fk and Fg// in the equation) because this one is already out (F crossed out). So it's already out. So OK, I want you to tell me something everybody, right the force is still going to be…

Learner: 116N

Mr T: 116N, it's not going to change but this one needs to be down…

Learner: Downwards

Mr T: because it's a force, it's a vector. Downward.

16:46

Mr T: so now the next question says calculate the distance between point X and point Y. OK, the distance from there to there after removing the force applied. So at point X if you ask yourself what was the velocity at point X? Vinitial is equal to?.... it was moving at a constant velocity until it gets to X, it was moving with a constant velocity until it gets to X so it was moving at 2m…..

Learner: per second

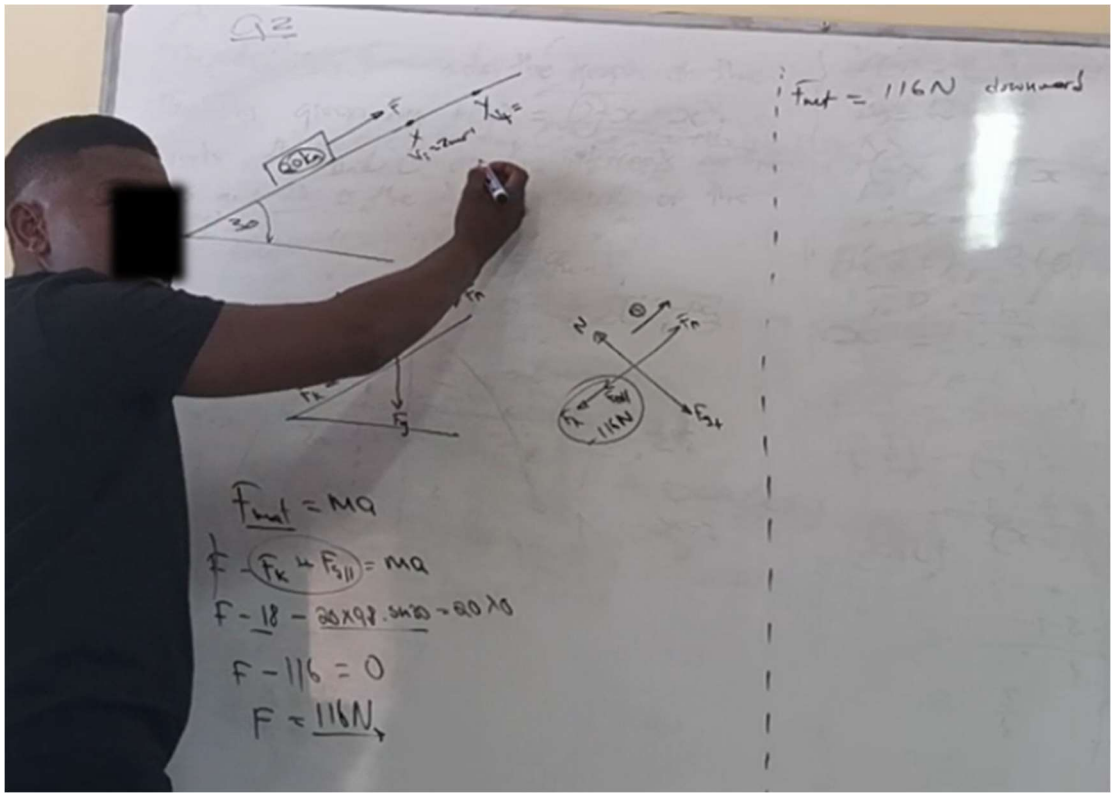
Mr T: per second (writes it on the board) But at point X the force A was removed, so was this thing moving with a constant velocity?

Learner: No

Mr T: Until you get what? So does it change the velocity? So a changing velocity is what? What is a changing velocity? What is the rate of change in velocity?

Learner: (Indistinct)

Mr T: Serious? Drawing vf on the board. So what is the final velocity



Learner: It's zero

Mr T: Because it comes to rest. So what is the change in velocity? Rate of change?

Learner: It's an acceleration

Mr T: It's an acceleration. We said the rate of change in velocity is an acceleration.

18:05

Mr T: There was an acceleration here (points between point X and Y), even if it was a deceleration, it was slowing down, so there was acceleration here because the speed was changing it was no longer constant. Right, now the next question here which is 2.5, this one was 2.4.

So 2.5 asks the distance here. Since there was a change in velocity we need to find the acceleration. So already we know that Fnet is equals to…..what? You know Fnet was equals to this (points at 116N). so Fnet, you start from Fnet. Fnet is equals to ma. So Fnet is equals to, we said negative 116. So this one is going to be -116 equals to, mass is how much?

Learner: 20

Mr T: 20 multiplied by a. so a equals to what?

Learner: (indistinct)

Mr T: What will the acceleration be equals to now?

Learner: -36

Mr T: It's going to be?

Learner: 5,8

Mr T: -5,8m.s^{-2}. So it's deceleration, but we are not looking for that, we are looking for the distance between point X and pint Y, so we are looking for delta x from here to here (points and labels on the diagram).

So what does change in x look for, equals to? So what formula are we going to be using?

Learner: (calls out the formula and Mr T writes it on the board)

20:06

Mr T: v final squared equals to v initial squared plus 2 a delta x , so the v final is how much?

Learner: zero

Mr T: our initial, before it start by X, it was what?

Learner: 2

Mr T: 2 and the acceleration is how much?

Learner: -5,8

Mr T: -5,8 and then change in x. so this two we bring it other side it's going to be negative 4 (learners say it with Mr T) and 2x5,8, negative 5,8 you get

Learner: 11,6 (Mr T writes it on the board).

Mr T: and so change in x is equals to

Learner: (indistinct); 0,03448 (Mr T writes on the board)

Mr T: so we need to round it off so the answer is going to be 0,3…….

Learner: 4

Mr T: and then?

Learner a: 5

Learner b: aah, ngithi

Mr T: The unit, you must put the unit there.

Learner: metre

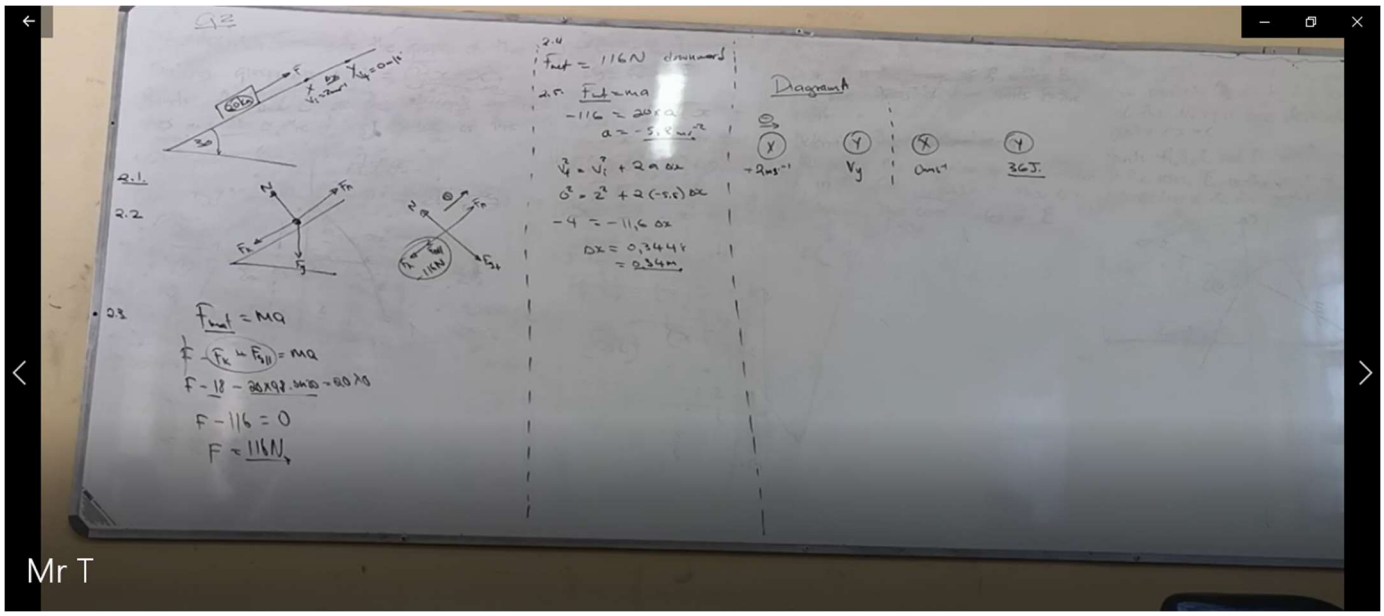
Mr T: writes the unit next to the answer.. you need to put the unit. We need a unit, so that will be the end of question number 2.

Alright, and we did question number 4 so we gonna just go to question number 4 which is based on momentum of the object, looking out for momentum of the object, how do you calculate it, ja, the conservation of momentum, so this is based on that. Question 4 it says that, a ball X of mass 10kg which was moving with an unknown velocity vy. Diagram A

23:02

By diagram A (draws the diagram on the board) it shows us X moving to the right, eastward and it moves by 2m.s^{-1} and then we have Y which is also moving but we don't know the velocity, it's moving with an unknown velocity vy. So since we know that X is moving eastward, let's go and take v as positive 2 because we know.

Now they are saying here, um, immediately after the collision, these two they collide (draws a collision dotted line) after they collide they are saying that ball X then comes to rest after colliding (draws it on the board) that means it stopped. So meaning now that it's not moving OK? Now they are saying that ball Y is moving eastward with a kinetic energy, um Y it move with kinetic energy of 36J.



Kinetic energy, kinetic energy. (Mr T is moving around the class among the learners). So we are not number 1. If you check we are not given the velocity, we are given the kinetic energy and we know that kinetic energy it's equals to Ek = $\frac{1}{2}$mv^2 , we have the mass, we have the mass of that?

We have the mass of that, we were given a mass of…..they said u-Y has a mass of how much, the mass of this one equals to? It has a mass of 2kg

Right, we have the mass of Y and the mass of X is equals to 10 so what is the velocity of Y if I may ask?

26:34

What was the velocity of Y because I saw some of you substituted 36J on velocity and it does not make sense, eish, it does not really make sense because it says that Y moved with a kinetic energy so kinetic energy is this (points to the board where 36J is written) so we have Ek = 36 = $\frac{1}{2}$ the mass of the object is 2kg and then v^2.

27:00

So half times two it gives 1 so it's v^2 then you have 36. So what is v velocity? So you put square root over both side so now v will now be equals to $6m.s^{-1}$. The square root of 36 is 6. So meaning that u-Y was moving after with a final velocity of vy = 6. Alright now, the question now, question 1.4. let's look at the question. The question says here: Explain the meaning of elastic collision. What does it mean an elastic collision? Because at the top we were told that these two balls Y and X they collide elastically. What does the concept mean? The concept of elastic. What does it mean?

Learner: It is the process whereby…..

Mr T: Process? You talking about process? We are talking of collisions here.

Learner: It is the collision whereby the total momentum is equal to the total kinetic energy is conserved. (other learners talk)

Mr T: Is it right?

(learners discussing- indistinct voices)

Mr T: No, no we are sayng here elastic collision, you have that on your notes, I don't know why you missing it. Right we said elastic collision it means that both momentum and kinetic energy, the total momentum and total kinetic energy are conserved. So they are conserved. So that is what it means, alright? Now it says here, meaning that if this collision is elastic, it means the total kinetic energy of the two, the total kinetic energy of the two if you add, it will be equals to this and we have done some examples on this.

29:57

OK now, calculate the velocity of Y before. Look for this before on the diagram A and this is diagram B. to calculate this one, we looking for this (points and makes a tick). So since we are told that the collision is elastic, so it means that if we say the total Ek initially or before is equals to the total kinetic energy after. So these bodies they don't move together, they don't move together so each body has its own kinetic energy individually. OK. So since we are using kinetic energy of the two we have to find the kinetic energy of that (points to X initial).

So we have the kinetic energy of X before the collision and we have the kinetic energy of Y after the collision. So we have $\frac{1}{2}mv^2$ initially and this is for X plus $\frac{1}{2}mv^2$ initially but for Y and then we do the same because we are told that this collision is elastical so definitely they must be equal energy across both sides. So this side is going to be $\frac{1}{2}mv^2$ of X finally plus $\frac{1}{2}mv^2$ Y finally. So it will be now the mass.

Learner: is 10

Mr T: of X is going to be times 10 and the velocity is going to be

Learner: 2

Mr T: is going to be 2 what? Squared. Once you forget the square it becomes incorrect. So now you do the same, the mass of Y is

Learner: 2

Mr T: is 2. What you are looking for is v of Y so you write vy now we continue. After the collision we have half mass of X after collision

Learenr: 10

Mr T: is 10. And then times velocity final after is…

Learner: 0

32:43

Mr T: zero squared. So you continue. So we are given the kinetic energy of Y so we don't have to write it again. It was equal to what?

Learner: 36

Mr T: 36J. Even we can take the energy of Y (points) we don't have to write it again. So no calculations because we were given. So all our formulas are in the kinetic state, so we were given kinetic energy on this one. So now you simplify this.

So half x 10 x 2^2 gives how much?

Learner: 20

Mr T: it will be 20 and this will equals to half x 2 it's going to be one and vy and then it equals to and this is equals to zero and so now you have +36. So now what do you do here?

Learner: transpose.

Mr T: which one?

Learner: the 20

Mr T: 20 goes that side, this is positive goes this side then we left with v equals, we going to subtract so it's going to be

Learner: 16

Mr T: 16 and you can see it's v^2 so vy^2 is 16. So now therefore we are looking for vy so it must be…

Learner: square root

Mr T: (Draws square roots)

Learner: Vy is equals to 4

Mr T: metres per second, so your answer therefore is positive so we can say this to the (writes west) but anyways v^2 is going to be +/-, it's going to be +/- right.

35:03

(offers an alternative)

Mr T: This, another way we could have approached this is that since it is elastical we could have used momentum instead but the challenge is you should know when to or how to because if you

mix up things you can't get your answer. Right if you use the sum of the momentum before is equals to the momentum after (writes formula on the board), so you are going to separate again because they have their own momentum. So it will be mv_xinitial plus mv of Y initial and then also mvfinalX and mvfinalY. So the mass of X we said is 10 so it was moving, remember direction is very important here, it's momentum it's not kinetic energy. Energy we don't consider much direction. So if velocity is 2 and then therefore this one is going to be 2vy OK and then this one is going to be 10 times zero and then this is going to be 2 times…..so if you use this you must first find the velocity. So since it move eastward it's going to be positive 6. So now you will have, you will have what?

Learner: 20 plus 2vy. 20 + 2vy = 0 + 12 (learner dictates while the teacher writes, accidentally writes 16 instead of 12)

Mr T: And then what do we do?

Learner A: you transpose and then you get

Learner B: 2vy = -4

Mr T: alright and from there what do you do?

Learner: Sir, 2x6 is 12 not 16

Mr T: Sorry? Checks, corrects. So if we transposing that side now, how much do we get? Minus? Minus 8. So therefore we divide by 2 and we get?

Learner: -4

Mr T: -4 and then you don't leave your answer negative, you make it to the west. So you must get the same answer.

38:24

Right the last question here, the last question says that the balls were in contact with each other for 0,1 second, given time, you know now where it's going. It's either you working with impulse or you're working with Newton's second law, Newton's second law in terms of momentum, that's where it's going. So calculate the magnitude of the force that ball X exerts on Y. so to avoid making mistakes, you remember we said each ball collides with each other, we said they exert force on each other using Newton's third law. The force will be equal, if ball X exerts a force on ball Y also Y exerts a force on X. that means in order to do that we need to find the change in momentum, but the problem here, if your answer on Y is wrong and you continue to use the same answer, then that is wrong. You can't get the right answer on the next question. You can't.

Why don't you use what is given? Or use the change in momentum for X, why don't you use that, because the forces are equal anyway.

CTS

40:27

But if you commit yourself on Y, you won't survive. So please try to work smart here please. Because if you are going to try to work with Y and your answer you are not sure if it's correct,

you will get it wrong again. For X at least here we have initial velocity and final velocity of X. so why don't you just use X? so that you can use the force. So now 4 point this is 1?

