Students' engagement with technology-enhanced resources in first year non-specialist undergraduate mathematics modules

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed:

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Table of Abbreviations

Abbreviation	Meaning
NF	National Forum for the Enhancement of Teaching and Learning in Higher Education
VLE	Virtual Learning Environment
OECD	Organisation for Economic Co-operation and Development
NRC	National Research Council
KA	Khan Academy (for the trials relating to KA)
FaSMEd	Formative assessment in Science and Mathematics Education (project)
CAO	Central Applications Office
DES	Department of Education and Skills

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Abstract

Caitríona Ní Shé: Students' engagement with technology-enhanced resources in first year non-specialist undergraduate mathematics modules

While students undertaking first-year undergraduate mathematics modules report using technology-enhanced resources (YouTube, Khan Academy, Wolfram Alpha) for their studies, and lecturers invest time and effort into developing such resources using tools such as GeoGebra and Matlab, there has been little research on the factors that encourage students to engage with particular technology-enhanced resources or in what ways students use these resources to support their learning. While a recent OECD report found that an increase in the use of computers in mathematics in schools correlated negatively with students' performance in mathematics, there are suggestions that the effectiveness of educational technology is not being adequately determined due to the lack of frameworks of evaluation. Additionally, more information regarding the implementation of the resources is required.

I worked as part of a team of academics from four higher education institutes in Ireland, who developed a suite of resources, called Technology-enhanced Resources for Mathematics Education (TeRMEd), for first-year non-specialist mathematics modules. My specialist role within the team was to evaluate the resources developed or implemented. The main aim of my research was to explore why, and in what way, first-year students engaged with these resources to support their learning for non-specialist mathematics modules and to determine what factors of the implementation environment impacted on this engagement. This research consisted of five stages: (1) literature review; (2) research design; (3) analysis of the TeRMEd evaluations; (4) development of the TeRMEd classification framework; and (5) supplementary investigations of first-year engineering students' engagement with Matlab and other technology-enhanced resources. The outcomes of this research will inform mathematics educators on appropriate evaluation of technology-enhanced resources and on how best to implement them to ensure appropriate student engagement. The research will increase our knowledge on how students engage with technology-enhanced resources and will inform practice in the field.

Conference Contributions and Publications

Conferences

- Ní Shé, C., Mac an Bhaird, C., Ní Fhloinn, E., & O'Shea A. (2019, September 5th – 6th). *Successful implementation of technology enhanced resources* [Conference presentation]. CETL-MSOR 2019, DCU, Dublin.
- Ní Shé, C., Mac an Bhaird, C., Ní Fhloinn, E., & O'Shea A. (2018, June 26th). *The Development of a Framework to Assess Technology Enhanced Resources for Mathematics* [Conference presentation]. SMEC 2018. DCU, Dublin.
- Ní Shé, C., Breen, S., Brennan, C., Lawless, F., Mac an Bhaird, C., McLoone, S., Ní Fhloinn, E., Nolan, B., E., O'Shea, A. (2017, February 1st – 5th) *Technology enhanced Resources for Mathematics Education (TeRMEd)*. [Conference poster]. CERME 10, Croke Park, Dublin.
- Ní Shé, C., Breen, S., Brennan, C., Doheny, F., Kelly, C., Lawless, F., Mac an Bhaird, C., McLoone, S., Ní Fhloinn, E., Nolan, B., E., O'Shea, A. (2016, June 16th – 17th). *Assessment for learning: Resources for first year undergraduate mathematics modules*. [Conference presentation]. SMEC 2016, DCU, Dublin.
- Ní Shé, C., Mac an Bhaird, C., Ní Fhloinn (2016, August 22nd). *Using Think Aloud Interviews and Questionnaires to Evaluate Online Formative Assessment Resources for First Year Undergraduate Mathematics Modules* [Conference presentation]. ECER 2016, UCD, Dublin.
- Ní Shé, C., Lawless, F., Mac an Bhaird, C., Ní Fhloinn, E., Nolan, B., O'Shea, A. (2016). Assessment for learning: resources for first year undergraduate mathematics modules. *In Green, D. (Ed.) Proceedings of CETL-MSOR Conference, (p. 35).UK.*

Related publications

- Ní Shé, C., Mac an Bhaird, C., Ní Fhloinn, E., & O'Shea, A. (2017). Students' and lecturers' views on mathematics resources. T*eaching Mathematics and its Applications: An International Journal of the IMA, 36*(4), 183-199. https://doi.org/10.1093/teamat/hrw026
- Ní Shé, C., Mac an Bhaird, C., Ní Fhloinn, E., & O'Shea A. (2016): Problematic topics in first-year mathematics: lecturer and student views. *International Journal of Mathematical Education in Science and Technolog*y, *48*(5), 715-734. DOI:10.1080/0020739X.2016.1272142.