4 point 3. This was 4 point 2 (correcting on the board).

Now we know the force net is equals to the mass, final velocity minus initial over change in time. So we're gonna go for X now. The mass of X is?

Learenr: 10

Mr T: 10 and then the final velocity is…

Learner? 0

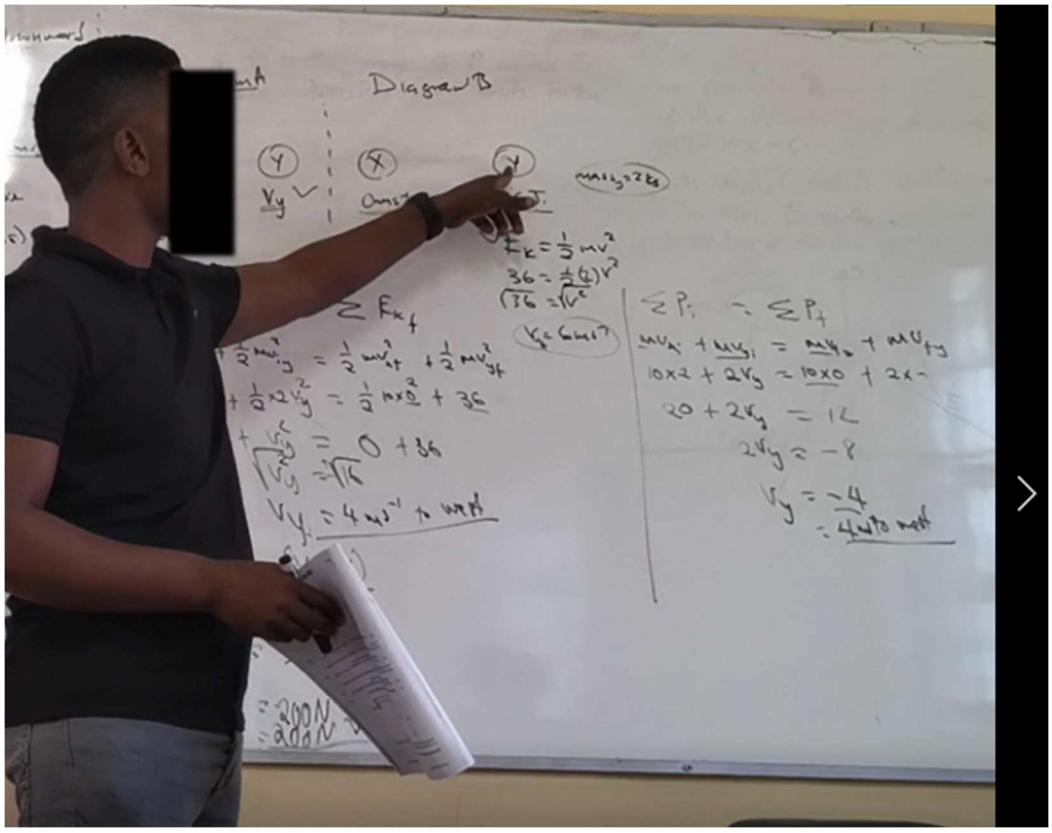
Mr T: and the initial was +2 and then you divide by 0,1 so it gives you how much?

Learner: 200

Mr T: So it gives you 200N. so because the question says the magnitude, we are looking for the size, the question says magnitude, we are looking for that 200, not the direction.

Learner: (indistinct)

Mr T: So this is what? It's 200 but it would be easterly, in easterly direction towards easterly direction because it's X exerting a force on Y. It's X exerting a force on Y so it must be towards this…



Because Y is moved east.

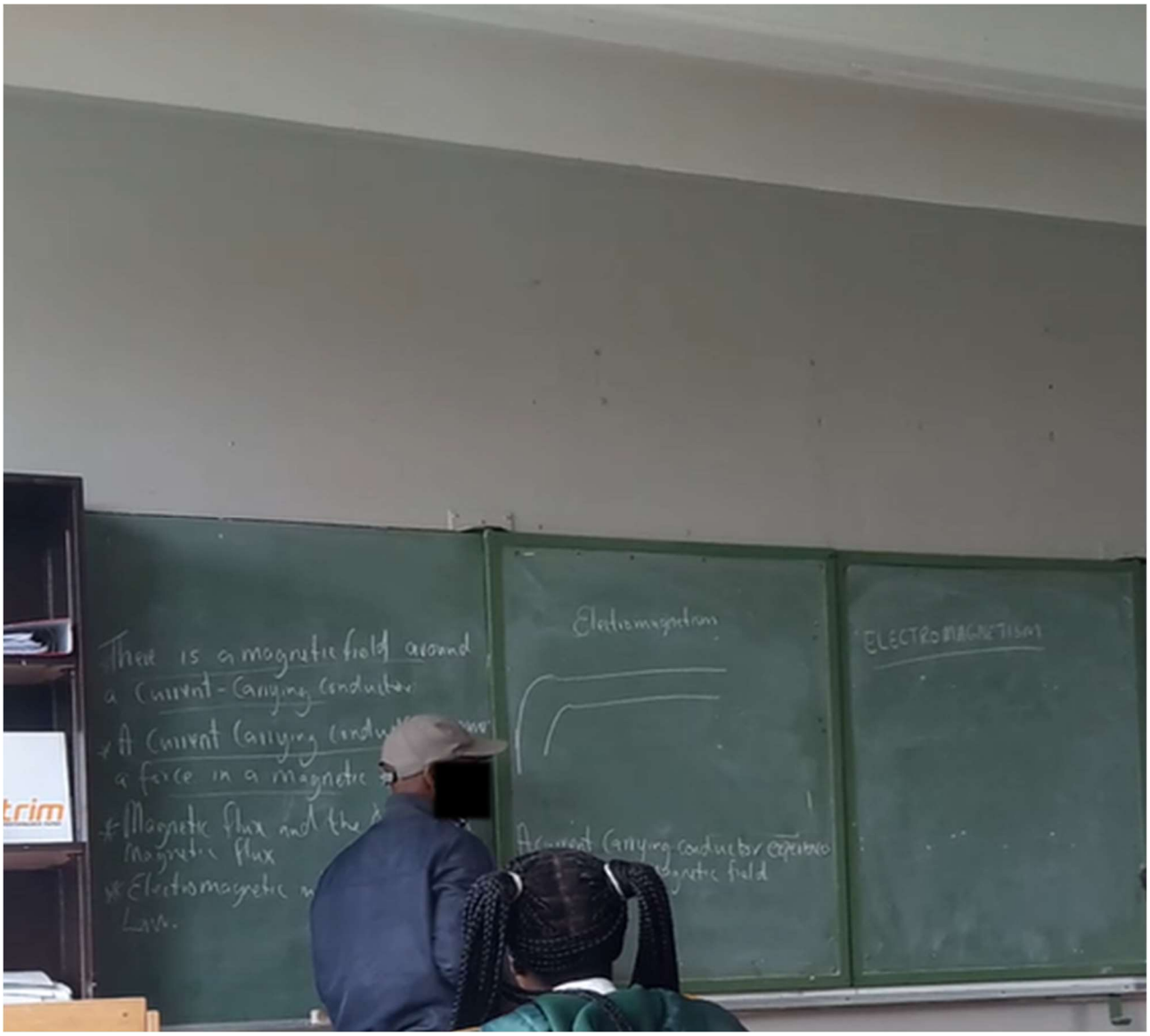
So that's how we are supposed to answer those two questions. Right, and then it ends there. Right, we are done now.

43:08

Transcript from Mr K Lesson

0:00 it is evident that filming started after the lesson, possibly a minute before filming has begun.

(draws a representation on the board)



K: until it's what? It's connected to a power source, neh.

The power source contains a positive and a negative neh.

Let's say for example this is a battery (draws battery) it is a positive and negative (draws charges +/- on poles of battery) and remember charges are moving from negative to positive in a circuit, neh?

00:23

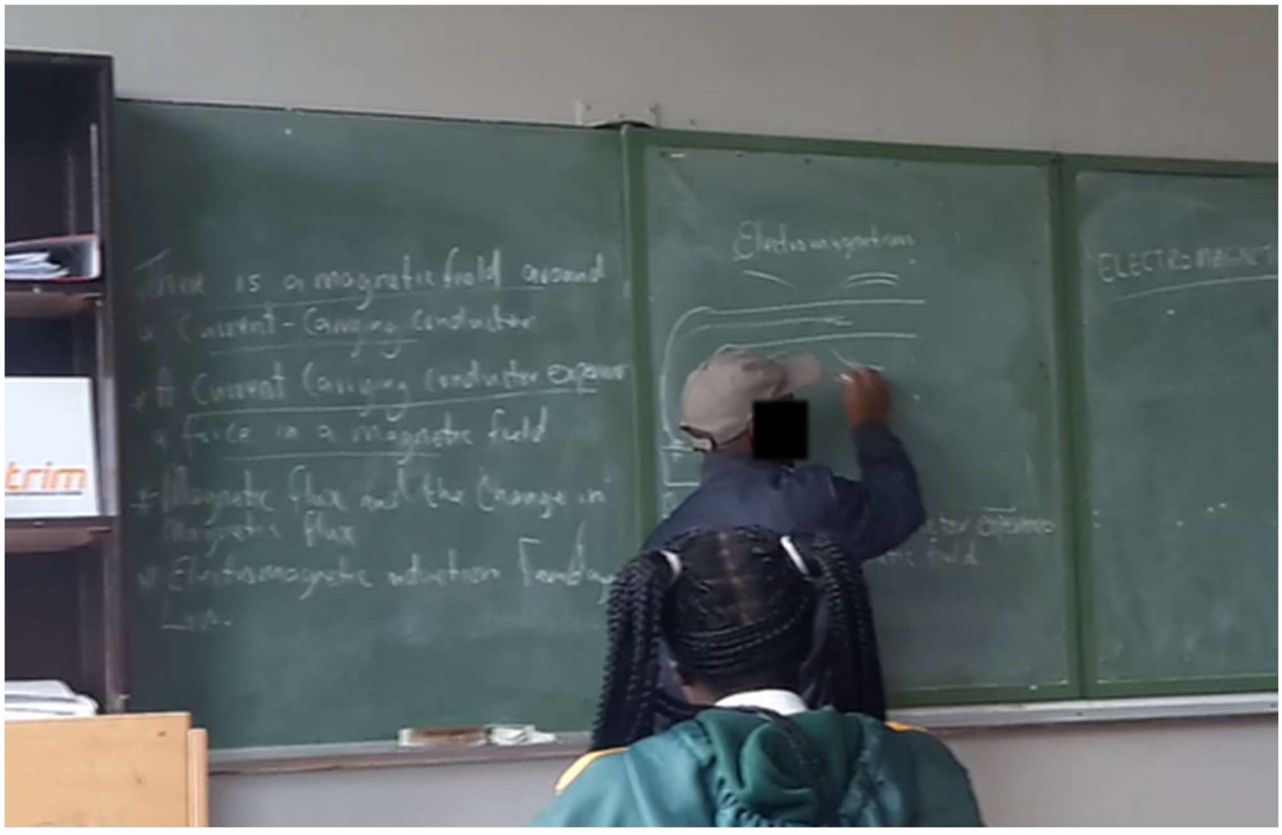
Now the movement of charges in the conductor, they what? They induce electromagnetic field.

It means there will be a field moving around a conductor because there is a current that is moving neh?

00:23

Alright now we say there is a magnetic field around a current-carrying conductor (written on the board) which means the conductor on its own without power, there's no field around it neh?

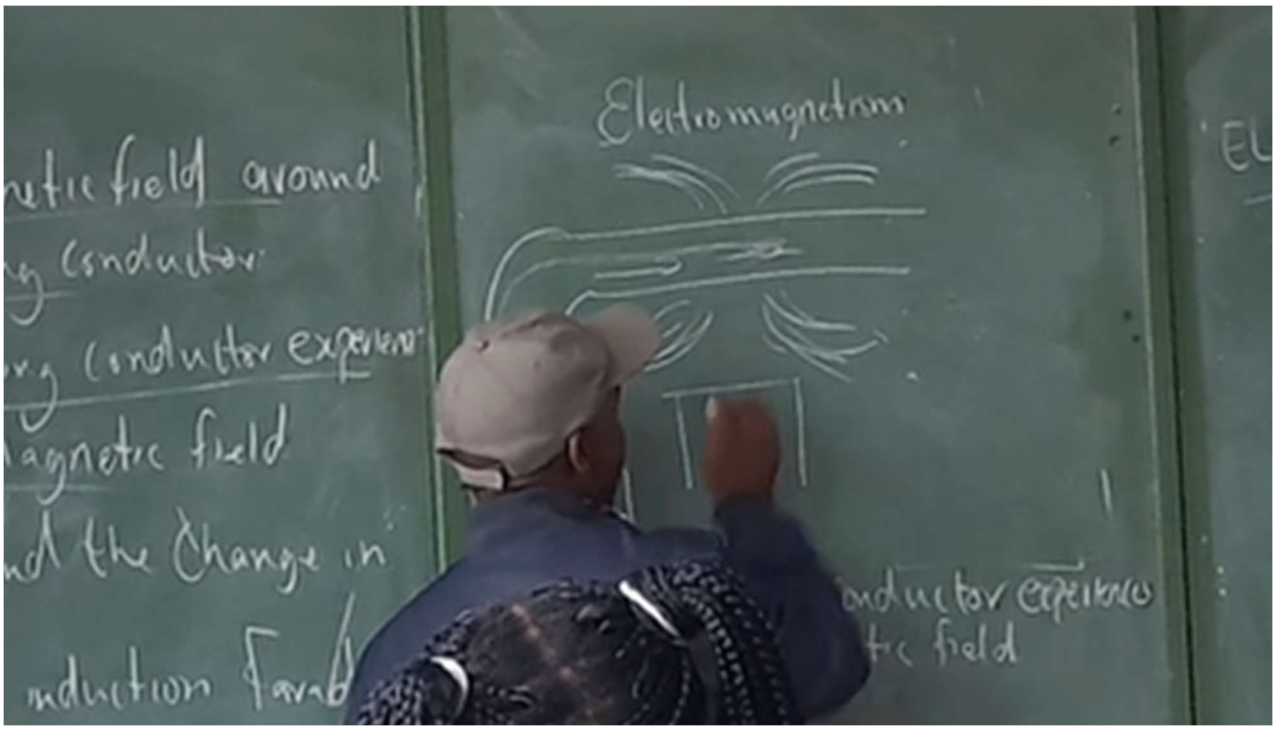
And then there is current moving it started to experience what> to experience field, we represent it like field lines neh.



What we are explaining here we are not meaning that the field is moving, neh, it's standing still, but its what? It has like a state of direction neh, so the magnetic field is pointing in a certain direction depending on which way the current is flowing right, now we said number 2

01:18

A current-carrying conductor experiences a force in a magnetic field (points at this sentence on the board_. Alright, what are we saying about that, neh? When the current is flowing there is what you call the magnetic field if you place a magnet here (01:33)



Alright the magnet have what we call the south and the north. Alright, what you need to understand is that the magnet field is different from the electric field, neh, in terms of what the charge is, neh. What is happening here is not what is happening at the end of the poles, neh.

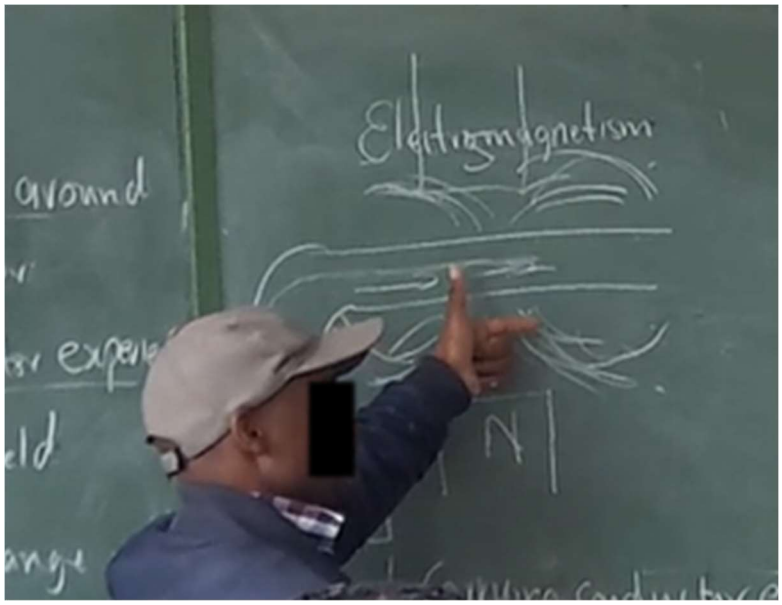
The positive and negative there is attraction and repulsion. At the end here (end of magnetic field line of conductor) is not what's happening at the end of the poles, neh, at the poles there is positive and negative, attraction and repulsion, neh. It's just what, field lines showing what, the movement of the force, neh.