Other Contributions

- Breen, S., Ní Shé, C., O'Shea, A., (2019). Conjecturing tasks for undergraduate calculus students. *In Jankvist, U. T., Van den Heuvel-Panhuizen, M., & Veldhuis, M. (Eds). Proceedings of the Eleventh Congress of the European Society for Research in Mathematics Education (p. 4178), Netherlands*.
- O'Shea, A., Breen, S., Ní Shé, C. (2017, July 10th – 12th). *Designing calculus tasks to encourage the development of mathematical thinking* [Conference presentation] CETL-MSOR 2017, University of Birmingham, UK.

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Chapter 1 Introduction to thesis

1.1 Introduction

The use of digital technologies has become ubiquitous in our societies. In higher education institutes, students are constantly connected via smart phones, laptops and the internet. Multimedia information on any topic or skill can be sourced effortlessly by students. Consequently, it would be expected that students would effectively engage with technology-enhanced resources provided by lecturers to supplement their learning. However, is this actually the case? How effective are these resources? Are some more effective than others? How can we tell? Currently, there is an ongoing debate in the international educational community about how best to use digital technology to support student engagement, and as a consequence learning, in higher education (Bayne, 2014; Selwyn, 2010).

In mathematics education, researchers have pointed to the need to establish which technology implementations work best and why, so that they can be used effectively (Drijvers, 2016b). In his lecture on digital technology in post-primary mathematics education, Drijvers (2015) refers to “decisive factors” that beneficially influence the use of technology-enhanced resources. One of the barriers to establishing these decisive factors is the lack of frameworks that can be used to evaluate the use of technology-enhanced resources (M. King et al., 2014).

This study sets out to identify the decisive factors that influence the effectiveness of the use of technology-enhanced resources in higher education mathematics. Their effectiveness is evaluated in terms of student engagement with these resources.

1.2 Research Intent

In their report on building digital capacity in higher education in Ireland, the National Forum for the Enhancement of Teaching and Learning in Higher Education (NF) recognised the importance of building first-year undergraduate students’ underlying skills, such as mathematics (NF, 2018). The research outlined in this PhD thesis stemmed from one of the associated NF-funded projects, ‘Assessment for Learning Resources for First-Year Undergraduate Mathematics Modules’ (NF, n.d.-b). The resources developed for this NF-funded project were aimed at addressing a widely-reported problem: that first-year undergraduate students in Ireland are under-prepared for the non-specialist mathematics modules they encounter (Faulkner et al., 2010; Gill & O’Donoghue, 2007b). This has been found to impact on their ability to successfully complete their first year at higher education (Liston et al., 2018), which has consequences for the targets for higher education set out by the Department of Education and Skills (DES) (DES, 2011). The lack of basic mathematical skills on entering higher education, and the resultant impact on progression and retention, has also been identified in an international context (J. Allen et al., 2008; Galligan et al., 2015; Liu & Whitford, 2011; Loughlin et al., 2015; OECD, 2009; Trenholm et al., 2019; Wang, 2009). Mathematics Learning Support Centres (MLSCs) have been put in place in an attempt to address this issue in a number of higher education institutes, particularly in Ireland, the UK and Australia (Lawson et al., 2012; Mac an Bhaird et al., 2011; MacGillivray, 2009; Samuels, 2010). Lecturers have also sought to address this issue through the provision of technology-enhanced resources (Coupland et al., 2016; Kay & Kletskin, 2012; Loch et al., 2012). Furthermore, students attending first-year undergraduate mathematics modules self-select support materials and use technology-enhanced support resources such as YouTube videos, Khan Academy and Wolfram Alpha to support their mathematics learning (Anastasakis et al., 2017b; Dalby et al., 2013; Ní Shé et al., 2016).