Alright, between two magnets the south pole and the north pole (points) and we have the wire here, neh? It's connected to a battery, which means there is what? There's a flow of charges neh?

02:27

So what is happening?

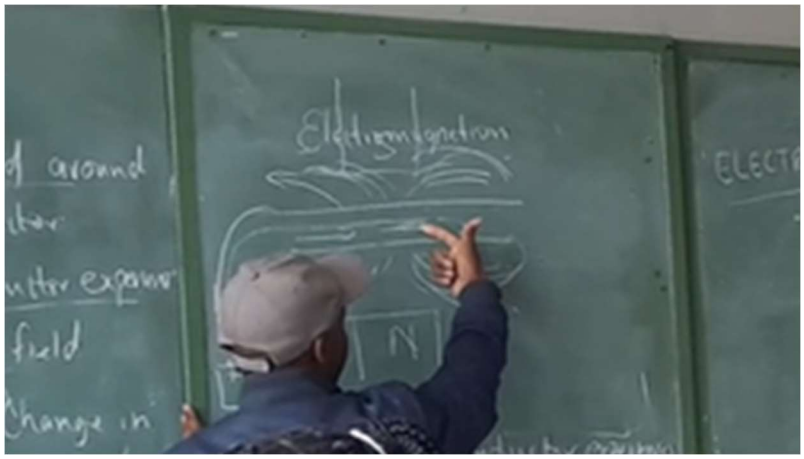
They say it is going to experience a force (underlines this on the board) what do I mean by that is that if we have a wire in between neh there is what we call eh electromagnetic induction and we use the right hand rule to describe it neh? (lifts up his left hand) to find what? The direction of the force, neh. If I place like this…..



…it means the current is flowing in this direction neh, so the force is pushing it, the force is moving the other down, these fingers they what? They showing us the direction of the what? Of the magnetic field which means the field is moving in this direction.

03:15

When the ask you about the direction of the magnetic field, you must first look at the direction of the current using the right hand rule (now using the right hand)



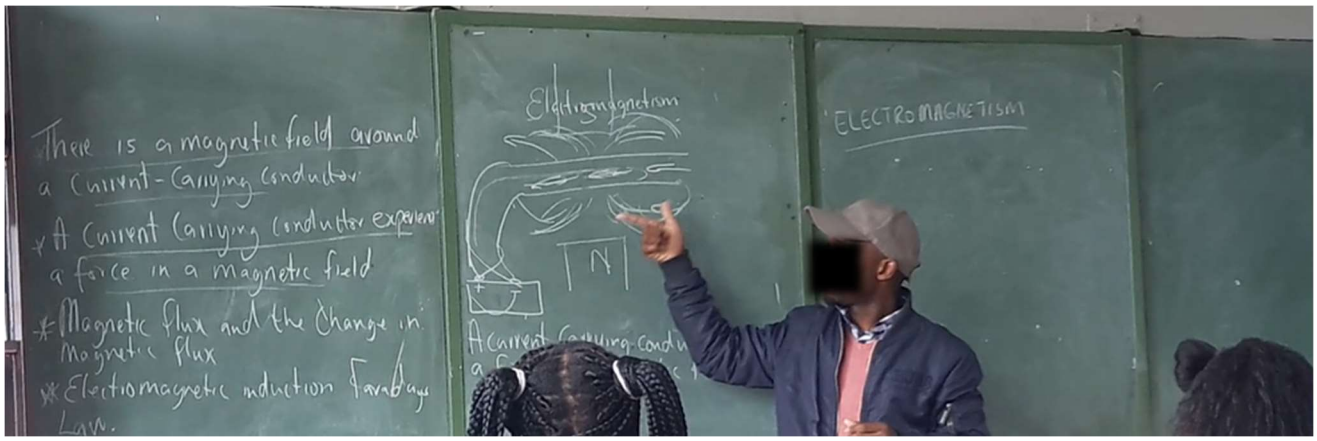
03:19

Which means that if you change this positive and this negative, this wire going to this side and this wire going to this side (showing a change in the connection of the wire to the poles of the battery) we are doing what? We are changing the direction neh.

Remember it's flowing from what? From the negative to the positive. So now if we change it, it means we are changing what? The direction of the current flow, neh.

3:42

So what happens if the current moves in this direction? So what will happen to the field?



L: It changes.

Mr K: It changes, neh, and also if we use our right hand rule again it's going that side (changes the direction of current on his right hand rule) and the force now where is it going? It's going that way (points out of the board)

04:01

So and then the field is also moving in this direction, neh (incorrect use of the right hand rule)

Alright, here I have a small thing to show you what's happening we don't take the whole magnet, neh?

(Takes out his laptop and points the screen to learners)



04:18

Can you all see? Just make sure you can see- learners moving in the class to get a view of the laptop screen)

(plays a video)

04:40

Now what you need to see here is the force that is experienced by the conductor. (wording in the video is indistinct but demonstrates the right hand rule)

Mr K: So what is changing? He is only changing the direction of the current, the current does the same to that direction then it's going inwards and when he is changing the direction then it's going outwards which means that the influence between the north and the south pole, so that's what we found.

(video continues)

L: Isn't North supposed to be at the top and south at the bottom?

Mr K: It doesn't matter which way neh? What matters is that if, you know this one, because its facing upwards (points at the north pole of the magnet) what is happening here is that the magnetic field is going upward and if we change the magnets around it means it's going down, so they are fine like this, but she is just noticing what is happening around this field OK?

(video resumes)

Mr K: Right do you all understand?

L: Yes

Mr K: So if it's in reverse we do the same but in the reverse direction.

Addendum I- Creating an animation.

Chapter 5 defined a new construct to pedagogically transform content knowledge on a digital platform. The literature meta-synthesis amalgamated three constructs of TSPCK, ICT framework and CTML as the first part of the study to describe the new teacher knowledge to teach on a digital platform. The second part of the study involves an intervention with practicing physical science teachers to design and create their own teaching animations. In this addendum, a description of the technical process involving the development of an animation using the digital-TSPCK construct that will be used in the intervention with the teachers as discussed in Chapter 6.

1 Introduction

As alluded in the problem statement in Chapter 1, the separation of teacher and learner during the COVID-19 lockdown forced teachers to find new methods to reach their learners and to transform the content, usually onto digital platforms. Teachers were expected to devise their own strategies as there were no programs prepared for teaching in lockdown situations (Palau et al., 2021). With the change from face-to-face learning to online classes in such a short space of time, teachers experienced several challenges regarding a lack of infrastructure, resources and educational content for online teaching (Palau et al., 2021) and was intensely experienced in South Africa where many of the schools and the learners were under-resourced and impoverished. In addition, teachers were not digitally competent to the extent where they could transform their teaching content onto digital platforms (Ogodo et al., 2021). The possibility of widening the skills and poverty gap intensifies the search for cost-effective methods to place the content within the reach of all learners (Shava, 2022).

This study aims to empower teachers with knowledge to incorporate digital technologies into the pedagogical practices of the teacher in order to create effective content, noted by Castañedaa et al. (2021) to be a crucial aspect in the

progression of teaching and learning in the digital age. This study proposes the use of teaching animations to teach science content to learners which can easily be sent to the learner's phone and enables immediate access to the content. McLoughlin and Lee (2010) noted that learners respond well to lessons using digital tools such as animations. Dori and Belcher (2003) and Belcher and Olbert (2003) concur that certain topics in science, including electromagnetism have abstract concepts to understand, and the use of animations of these concepts could reinforce understanding by the learner as they connect shapes and dynamics within the concept. Researchers like Mutia et al. (2020) and Ju and Mei (2020) cite the advantages that animations offer in the classroom to significantly improve the quality of learning and performance.

This study has already defined a theoretical construct called digital-TSPCK that can be applied to the planning and creation of science animations where the pedagogical transformation of knowledge is the foundation for the creation of the content, using technological knowledge in tandem with the factors that improve learning and retention based on learning through multimedia. In the discussion below, the processes and techniques used to create effective teaching animations will be discussed.

2 Choosing the animation software

A wide range of animation software exists and is easily downloadable from the internet. Examples include Stop-motion, Jigspace, Animaker, Blender and Synfig to name a few. For this study the initial search criteria was software that was free, given the South African context where teachers or schools might not be able to afford purchasing software. Secondly, keeping in mind the general low levels of teacher digital competencies as mentioned above, the software would need to be simple, user-friendly and easy to learn. Stop-motion and Jigspace were time consuming, working with one frame at a time or needing time to import objects, Blender (*Blender - a 3D modelling and rendering package.*, 2018) and Synfig (Quattlebaum, 2021) were 3-D animation software programs able to produce high quality animations. They were complicated in terms of the home screen and the level of technical knowledge required to navigate through

the functions in order to create objects one at a time and then place them into the animation space.

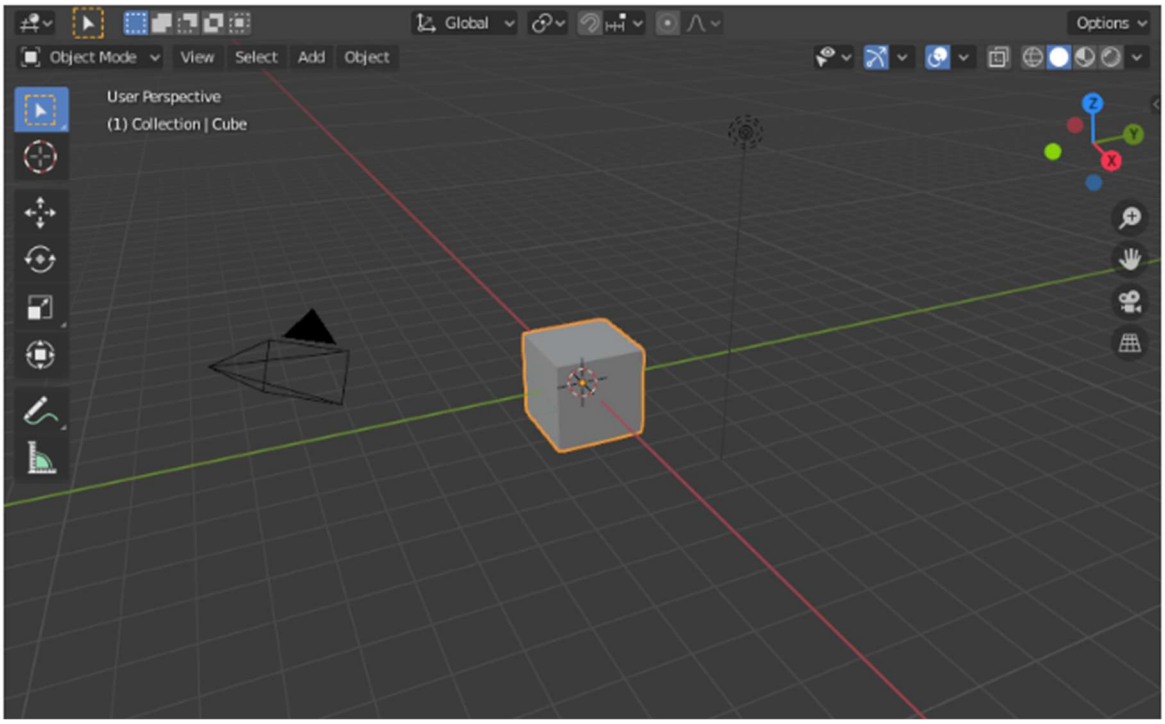


Figure 1. Image of Blender animation software home screen

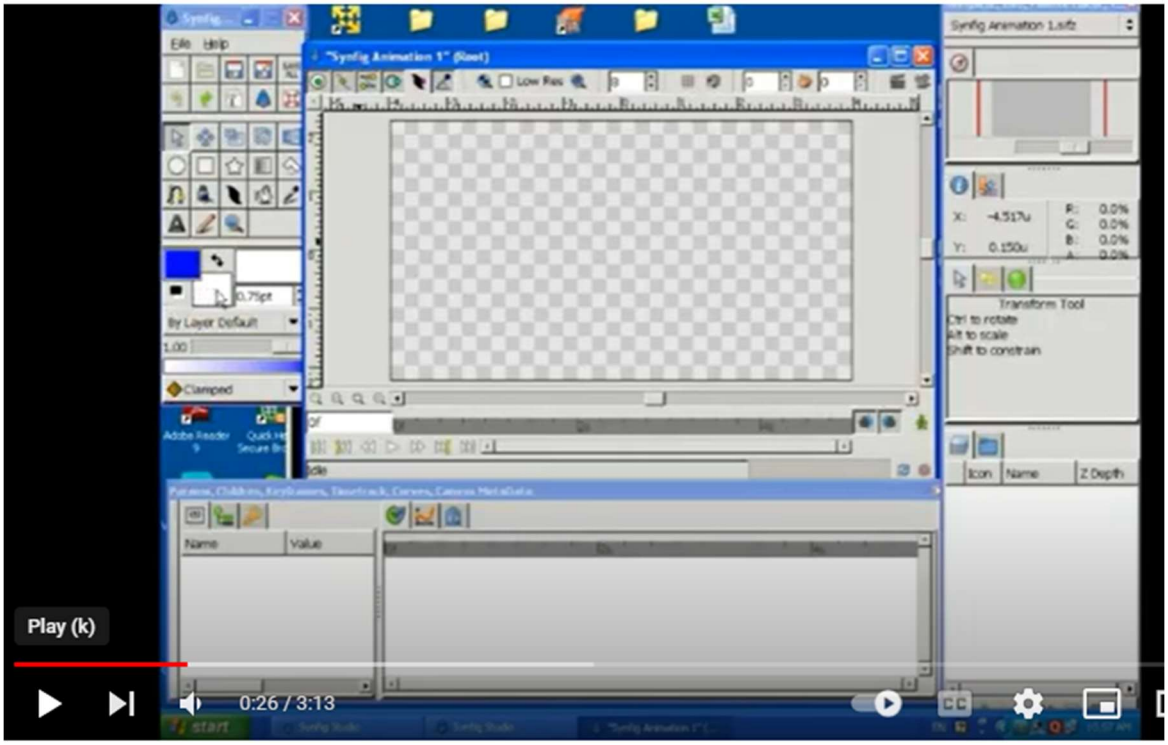


Figure 2. Image of Synfig animation software home screen

For this study, Animaker was chosen as the simplest, most user-friendly program that would enable teachers to produce effective science animations. The video editing program Hitfilm Express was also investigated for editing the animations after rendering with other media clips (Zondi, in press) but it was found that Animaker had sufficient editing functions and was the predominant software used.

3 Features of the animation software

Signing in to Animaker on google search using https://animaker.com opened a registration page to log on to Animaker in the future, with all projects saved online on the program itself. This enabled projects to be worked on over a period of time without losing any work, and rendering the animation to export only when the project has been completed. If the page is shared with other users, they each reap the benefits of each other's created images and projects, making collaborative projects possible. The user is then directed to the home page where a new project can be started as shown in Figure 3.

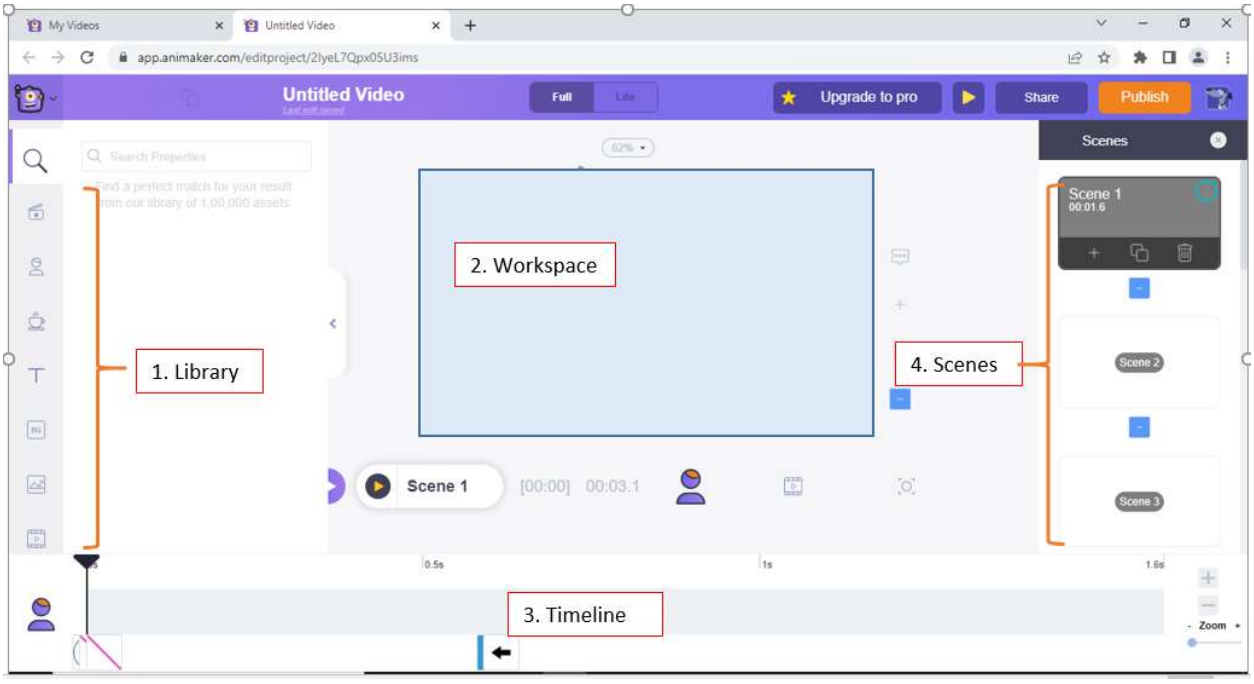


Figure 3. The home screen of the Animaker program

Opening the home screen, as shown in Figure 3 above, there are 4 clear sections to the page that can be navigated. The library contains icons that helps the user to find characters, objects, backgrounds or images saved on the computer to add to the animation. Using the library, text can be inserted into the workspace and other images can be downloaded from the computer files or internet when needed. Template animations are also available that already have backgrounds, images and text which can be edited and customized for a specific topic. Templates save time when creating explanatory scenes. The workspace is the area where the animation takes form and all objects are placed on it. The workspace allows review of the animation when set to run in real time as the project progresses. The timeline shows the duration of the animation and the specific times when an object, text or audio snippet is played and its duration. This enables the animator to synchronize audio and visual cues. The timeline controls when characters appear in the animation, which effects are used on specified objects and the duration of the effects. The timeline scene length has a (+/-) icon to its right of the home page in order to adjust the scene length. The scenes section shows how many different scenes have been created for the animation. Each scene can have its own background and objects for discussion. If an animation was created for electromagnetism, the scenes could each represent a concept within the topic. For the example used in this chapter, scene 1 could show current flowing through a conductor, then a magnetic field appears around the conductor with text and audio indicating the formation of the magnetic field. The second scene could show the current-carrying conductor inside an external magnetic field, and so on. In this way, the entire topic could be linked together, scene-by-scene to form a coherent animation without requiring any additional editing software provided all scenes exist on the Animaker program.

On the home screen there are various icons enabling the user to perform specific functions within the animation. Figure 4 shows the icons and their functions

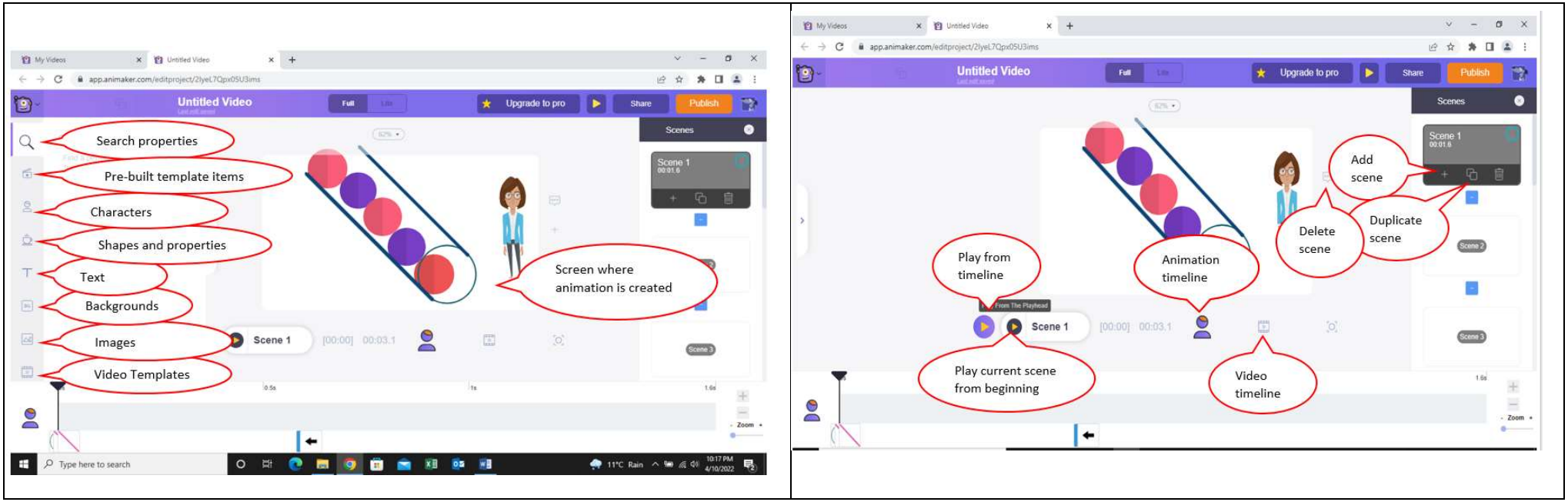


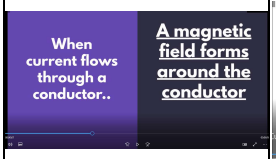
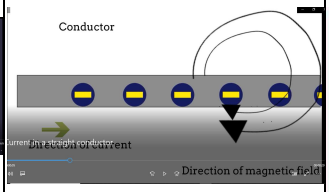
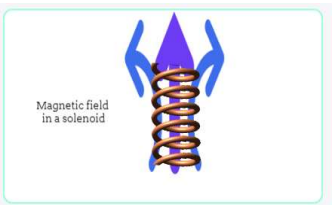
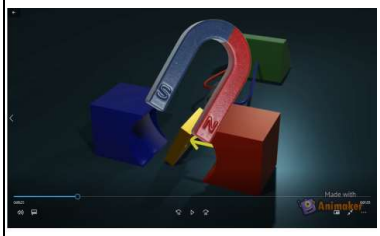
Figure 4 The home screen of the Animaker program

Unpacking the icons on the Animaker home screen as depicted in Figure 4, reveal the items which can be added to a scene or section of a scene from the background, pre-built template snippets, text and characters. Each icon opens up to show the variety available for each property which will be discussed in detail in this chapter as specific functions in the creation of animation are described.

4 Creating the animation

The creation of an animation depends on the type of animation required, in this case for teaching purposes and each teacher plans for a specific topic and vary in their creativity. The range of animations that can be created are limitless, but for the purpose of this study, an exemplar animation of electromagnetism will be discussed to describe the basic functions of the Animaker software. Our animation begins with a template animation for the introduction of the topic using text moving in and out of the screen. Thereafter a straight current carrying conductor showing the movement of electrons across the screen is shown. The direction of the current is indicated and the direction of the magnetic field around the conductor is shown. The conductor is then shown as a solenoid with the magnetic field around it while the electrons can be seen moving through the loops. Finally the application of electromagnetic induction in the form of Faraday's Law is shown using a generator simulation to indicate how current can be generated from interaction with a magnetic field if the coil is manually rotated. Table 1 shows the scene progression for the animation example used in this study.

Table 1. Animation scenes for electromagnetism animation

Scene 1	Scene 2	Scene 3	Scene 4
			

Template animation introducing the topic	Magnetic field around a straight conductor	Magnetic field around a solenoid	Faraday's Law

Each part of the animation should be carefully planned out as discussed in Chapter 7 and the technical applications as described below were used.

Creating a background

To create a plain background, click in the workspace area where two blocks appear at the bottom of the timeline. Clicking on the pencil button shows the choice of colour of the background as well as textures and colour gradients. If there is an object that will need to be present in each scene, with the plan to have other objects move in front of it, it is advisable to import the image, click on it and set it as the background. In our exemplar, the first scene shows electrons moving through a conductor. The conductor was set as the background, electrons were added to the screen and could move across the conductor without having to add the image repeatedly through each scene as shown in Figure 5 below.



Figure 5. Conductor set as background image on Animaker

Bringing in a character.

Go to the library icon and click on a character which will appear in the workspace. A purple line will appear on the timeline which indicates when the character appears and for how long. Manipulation of the time which characters or objects appear on the timeline can be controlled by clicking on the purple line for that image and dragging it to lengthen or shorten the time it will appear in the scene, and if it appears, fades in/out or drops into the screen. The principle works the same for any other image imported from the library.

Bring in text

Click on the text button in the library to choose the text button. A text box will appear in the workspace and can be moved to the position where the text is to be displayed. Options regarding type of text are available in the text box, and using the timeline will determine the time the text appears on the screen and for how long.

How to make an object animate across the screen

To animate an object, click on the object/character you want to move and click on the smart move button above the workspace, and choose a motion type from the options. The actions show an outline of the type of motion chosen for the image and by clicking on each of the pointers in the motion, it allows the user to change the shape of the motion to suit the teacher as seen in Figure 6.

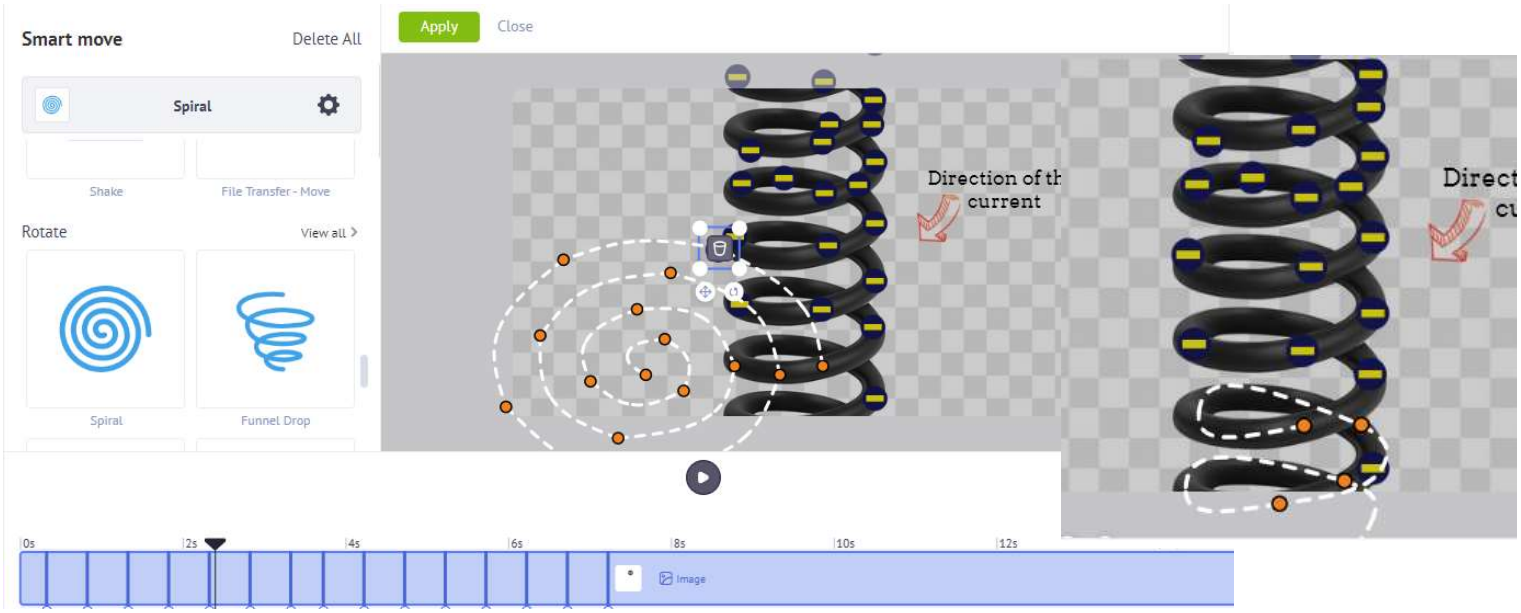


Figure 7. Changing the path of motion of an image on the smart move function

As seen in Figure 7, a spiral smart move was chosen as an option for the motion of an electron through a solenoid. The dotted lines represent the path of motion and the orange dots are points in the motion that can be clicked on and moved to change the motion path. On the right hand side of Figure 7 it can be seen that the path was changed to coincide with the shape of the solenoid which was set as a background, the parts of the path not needed have been deleted. The electron

can now travel through the solenoid in a spiral shape matching the shape of the solenoid. On the timeline it can be seen that each segment represents how long each of the motions last per orange dot of motion, allowing the teacher to make it move faster or slower as desired.

Due to the specific nature of the topic of the study, electromagnetism, and that Animaker focuses more on recreational animation design, not all items required for creating a science animation would be found on the program repertoire. It is possible to import images or video snippets from the internet or a computer into the scene to make it more customized for the topic. However, if the animation is created from a blank home screen, the designing teacher would probably be required to create custom objects, images or shapes that could be imported into the animation to be placed and manipulated as needed. Simply creating a set of combined shapes from word, or other similar programs and importing them would cause distortion to the image if enlarged or adapted on the home screen of Animaker. High quality images need to be created on a program, for example Vectr (https://vectr.com) which is free vector-creation software and then imported onto Animaker. Vectors are images rendered into PNG format and have a higher resolution and do not pixelate when enlarging them, allowing it to render a better quality animation. The electron images in Figure 7 are examples of vectors that were created and then imported into Animaker. This is a useful function if there is not a suitable image available and can also be used multiple times in an animation snippet to ensure consistency of a concept to prevent the formation of learner misconceptions.