Student engagement in higher education is known to be a predictor of successful retention and programme completion (Fredricks et al., 2016; Kahu & Nelson, 2018; Trowler, 2010). Student engagement, as examined by Trowler (2010) in her report for the Higher Education Academy in the UK, is reflected by the time and effort spent by students interacting with relevant resources and institutional supports. Improving student learning is central to the idea of student engagement, as described by Coates (2005, p. 26):

'*In essence, therefore, student engagement is concerned with the extent to which students are engaging in a range of educational activities that research has shown as likely to lead to high quality learning'.*

Student engagement is known to be influenced by factors such as the provision of effective resources and supports (Beer et al., 2010; M. Bond & Bedenlier, 2019; Kahu, 2013; Zepke & Leach, 2010). It is important, therefore, to evaluate the effectiveness of resources that are put in place in terms of student engagement. The initial inspiration for this PhD thesis was the need to evaluate the effectiveness of the technology-enhanced resources developed by the lecturer team involved in the NF-funded project 'Assessment for Learning Resources for First Year Undergraduate Mathematics Modules'. Following an initial literature review and early results of the evaluations, the project was refined to focus on factors that impact student engagement with technology-enhanced resources and widened to include the development of an evaluation framework that practitioners can use to support their planning and evaluation of such resources.

The effectiveness of using technology in mathematics education is under question. A recent OECD report (2015) identified that an increase in the use of computers in mathematics in schools correlated negatively with students' performance. While this has been echoed in other studies

(Coupland et al., 2016; Geiger et al., 2016; Selwyn, 2012a), these findings are disputed. Research reported by Rakes, Valentine, McGatha and Ronau (2010) claims that the use of technology tools do improve students' conceptual understanding of mathematics. It has also been suggested that the effectiveness of educational technology is not being adequately determined due to the lack of frameworks of evaluation (M. King et al., 2014) and that more information regarding the implementation of resources is required (Drijvers, 2015). Drijvers (2016b) suggests that empirical studies which focus on experimental research do not examine the educational setting and how the technology has been implemented by the teacher and that 'we need to know more about where and how it is used to greatest effect' (Higgins et al.,2012 as cited in Drijvers, 2016b, p. 6) so that the 'decisive factors' that establish 'eventual benefits' can be determined (Drijvers, 2016b, p. 7). The importance of implementing appropriate pedagogical practices when using technology to support learning in mathematics education has been long established (Bray & Tangney, 2013; Geiger et al., 2016; Pierce & Stacey, 2010). However, studies reporting on the use of technology do not necessarily examine the effects the particular pedagogical practices have on student engagement with the technology (Drijvers, 2015; Henrie, Halverson, et al., 2015).

Two interconnected problems have been identified from the literature. The first problem relates to the necessity of determining factors that encourage students to engage with technology-enhanced resources to support their learning of mathematics. The second identifies the lack of frameworks of evaluation that can be used by practitioners to examine the effectiveness of technology-enhanced resources that they develop for their students.

1.2.1 Research Aims

The aim of this research is to explore why, and in what way, first-year undergraduate students engage with selected technology-enhanced resources to support their learning of mathematics for non-specialist mathematics modules and to determine what factors of the learning environment impact on their engagement.

Research Objectives:

(1) To review the current literature on the use of technology-enhanced resources by first-year undergraduate students in supporting their mathematics learning.
(2) To investigate how the effectiveness of such resources has been evaluated.
(3) To evaluate the effect the learning environment has on students' engagement with selected technology-enhanced resources.

(4) To develop a research-based evaluation framework that can be used by practitioners to determine the effectiveness of technology-enhanced resources that they develop for their students.

1.2.2 Research Questions

Three research questions have been identified to address the aims and objectives of this PhD study. The first two research questions are used to determine the implementation factors and pedagogical features that impact on student engagement with technology-enhanced resources. The third research question addresses the development of an evaluation framework to be used by practitioners when evaluating the technology-enhanced resources they provide for their students. The three research questions are:

Research Question 1 (RQ1): What are the key factors of technology-enhanced resources and their implementations that influence students' engagement with these resources?