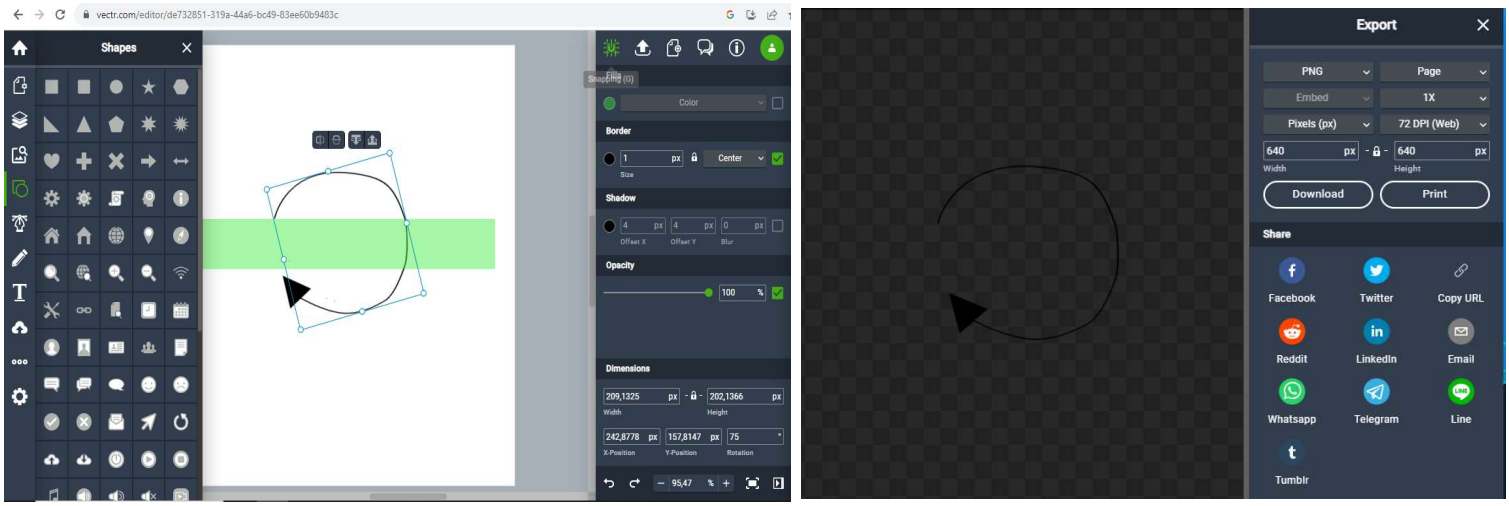


Figure 8. Creation and rendering of a vector for download into Animaker

Figure 8 shows the creation of the arrow vector using the pen and shape tools. Markers feature on the shape that the user can click on to adjust the shape of the object at that point. The markers allow manipulation of a shape to suit the purpose of the object, in this case the arrow will be used to depict a magnetic field line and needs to appear as though it passes across the front of the conductor, and around the back of the conductor where it cannot be seen in the animation. Colour, opacity and dimensions of the image can be adjusted as required by the teacher on this tab. The image on the right of Figure 8 shows the completed vector image which is ready to rendered as a PNG image on the export tab. Thereafter, the vector image is ready to be downloaded, saved on the computer where it can then be uploaded onto Animaker for use.

In order to create an animation that consists of more than one scene, the home screen allows for the addition of more scenes. Each scene becomes a snippet of the final product and can be used to create a full animation of an entire topic. Within each scene the image library has a download function where other video snippets, powerpoint videos etc can be downloaded onto the scene, allowing for video editing to be performed on Animaker itself. Initially the use of Hitfilm Express was considered for video editing, and was discussed in the intervention as discussed in chapter 8, but was minimally used. At the bottom of the timeline

the voice-over icon allows sounds, music or voice-overs to be added to the animation to complete production with a feature including the choice of voice and accent if the teacher does not feel comfortable recording their own voice. Once all the scenes have been completed, the animation can be rendered. At the top of the home screen the icon for publishing the animation is used to render the animation into the MP4 video format. Thereafter, the final animation is ready to be downloaded from Animaker and saved by the teacher for use.

5 Conclusion

In the design and creation of an animation using Animaker it can be noted that the teacher would need to become competent with the software, the features and the affordances they lend to the end product. This chapter dealt with the technical, practical aspects of creating an animation, but in reality this study goes more in-depth than that. The aim is to incorporate these technical skills into the digital-TSPCK model to create their content with a deeper pedagogical reasoning than content creators are currently doing. The reasoning behind using a sound theoretical construct that embraces pedagogy and how learners respond cognitively to digital lessons is to ultimately enhance learner achievement (Stelzer et al., 2010) whether the teacher is in the classroom with them or they are learning away from the traditional school setting.

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Addendum J- Animation creation workshop resources guide

Resources and guidelines

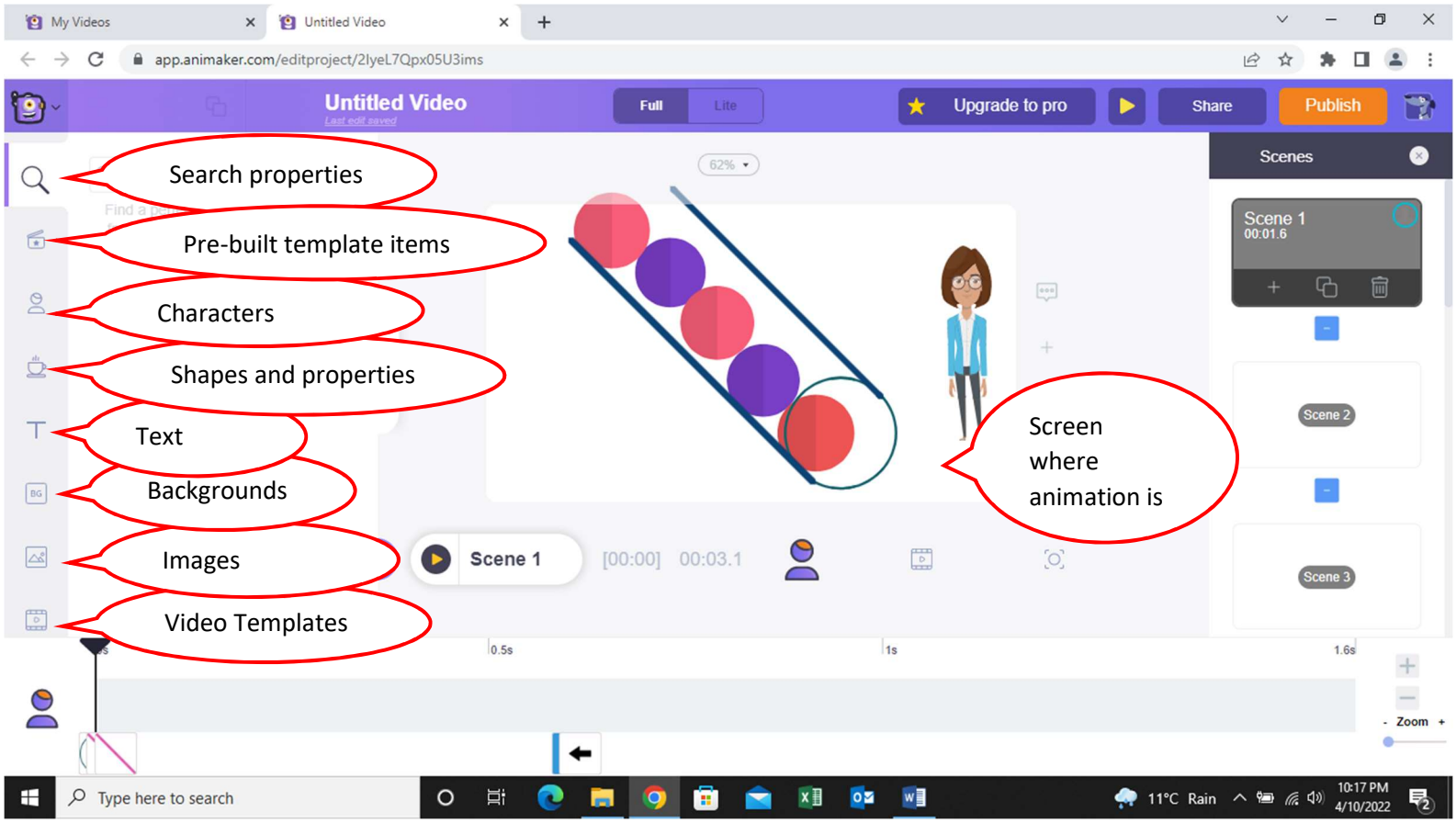
Required software for the workshop: Sign in to Animaker https://animaker.com

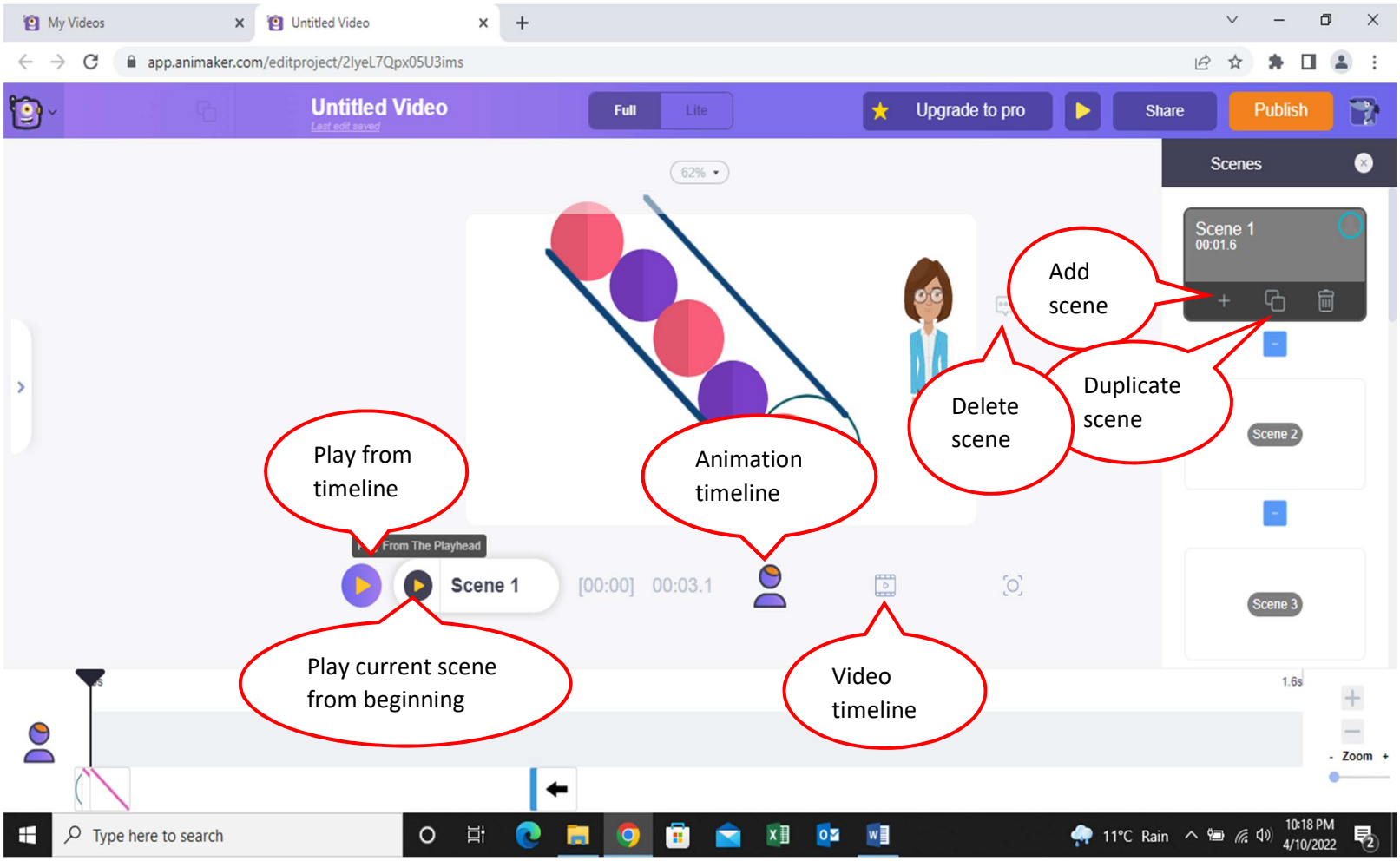
Sign into Vectr https://vectr.com

Open file Animation creation supplied (contains stock animations and vectors)

Download Hitfilm express https://fxhome.com/product/hitfilm-express

Basic icons for Animaker

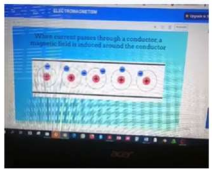


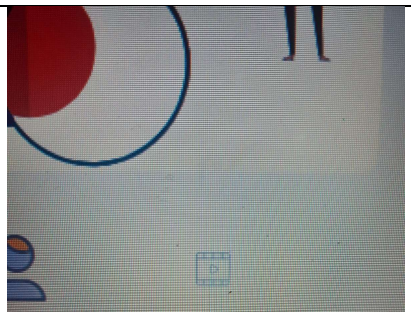
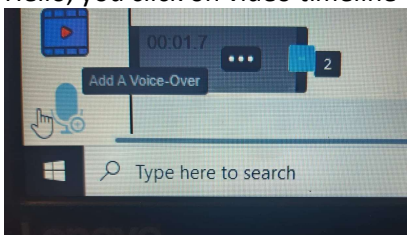
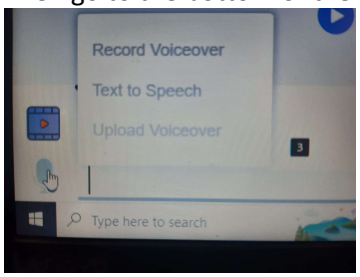

My Videos
Untitled Video
app.animaker.com/editproject/2IyeL7Qpx05U3ims
Untitled Video
Last edit saved
Full
Lite
Upgrade to pro
Share
Publish
Scenes
62%
Scene 1
00:01.6
Add scene
Delete scene
Duplicate scene
Scene 2
Scene 3
Play from timeline
Animation timeline
From The Playhead
Scene 1
[00:00]
00:03.1
Play current scene from beginning
Video timeline
1.6s
Zoom
Type here to search
11°C Rain
10:18 PM
4/10/2022

Addendum K- Transcript of the workshop WhatsApp group

Researcher = R

Name	Conversation
2 June 2022	
Researcher	Good evening. Thank you for agreeing to be part of this workshop to learn how to create basic animation videos. I will send you the google drive link for the training videos and resources you need to plan and create animations. There will be some real-time sessions on MST for discussion purposes. Please complete the permission forms that were emailed to you and return them to me. Watch the introductory training video "To plan an animation lesson". Please let me know if you will be available on Saturday for a quick demonstration on how to use the animation software.
3 June 2022	
Researcher	Good day. Will you be available for an animation session at 14:00 tomorrow?
Mr C	Yes ma'am
Researcher	Those who are not available, please let me know so that I can schedule individual virtual sessions with you.
Ms N	I am good for tomorrow.
Ms G	Me too
ReasearcherAdded	Mr D, Mr E
	Good afternoon. I have started the first meeting, is anyone struggling to join the meeting?
Mr M	From my side it says switch board and then it wants me to create my own meeting
R	Try logging in again
Mr C	It says "you'll join the meeting when someone lets you in'
R	I do not see you, will search I will send a new invite.
Mr C	OK
R	Just sent new invite
Mr C	OK
Mr M	I managed
6 June 2022	
R	Good evening. I want to schedule a meeting for this Thursday at 15:00 for those who could not make it to the Saturday session. I will send the link via email.
Mr C	Good evening. I would like to join the Thursday's meeting if possible.
R	Yes
Ms N	How long is the training scheduled for? Just planning some logistics.
R	One hour, did you get the link?
Ms N	Yes thanks
25 June 2022	
R	Good evening. I hope that you are well. If there are any queries or issues you need addressed while you create your animations, feel free to post on this group.
27 June 2022	
Ms G	Good afternoon. I need more time. Can I get an extension?

R	Yes Ms G. Is there something in the software that is holding you up? These are the issues I want to help you with on this platform.
Mr C	I will let you know when I encounter difficulties. I have not started yet.
Ms G	I don't have problems. I was just busy with my proposal. It's due Wednesday so I'm just under pressure. I will do it tomorrow and Wednesday.
R	Not a problem. This is just part of my data gathering to determine and solve technical issues.
29 June 2022	
R	Good afternoon. Please let me know how each of you are doing? I would also like to know which Big Idea each of you has chosen to work with. Please also email me your CoRe storyboard so far, even if there are only 2 sentences. I am documenting the work in progress. If you have the beginnings of an animation and voice recordings of your process so far, please send it to me. You do not have to be finished, I just want to see where you are at the moment.
Ms N	Hi there. I am away for a few days with intermittent signal so will get stuck in on Sunday.
R	Thanks for letting me know
2 July 2022	
Ms. G	 Good day. Please help. I'm trying to create a flow of charges in a conductor but I don't see a shape that I can use to create the conductor. I've tried to use the pencil tool in vector but my lines are not straight.
	 Do we just click export only for exporting? And how do I import things in animaker? I don't see the import button
R	Hi G, you can google images for a conductor, the save on your desktop or image file. Then when you are in animaker you click on images and then there is a download function that will allow you to download the images from your computer Export is only for when you are done and want to submit. The animation will stay on Animaker so that you can work on it again after our next meeting
5 July 2022	
Ms. G	Hello. How to add an audio on the animation?