Research Question 2 (RQ2): What are the key pedagogical features of technology-enhanced resource implementations that impact on student engagement with these resources?

Research Question 3 (RQ3): How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?

In the first instance in this thesis, it is important to define and understand the difference between RQ1 and RQ2. According to the Oxford English Dictionary (OED) (OED, n.d.-a Definition 1), a factor is '*An element which enters into the composition of something*; *a circumstance, fact, or influence which contributes to a result'*. RQ1 seeks to find those elements of technology-enhanced resource implementations that influence students' engagement with such resources. On the other hand, a feature is defined as '*A distinctive or characteristic part of a thing; some part which arrests the attention by its conspicuousness or prominence.'* (OED, n.d.-b Definition 4). Thus, RQ2 seeks to find the characteristics of the pedagogies associated with technology use that impact on students' engagement with technology-enhanced resources. For example, a factor may be whether the resource is used in class or not, whereas as a feature of the pedagogy will be the types of tasks supported by the technology.

1.3 Research Methodology

In order to address the aims and objectives of this PhD research study, both pragmatic and interpretive approaches are taken. An interpretive approach was beneficial when investigating how students engage with technology-enhanced resources. In order to generate theory on why and in what way students engage with technology, meanings were derived from the documented student and lecturer experiences. On the other hand, a pragmatic approach was used to develop a framework of evaluation. This involved the identification of the factors that impact student engagement with technology-enhanced resources and converting these into a practical application: a classification framework that practitioners can use to evaluate the effectiveness of the technology-enhanced resources they develop for their students.

The research methodology chosen for this PhD study reflects the need to select methods that support the paradigm taken by the researcher (Kivunja & Kuyini, 2017; Lincoln & Guba, 2000). In a pragmatic approach, careful and complementary use of both qualitative and quantitative methods allows exploration of the complexity of human behaviours, which are then used to develop a solution for a problem; a mixed methods approach is then appropriate (Duram, 2012; Farrow et al., 2020; Morgan, 2014; Morrison, 2007). Interpretive approaches generally involve qualitative research methods to gather data, and inductive analysis is then used to generate theory from the documented real life social experiences (Farrow et al., 2020; Kivunja & Kuyini, 2017). Thus, a mixed methods study was designed for this PhD study.

1.3.1 Research Stages

There were five stages in this research study:

- Stage 1: Literature review
- Stage 2: Research Design
- Stage 3: NF-funded project technology-enhanced resource evaluations
- Stage 4: Technology-enhanced Resources for Mathematics Education (TeRMEd) framework development
- Stage 5: Using the TeRMEd

Data was gathered and analysed at various stages throughout the research study period. The outcomes of the analysis of each stage of the research were then used to inform subsequent stages. In addition, the outcomes of the analysis at various stages of the research were used to address the research questions posed as a result of the literature review. This research design process is illustrated in Figure 1.3.1 below.

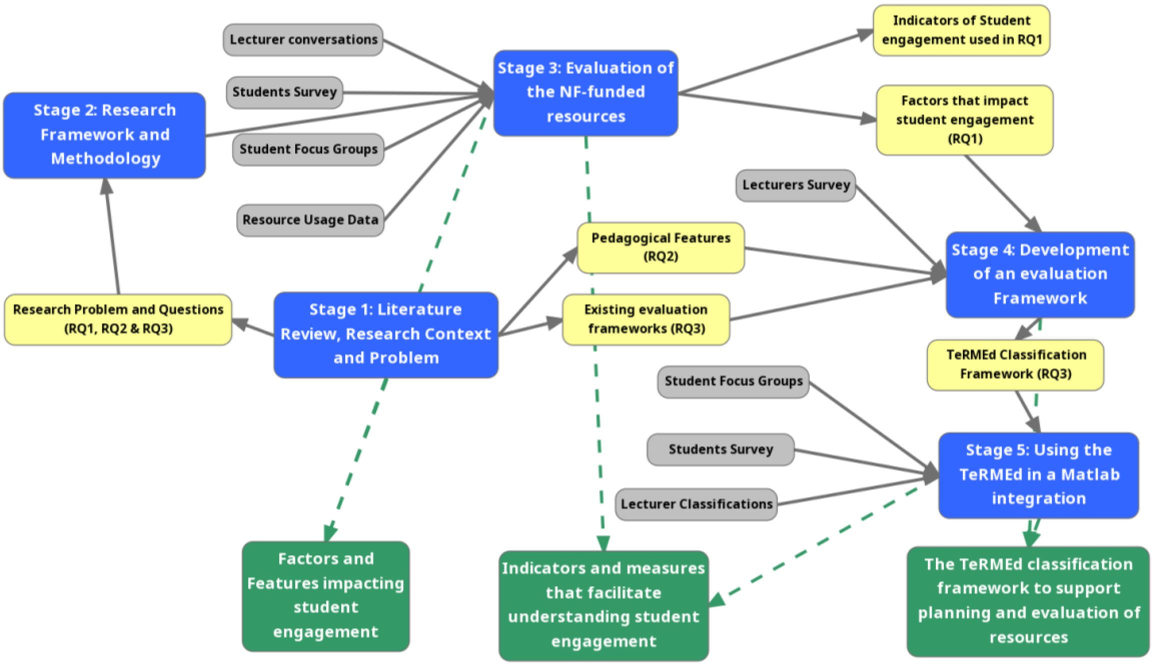


Figure 1.3.1: Research design and associated outcomes

Colour code: Blue - Stages of the research; Grey - Data gathering methods; Yellow - principal outcomes from each research stage. Green - Main research contributions of this PhD study. Green dashed lines – research stage outcome to a main contribution.

1.3.2 Research Methods

The data gathering methods were selected to reflect the mixed methods nature of the study. During stage 3, a student survey was designed to elicit quantitative data with respect to student opinions of the NF-funded project resources. The survey findings were used to identify factors that impact on student engagement. A total of seven different student groups completed this survey. Usage of the resources was either recorded electronically or provided by the lecturer. Student qualitative data was gathered, both as an open question within the survey and as part of two student focus groups. Lecturer comments on the use and evaluation of the resources were elicited through phone and email conversations.

During stage 4, outcomes of the literature review (completed in stage 1) were used to contribute to the design of the TeRMEd framework, together with the factors identified in the evaluations of the NF-funded project resources. A lecturer survey was designed and implemented to gather lecturers' opinions of this framework, and used to assess the value of the framework in the planning and evaluation of technology-enhanced resource integrations.

In stage 5, the TeRMEd framework was put into practice. The classification of Matlab within the TeRMEd framework, by this researcher and the lecturer involved in the module, was used to plan and predict the expected students' engagement with the resource. A specially-designed student short survey was then used to evaluate the effectiveness of the integration of this resource within the module. Following on from that, two student focus-group interviews were held to corroborate the outcomes of the Matlab evaluation and further probe the factors that influence student engagement with technology.

Quantitative analysis was conducted on the resources' usage data and the students' survey, using both MS Excel and SPSS. Qualitative inductive analysis was used to code the open survey and focus group responses within the NVivo application. The outcomes were examined through the lens of the holistic nature of student engagement as suggested by Kahu and Nelson (2018). Specifically, student engagement with technology was examined in the context of the learning environment within which the technology is integrated. This latter analysis served to focus the study on the exploration of why and in what way students engage with technology-enhanced resources.

1.4 Research Contribution

The three main contributions of the study are illustrated in green in Figure 1.3.1. above and discussed in more detail below.

1.4.1 Factors and features that impact student engagement with technology

The evaluation of the NF-funded project resources enabled the identification of a list of implementation factors that impact on student engagement with technology-enhanced resources within first-year undergraduate non-specialist mathematics modules. The focussed literature review revealed further pedagogical features that have been found to influence this cohort of students' engagement with technology-enhanced resources. While many of the 12 factors identified are corroborated in the literature, a number of them have not been examined and investigated through the lens of student engagement. When considered together, they provide a response to Drijvers (2016b, pp. 1–7) quest to find the 'decisive factors' that establish 'eventual benefits' of using technology in mathematics education.