	 Hello, you click on video timeline  Then go to the bottom of the screen where the scene timeline is  Click on Add voice over. It will give you 3 options. Click on your choice
Ms G	Thank you
7 July 2022	
R	Good morning. I have created a google drive file for each of you to upload your submissions. Each person has their own file. Please let me know if you have not received your link- the file will have your name on it
21 July 2022	
R	Good morning. Hope you are all well. Let us continue with the animation workshop. Thank you for your support. If you have not submitted your permission forms, you can add it to your files on google drive. Please remember to submit a video of a lesson you are currently teaching if you have not already done so. Please submit your storyboard and animation onto your google drive file. It is not supposed to be finished or professional yet. I will look at it and then schedule another session to iron out details before you finalise your animation. For those who missed the workshop session 1, I will let you know of a new date shortly.
8 August 2022	
Ms G	Can you please resend the link.
R	Hi. I will do so. Will be home by 15:00
R	Links have been shared. Please let me know if you did not receive. Please send what you have, no matter how small. I will arrange for a follow up meeting to finalise the workshop
19 September 2022	

R	Good afternoon. Please upload any new progress on google drive for me. For those who missed the sessions, please let me know when you will be available for a session. If you want a workshop at my school I can arrange that for you too.
R	Good evening all. I have made contact with most of you this holiday, but some were out of reach. I am trying a new approach to the animation workshop, it will be a 2 day workshop at HS Elsburg on 15 and 22 October from 09:00-12:00. We will be able to meet face to face and work on the animations together. Wi-fi and refreshments will be supplied as well as an appreciation token at the end of the workshop.
Mr O	Noted with thanks mam
R	
	WITS UNIVERSITY **Teacher invitation to science animation creation workshop** Dear Participant, Due to the technical hurdles experienced with the online animation creation workshop, an opportunity will be created for you to attend a physical workshop instead. You are cordially invited to attend a 2 session workshop at Hoërskool Elsburg staffroom on the following dates: Saturday 15 October 2022 from 09:00-12:00 Saturday 22 October 2022 from 09:00-12:00 We will be discussing how to plan the creation of an animation, creating the animation and enriching the animation with video-editing techniques, all valuable skills for teachers entering the 4th Industrial Revolution in Education. Each participant should bring their own laptop to the workshop. You will be requested to submit your attempts after each session for analysis and support for the subsequent session. You are also reminded to submit a teaching video of one of your current teaching lessons showing how you use technology in any form. Refreshments will be supplied during each session. Wi-fi facilities are available and you will receive a Thank-You token of appreciation for attending the full workshop. RSVP availability to attend to Denise van der Merwe at 072 207 2144 or vdmerwe.denise@gmail.com by 12 October 2022 Yours in Education DvdMerwe Denise van der Merwe
Mr K	Noted, thank you ma'am
R	Please also use this week to make a video of yourself teaching with whatever resources you usually use. You do not need to show the learners' faces, the focus is on what you are teaching with.
11 October 2022	

Mr T	Thanks Ma'am
13 October 2022	
R	Good evening. This is a kind reminder of the animation workshop at Hoërskool Elsburg from 09:00 to 12:00. Snacks, drinks and wi-fi will be supplied. Just bring your laptops. If I do not have your email address, please send it to me so that I can add you to the google drive files where there are resources you will need for the workshop
R	Please upload the following free software on your laptop before the workshop https://animaker.com https://vectr.com https://fxhome.com/product/hitfilm-express
15 October 2022	
R	Good morning. The workshop at HS Elsburg is taking place in the upstairs staffroom. Please let me know when you are at the gate so that I can open for you
17 October 2022	
	Question was posed directly to researcher on private message, answer was relevant to all team members and therefore posted on the group.
R	 WhatsApp Video 2022-10-17 at 21.29.34.mp4
	In this way you can control the speed of each electron so that they move in sequence
21 October 2022	
R	Good day. A gentle reminder of tomorrow's animation session, starting at 09:00. Looking forward to seeing you there. We will meet downstairs in the boardroom for ease of wi-fi use
5 November 2022	
Mr T	Example video sent to the group  WhatsApp Video 2022-11-05 at 22.11.16.mp4  WhatsApp Video 2022-11-05 at 22.11.24.mp4
10 November 2022	
R	Good afternoon. I have resent the google drive link to those of you who have not yet submitted your videos and storyboard etc. If you are struggling you can email me the consent forms. Create your own folder on google drive then share it with me, then I will have access. Otherwise let me know how I can assist you.
17 January 2023	
R	Good evening. Please email your storyboards to me, I need to analyse them and I have only received 1
28 March 2023	
R	Good evening everyone. I hope you are resting well during these holidays and you are making time for your families. I have a final request for you now that you have had time after creating your animations. Please post on the group your review of how the workshop went. Did you learn anything new?

	Did you notice any self development? When you learnt how to make your vectors and how they move, what then formed your reason for placing arrows or words in certain places of your animation? Do you feel more empowered with this skill? Please answer on this group, I will incorporate it in the write up
22 April 2023	
Ms G	1. Yes.. Firstly, I have learnt that animaker is a software that can promote visual learning and I did not know animaker before the workshop, now I know how to use it to create 2D animations for learning. *secondly, I have learnt that you can use text to speech option as an alternative to recording your own voice if you want to. * I have also learnt Animaker works with other softwares like vectors for effective use. i.e for adding objects that are not on animaker. 2. Yes, To me teaching with animaker promotes more of visualisation learning. That is a pedagogy I am willing to implement in my teaching because it can help learners to remember and understand complex concepts. It also caters for different learning styles for different learners since there's audio in it, images and arrows.. 3.I have used the arrows to direct the learners and as for words, I have used them to emphasize what I was saying in the audio. I have also used the words, to cater for learners with hearing problems so they can read. 4.Yes. This skill can be used for a variety of things i.e for other presentations that are not related to teaching. .There's one question that is missing here.. What was difficult? 🙈🙈🙈🙈🙈🙈 Getting the electrons to move properly.. They either moved very fast or too slow.. 💔💔 it was a struggle. Getting them to move on a solenoid was extremely difficult.. I gave up🙈
R	Thanks Gloria🌸this is extremely helpful. I sent you the meeting link
Ms G	Noted.
23 April 2023	
	Edit :promote visualisation learning not virtual. For number 1.

Addendum L- Transcript and description of the animation scenes

Ms G

Scene 1

"Magnetic field pattern due to electric current in a straight wire."

(This heading is spoken and displayed on the screen at the same time. There is a plain blue background which remains unchanged during the animation)

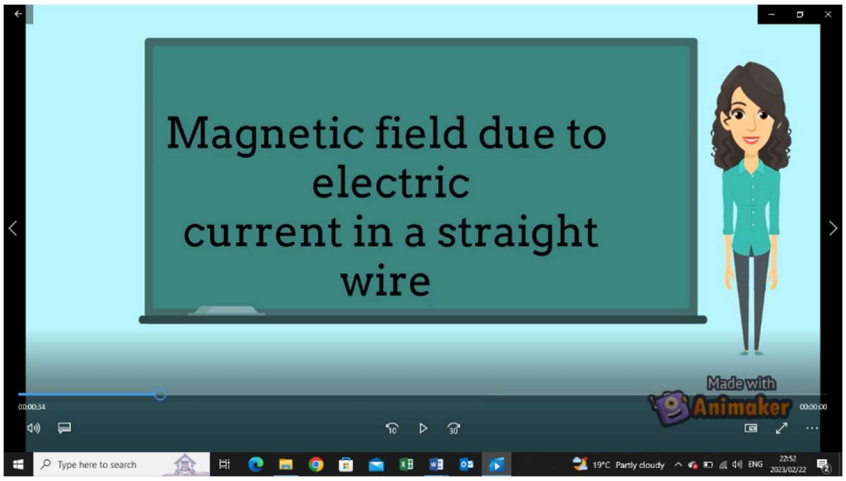
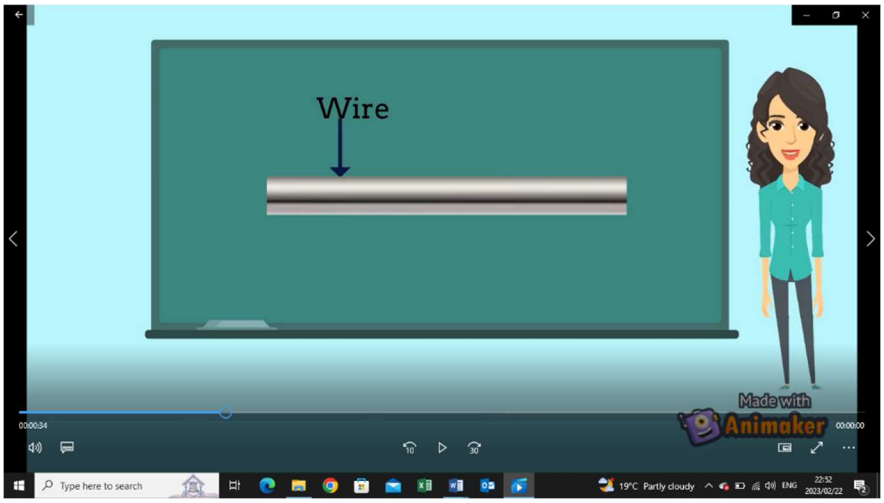


Image on screen disappears

"This is our wire"

(Image of wire appears, written word "wire" appears with an arrow pointing from the word to the wire)

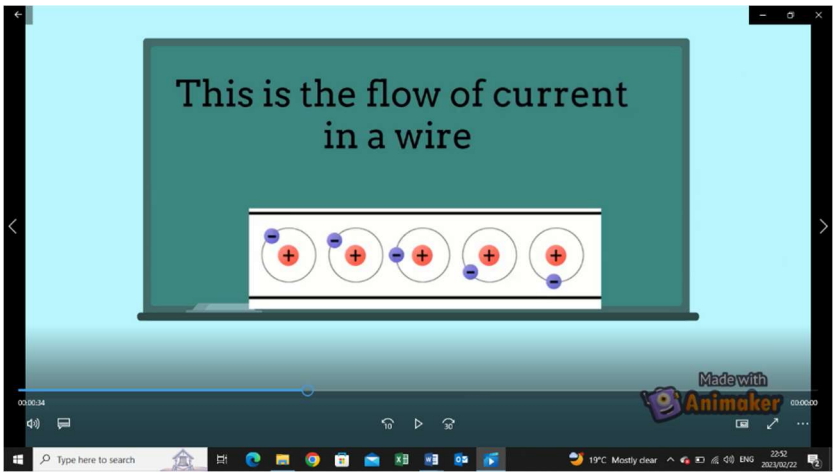


Scene 2

“This is the flow of current in the wire”

(words appear on the screen together with the verbal sentence and wire image and submicroscopic representation of the atoms in the wire. The nuclei are stationary and the electrons are moving around the nuclei, but delocalized to move in a resultant path from left to right in the screen.)

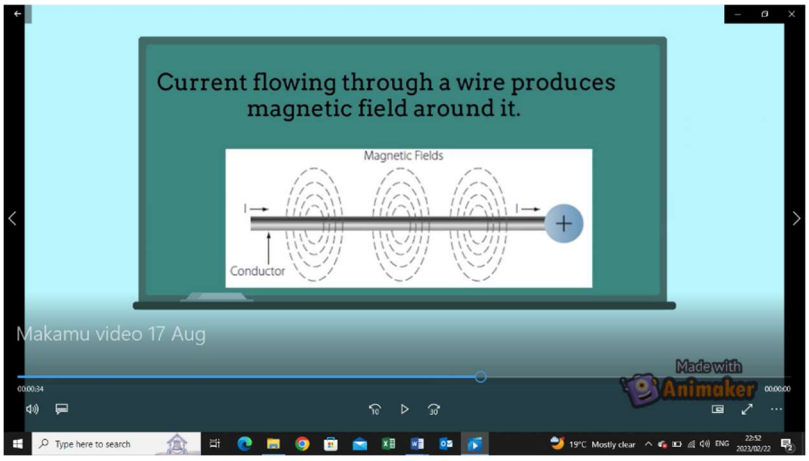
Image on screen disappears.



Scene 3

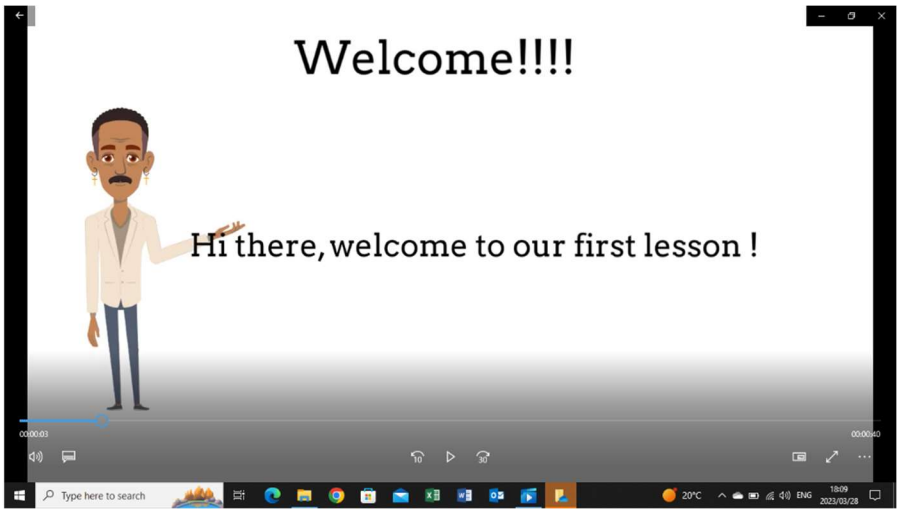
“Current flowing through a wire produces magnetic field around it.”

(Words appear on screen together with the verbal sentence and wire image. The wire has magnetic field lines around it, the direction of the current in the wire is shown with the symbol, I, and arrow. The word ‘conductor’ is also on the screen with an arrow pointing to the wire.



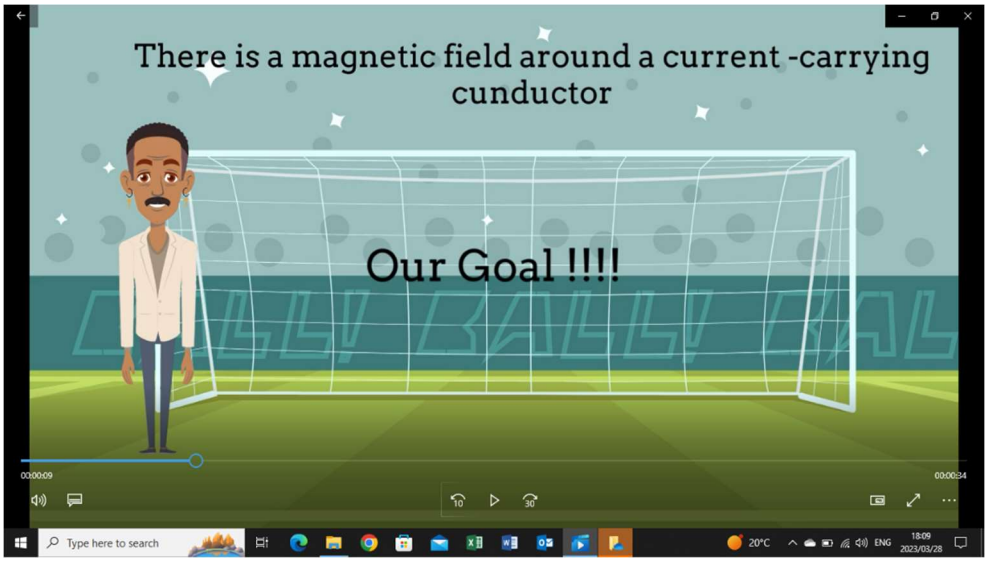
Mr M

Hi there, this is Mr M.

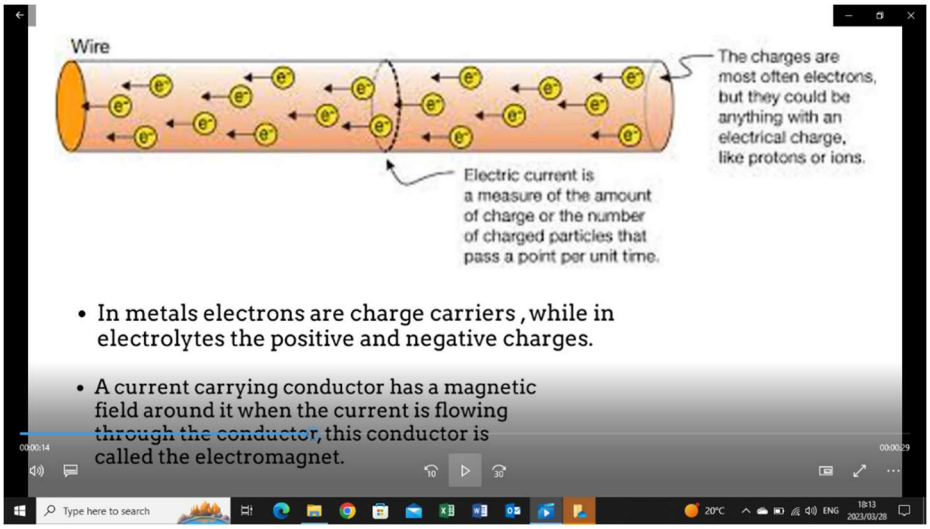


Welcome to our first lesson.

In this lesson you will learn how the current-carrying conductor produces magnetic field around the conductor.

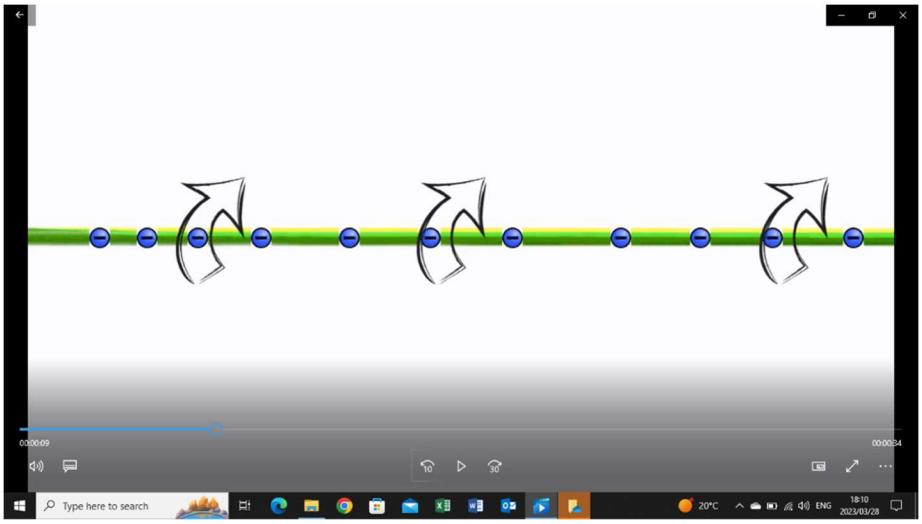


Electrons are charge carriers in a metal whilst in an electrolyte, positive and negative charges are charge carriers.

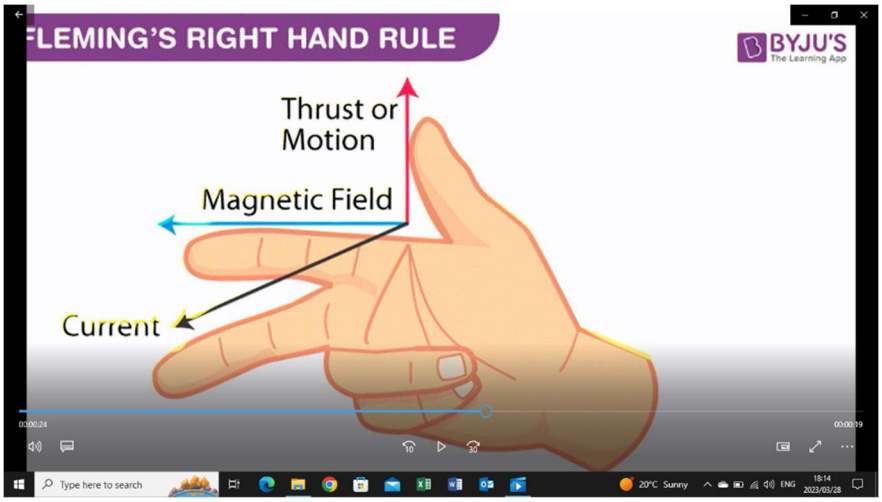


Let's talk about the right hand rule.

The thumb, second and third finger must be at the right angle to each other.



The motion, magnetic field and current are represented respectively



(electron seen moving through the wire)

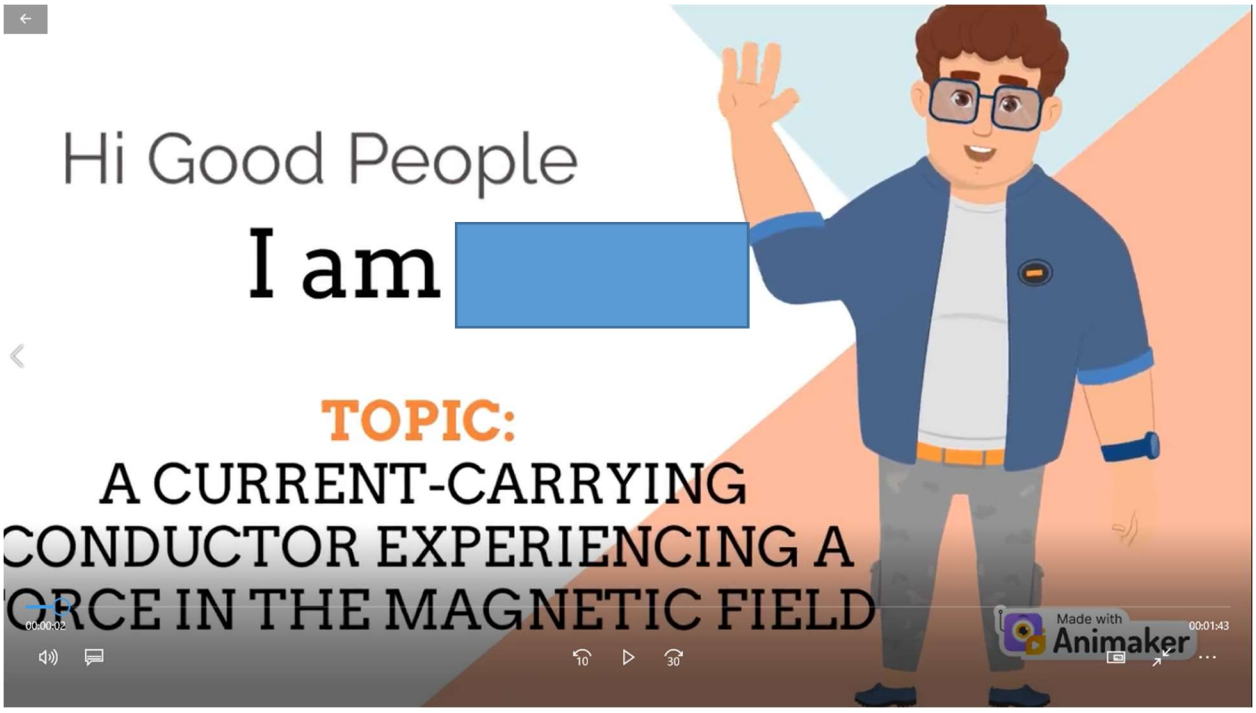
Mr T

Attempt 1

This animation was almost identical to attempt 2 but there was no matching modality and the signaling was out of sync with the slides themselves. This attempt would need to be classified as more simple as the animation would not be usable in a classroom in this format.

Attempt 2

Hi good people, I am Mr T.

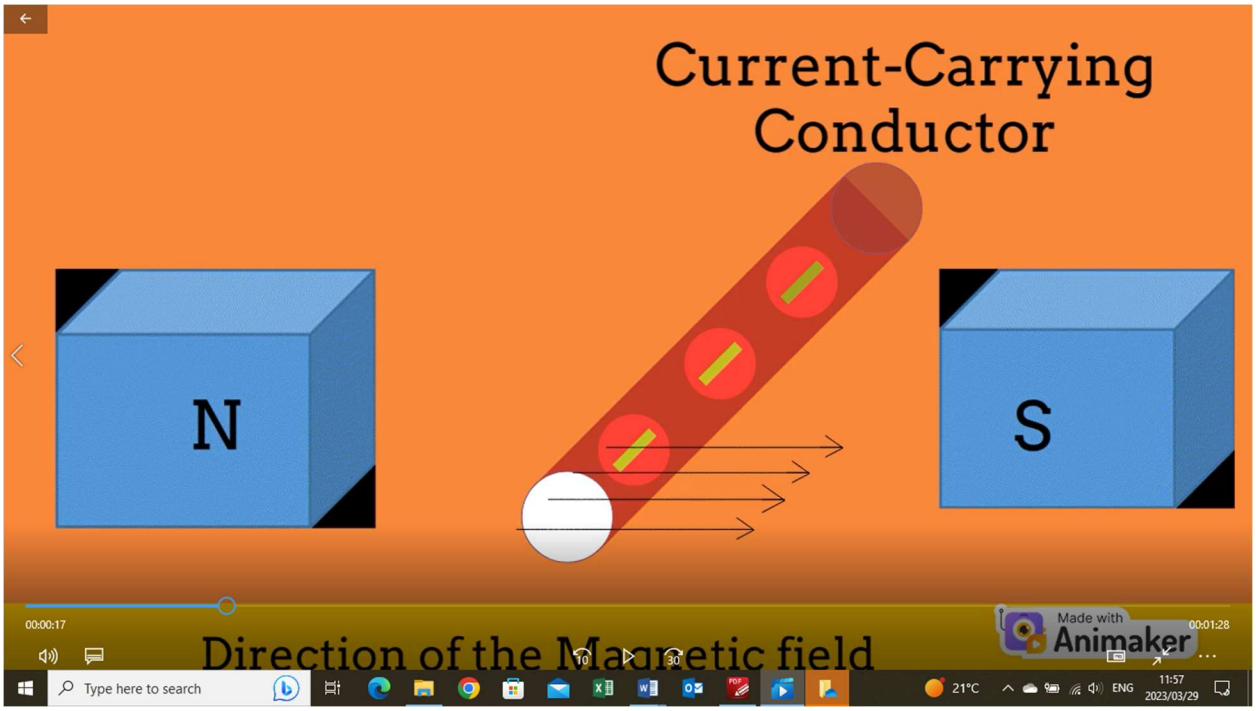


Today's lesson we will be looking at a current-carrying conductor experiencing a force in a magnetic field.

The image starts with a representation of a conductor in a magnetic field. Wording fades into the screen as the audio plays- matching modality. Flowerpot and clock fades in from the background-unnecessary- no weeding.



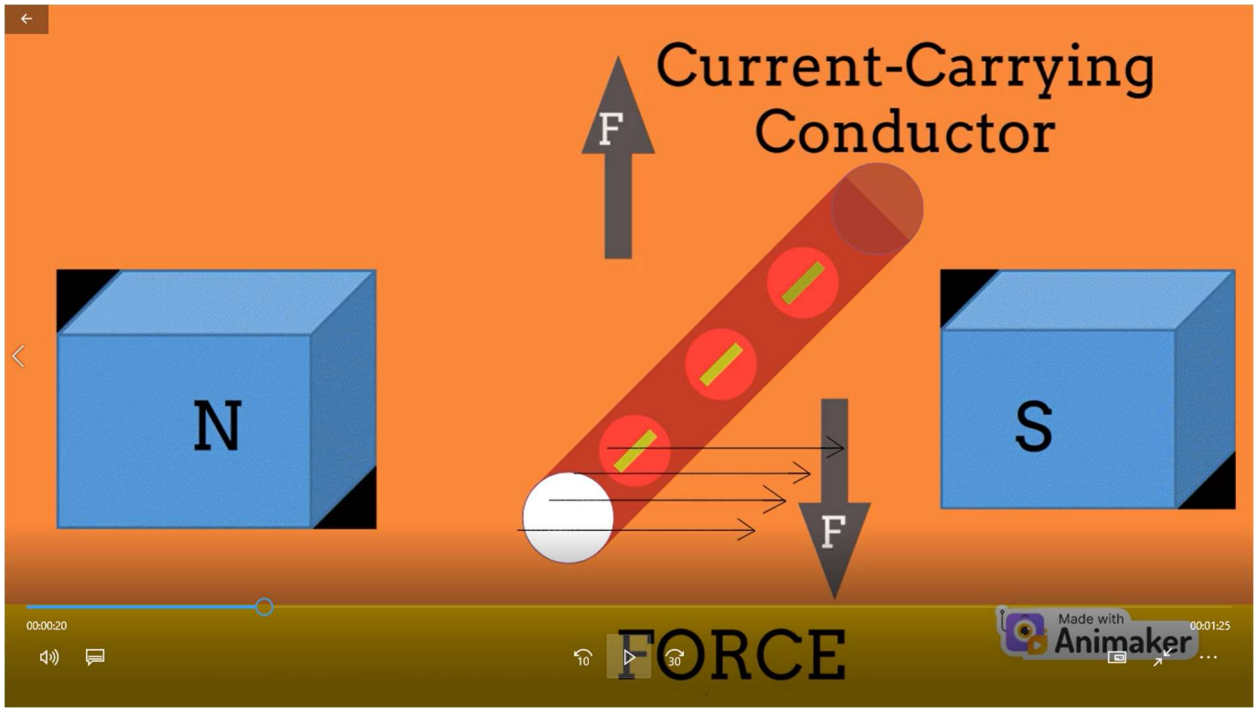
When a current-carrying conductor is placed in the magnetic field, remember magnetic field is represented by imaginary lines from the North Pole to the South Pole.



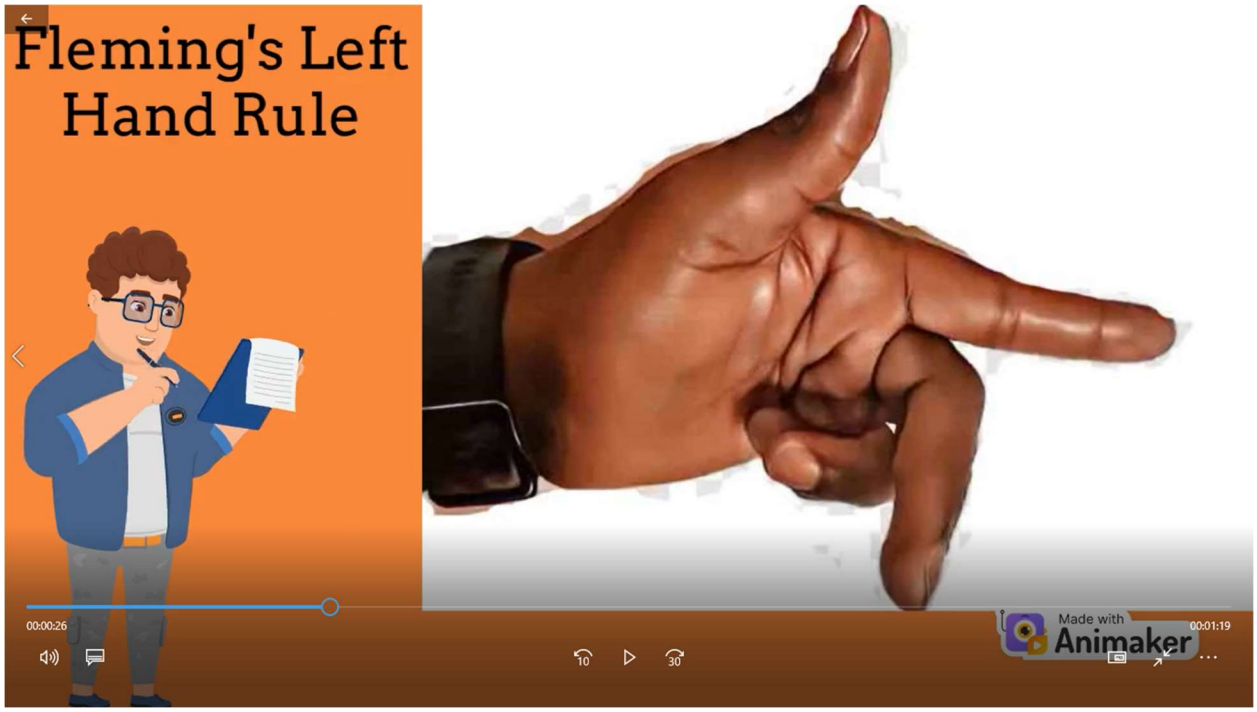
North and South poles are both represented as blue, could cause confusion based on prior learner knowledge. The current-carrying conductor drops down next to the wording and audio plays at the same time- matching modality. Electrons in the conductor are labelled, content control. Magnetic field lines appear as the audio refers to it, writing also matches (matching modality and signaling)

Words on the screen disappear as the labelled force arrows appear (content control) the written word is placed in the scene with matching audio (matching modality).

The wire will experience a force that will move it out of the magnetic field and the direction of the force can be determined by using the Fleming's Left Hand Rule.



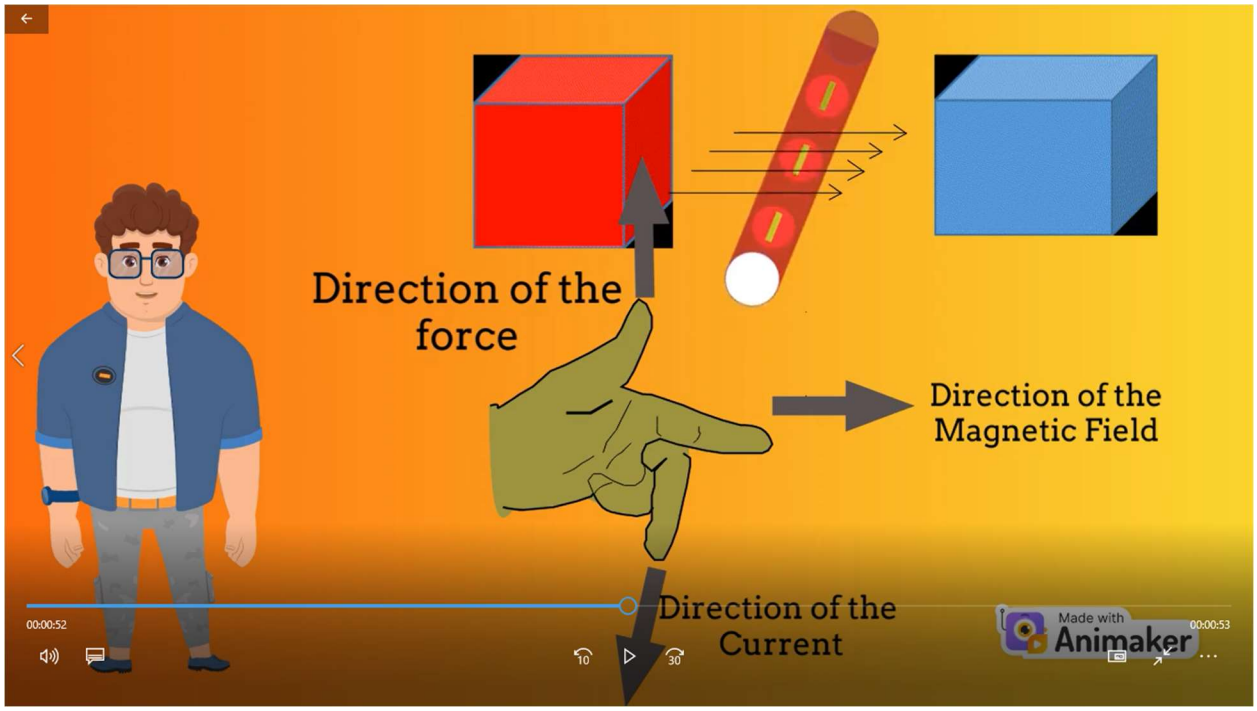
Fleming's left hand rule is that simple way to find the direction of the force or the motion of the conductor when direction of the magnetic field and current is known.



Fleming's Left hand rule stated that if the thumb, forefinger and middle finger are stretched to be perpendicular to each other such that the forefinger is stretched in the direction of the current and then the thumb will represent the direction of the force.

The man on the left writing while the narrator talks could be distracting (weeding should be considered) then arrows appear for each pointed finger with matching written text and audio- matching modality.

Let's look at the next example.



Now let's look at this diagram on my left.

The current-carrying conductor is placed in-between horse-shoe magnets.

These magnets produce some magnetic field in the direction indicated by the forefinger.

Horseshoe magnet is now in red and blue, conductor drops in, signaling and matching modality. Current is shown to pass through the conductor – content control and signaling- conductor moves when it experiences the force.

The current passes through the conductor will be in the direction of the middle finger.

And then this conductor will experience a force in the direction indicated by the thumb, moving up and out of the magnetic field.



We have come to the end of our lesson on a current-carrying conductor experiencing a force in the magnetic field. I hope you thoroughly enjoyed the video lesson.

Lastly, Madhur says that if someone always discourages you with a thumbs down, and point at you only for criticism then the middle finger shows them their position in its direction.

Goodbye, see you later.

Addendum M-Transcript from stimulated recall interviews

(R – Researcher)

Mr M	
The interview starts with a look at the CoRe storyboard that he had designed and the components that were found on it in order to confirm that his planning matched with my image of his planning.	
R.	Your animation and everything has been transcribed. OK, um so this is just my interview with Mr M just to confirm and verify the data that was found during the analysis of the storyboard and the animation. Alright, so based on your storyboard based on your storyboard I saw, I don't know if you want to come a bit closer so that you can see…
M	OK
	Shifting so that researcher and Mr. M have equal view of the screen which is open on his storyboard.
R	…this. Let's get these things out of your way. Ok, switch this on so long. OK, now the first thing I noticed in the way that you were planning, I think the storyboard also helped a bit with this
M	yes
R	Because it was structured, is curricular saliency. Now remember curricular saliency is a component that talks about how to sequence the concept as you teach them as well as bringing to light the big ideas
M	yes
R	Alright so I picked up that this was like the overriding factor and everything was planned in a specific sequence
M	Yes
R	And it was.. it shows that it was thought out, it didn't just randomly happen
M	Yes
R	Alright. Then learner prior knowledge?
M	Learners already knew what charged particles were.
R	Existing in atoms and that magnetic fields exist?
M	Yes
R	Alright. Then with your representations. You made um you planned the representation of a magnetic field that was forming around a conductor
M	Yes
R	You also noted in your storyboard that what was difficult to teach was the difference between a magnetic field and electric field so that would have to be addressed
M	Yes
R	How did you plan to signal information to the learners?
M	Using arrows to show the direction of the current and the movement of the magnetic field, and the flowing of the electrons.
R	OK, then the representation that you used was the conductor and the electrons that were flowing in the conductor
M	Yes
R	And that flow is also part of signalling?
M	Yes. Because if it was not moving then it wouldn't catch their attention and then it would also take the problem there then the learners would have a wrong idea about the current.
R	And also the direction of the current?
M	Yes

R	Alright
M	Then, you have another representation of the right hand rule that you were planning to use and here we bring in again the sequencing of concepts, because you started with the conductor on its own and then you went through to the right hand rule, so that you were able to bring to light
M	Yes
R	That big idea
M	Yes
R	So we can confirm that this is a reflection then of what you had planned
M	Yes, that's a reflection of what I had planned.
R	Ok
R	Do you want to watch your animation again?
M	Um maybe, maybe I can
	Researcher opening the animation
R	I just want to see if this is the… ja Ok. Don't want to lose our sound.
	Playing of the animation
R	We can revert back and forth as we need to (referring to the tabs on the computer containing his storyboard, animation and digital-TSPCK maps). So the components that I picked up from you there um that comes through as you can see curricular saliency and representations I was able to pick up easily
	Yes
	The curricular saliency, was the sequencing as you had planned it?
	Yes
R	Alright. Then the representations I've got all the imagery is representations, then for the weeding, where it says that there's visual or audio distractions that drives the attention away from the main ideas that you are trying to teach, I can see clear evidence of weeding
M	Yes
R	Because I didn't see any visual or auditory distractions
M	Yes
R	So it was, nothing was diverting my attention or pulling away there
M	Yes
R	And then these two components, signalling and the matching modality. Remember the signalling is bringing attention to certain things and matching modality is with the audio and visuals come together
M	Yes, it came at the same time so it matched.
R	Alright. So you're happy with that?
M	Yes I am happy
R	Now what you can't see on this animation is What is difficult to teach. Alright?
M	Yes
R	Now, what you did show (shows a piece of the animation with the magnetic field showing) let's look at this one.
M	Mmm
R	Now when you planned, you said that what is difficult is showing the magnetic field around the conductor
M	Yes, um, because as you can see, um the electrons are moving in a certain direction, so I was trying to show that around the conductor, there is a magnetic field, as the electrons are moving cause I also mentioned that the…in the conductor electrons are charge carriers. And then as they

	are moving, they are carrying a charge in a certain direction. And then as that charge is moving, which is current, are moving throughout the conductor, then around the conductor the magnetic field um will be… with the arrows I was trying to show that around the conductor magnetic field will be produced.
R	OK, and then the fact that you made them see-through
M	The electrons?
R	No. the arrows. The fact that the arrows
M	Ja, I wanted to eliminate distractions and using more colors so that learners might think that the colour represents um misconception, thinking that magnetic field has a certain colour. So I wanted to eliminate such things and I thought let me just use, let it just be colourless so that it just shows direction. If there was any better image I would have used it.
R	So if I see what you have planned and what you have done in your animation it matches and we've both agreed that when I 've picked up that the two components that I could not physically see
M	Yes
R	Were still intended. Do you agree with that?
M	Yes
R	So I can put them in my summary
M	Yes
R	As in the background
M	Yes
R	Alright. OK. Now I just have one or two more questions What did you learn from this whole experience that was new to you?
M	I honestly learnt that there are various ways that we can impart knowledge unto our learners, and something that is visually so, it makes it easier, attractive and makes it, makes learning easier because learners will be um, ok they will now, concept of moving electrons in a conductor, though it's not maybe shown in the way I wanted to, but they can clearly see that electrons are moving definitely in a conductor. And then it's easier and also the audio part of this whole planning was to instill that information to them that electrons are moving in a current carrying conductor and so forth. So I have learnt that there are better ways, or OTHER ways in which we can instill knowledge in our learners. And I have also learnt that, I didn't know much about animation. I was just thinking about those cartoons you see, and I didn't think of it in a way that we can bring it into our physics curriculum and assist learners. So I have definitely learnt a lot. And with the app as well save and store the information
	OK so that links with my next question. So did you notice any self-development on your side?
	Yes. Definitely. I must say that it needs more practice, so if I can practice more, I believe that I can make up my own , uh, develop my own ways of teaching and you know, I really , that would be helpful to the learners. So yes I have developed because there are other information that you must really be sure about so you go to and research, you research as well on a specific topic, if you still need to put some things there, on the animation then that adds also to what you already know, yes
	Thank you. Um do you feel more empowered now that you have these skills?
	Definitely. Definitely, and I'm planning on not forsaking this information, planning on growing obviously from it and also um using it in the future, using different ways of teaching, yes
	Thank you. Then, do you have any suggestions for me to possibly improve the workshop. You've gone through the entire workshop now, um, any suggestions?

	Um the workshop definitely was amazing. I really enjoyed the workshop and um maybe, but maybe also allowing us to present
	Ooh
	Ja, each and every person present their findings and then we will learn among each other as well. Yes.
	OK. That's excellent. Can definitely use that in the future.
	Yes
	Thank you so much and I really appreciate the effort that you've put in and the amount of hours that you've sacrificed. Um, in assisting with making this workshop a reality and I'm glad that we've been able to empower you
	Thank you so much, I appreciate as well
	Thank you
Ms G	
The questions for the structured interview were posted on the WhatsApp group, Ms G answered on the group, her interview was therefore …..	
R	Hi Ms G. Hi How are you?
G	Fine thanks, how are you?
	I'm good, thank you. Thank you so much for agreeing to do this. This is the last little bit that ties everything together
	Ok
	Ja, I just see that answered so well on everything I've got like literally two questions left for you
	(laughing)
	So it's going to be very short and sweet.
	(laughing)OK
	Alright. Um so what, I don't know if you want to watch your animation again or do you still remember what you did?
G	I can watch it
	OK, ja It's safer. Let me just find it, it's on my screen but…it's showing share content but it doesn't want to share.
	Oh. Or maybe you can share your screen and then display it.
	That's what I'm trying to do. It says here share content, it says screen, window or tab, I press itt, and then I just get another picture in there that says entire screen, select the tab to preview. And then I press that, and then
	Yes you have to click and say screen
	Ja I did
	Still not showing
	No, so let me just, do you see that
	No
	Oh, great. Ok let's go there…now do you see?
	No
	…this one….
	But it's only a few things, I think I remember the video, the coil and then the…OK now I do see it
	Ok so you're seeing it, so I'm just going to go through this route so that you can see your animation. Do you see it?
	Animation starts playing

	Ja but its not open it's only the audio, but it's fine
	Ok what I'm gonna do then is I will share , let me share something else with you, cause this is where my questions are coming from anyway. Alright, so do you see that?
	No, I only see the names of the folders.
	What do you see now?
	The names of the three files
	And if I open the file do you see it?
	No, it's still not open
	OK, then you remember your animation right?
	Ja
R:	Ok so I'm just going to ask you one or two questions about it because I've picked up certain kinds of um, OK, so I've seen specific things in your animation that matches up with your storyboard so your planning and your implementation matches up to a certain point…
G:	Mmmhmmm (yes)
R:	So the way that you planned your sequencing and what you wanted to bring forth in your big ideas, so the main concepts that you planned to put in the animation is coming through in the animation so the curricular saliency that looks at your sequencing, looks at the main ideas that you are bringing in, that matched up with planning and animation, I was able to see that. The …what you planned to represent was also coming through in the animation. Um then your planning of the weeding, the things that you want to eliminate so that it does not cause any disturbances to the learners, what you planned is what I saw, so that wasn't a problem, and also with matching modality, your audio and sound and pictures matched up. So what I wasn't able to see is, and it's not just you, it's for every single person who did this, because it's a tacit kind of component for an animation.
R:	The first one I could not see in your animation was Learner Prior Knowledge
G:	Ja, I knew that learners already knew about the magnetic fields so I drew them there.
R:	Ok
G:	Yes
R:	Now the second thing that you said that I can't see on an animation, is what is difficult to teach. Now on your storyboard you say what is difficult to teach is that current passes through a conductor. Now, if I look at your first attempt at your animation, where you has the electrons flowing through and your second attempt which had the beautiful electrons circling the nuclei being dissociated um...is that…is the reason why you changed it, because you realised that it was difficult to teach?
G:	Ja, that's why I changed it, and then I had to show them the flow of electrons, because I think that somewhere I mentioned that the electrons they cannot see them with their naked eyes so I had to indicate that on the, inside the wire and draw their attention to it.
R	Alright, because it's not coming through with any of the animations and I just need confirmation because that is how I understood what you did, and I need your confirmation that what I am seeing is what you intended.
G	Yes
R	Alright. So that was basically the first question that I wanted to ask you. And the second question is just the last little question, because you've answered all the others.
G	Laughing
R	Um…what changes, or what improvements can I make to this workshop in order to make it better. What suggestions do you have for this workshop for the future

G	OK, I think the …the training um…I think we learnt a lot of things in a short period and some of the things we learnt we could not apply them just like how to move the electrons on a solenoid. Ja the period of learning was too short. I think in the future we need more time. It's different from just allowing the electrons to move, but now we have… it's on a different level so we needed more time.
	And then, remember we started off as an online workshop
	Yes
	And then we move to face-to-face because everybody was more comfortable with that. If we had started it as a face-to-face, that would have probably given us more time?
	Ja, ja that's true
	OK, alright. And any other suggestions that you have?
	No, no
	Alright. Then I say thank you very much for participating. I'm still trying to get your little token to you
	Laughing
	Banter, end of interview.
Mr T	
	Not available for interview