1.4.2 Indicators and measures of student engagement with technology-enhanced resources

This study identified indicators of student engagement within the observations and measures used to evaluate the NF-funded resources. While engagement indicators are used to measure student's positive and negative engagement with technology (Bond & Bedenlier, 2019; J. Lai & Bower, 2019) mapping of such indicators to the three dimensions of engagement has been shown to be problematic (M. Bond et al., 2020; M. Bond & Bedenlier, 2019; Fredricks et al., 2016; Sinatra et al., 2015). The engagement indicators, found in this study, were mapped to the three dimensions of engagement, allowing the examination of student engagement with technology-enhanced resources in an integrated manner, and contributing to the discussion on the holistic nature of student engagement (Attard & Holmes, 2020; M. Bond & Bedenlier, 2019; Yang et al., 2018).

1.4.3 The TeRMEd classification framework

The pragmatic nature of the study involved the development of a framework of evaluation, the TeRMEd classification framework. The research illustrated how a practitioner successfully used the TeRMEd framework to support the effective design and integration of technology. The latter is a key requirement of using digital technology to support student engagement, and, as a consequence, learning in higher education (Bayne, 2014; Selwyn, 2010). Not only does this framework support the factors that influence student engagement identified through this research, it also encompasses many of the elements of existing frameworks used to consider the impact of technology on student engagement (Attard & Holmes, 2020; M. Bond & Bedenlier, 2019).

A note on terminology

While it is not always clear in the literature what delineates a theoretical framework from an evaluation framework (Nilsen, 2010), many education researchers refer to theoretical frameworks to describe how learning occurs in given situations, see for example Drijvers (2015). On the other hand, the term ‘framework of evaluation’ is often used to describe how (technology) integrations are evaluated, see for example King et al. (2016). To add to this confusion the term theoretical framework is also used to specifically describe the structure that guides the development of a research study.

In this context the TeRMEd framework is referred to as a classification framework of evaluation that supports both the classification and evaluation of technology-enhanced resource interventions. The term theoretical framework is used throughout the thesis to refer to either the development of learning theories within a research context, or to the framing of a research study, wherever relevant.

Two articles relating to the outcomes of this thesis are in preparation: one on the evaluations of the NF-funded project resources with respect to student engagement with technology-enhanced resources; and the other on the development and use of the TeRMEd framework.

1.5 Outline of this thesis

This chapter introduces the research work carried out in this PhD. The details of the research and its outcomes are contained in the following seven chapters.

Chapter 2: Literature review

Chapter 2 discusses and analyses the literature in the field under study. It concludes with the identification of the research aims and objectives and the development of the research questions that are addressed in the following chapters. There are four main sections in the literature review:

- Section 1: Student engagement with technology in higher education (and mathematics)
- Section 2: Technology in education and in mathematics in higher education: what works and what does not
- Section 3: Evaluating technology use in higher education (and mathematics) and the use of frameworks and models
- Section 4: Conclusion of the literature review

Chapter 3: The National Forum funded project

Chapter 3 establishes the context of the project. It discusses the background to first-year undergraduate non-specialist mathematics in undergraduate education in Ireland. It explains the context of the development of the NF-funded project resources and identifies the members of the project team and their role within the project. Finally, it contains a description of the various NF-funded project resources and specifics of the trials associated with each of the resources.

Chapter 4: Research Methodology

In Chapter 4, the rationale for the research design and methodology chosen for the project are considered. The research paradigm adopted by this researcher is justified and an appropriate methodology selected. Chapter 4 also describes the research design and instruments used at each stage of the research. The validity and trustworthiness of the study is discussed, along with a review of the ethical considerations.

Chapter 5: Student engagement with the NF-funded project resources

During stage 3, the NF-funded project resources, described in Chapter 3, were evaluated to determine the effect different learning environments have on student engagement. Chapter 5 contains an analysis of the data gathered and the relevant outcomes are then explored with a view to addressing RQ1 and RQ2.

Chapter 6: Development of the TeRMEd Framework

In Chapter 6, the rationale behind the development of the various sections and categories of the TeRMEd framework is described. The use of the 12 factors, identified in Chapter 5, to construct the TeRMEd framework is considered throughout. This framework was then tested. The NF-funded project resources were classified within the TeRMEd framework and the lecturers involved in the project were asked to reflect on the classifications. The outcomes of this research are discussed in terms of possible implications for future iterations of the resources, and the value or otherwise of using the TeRMEd framework.

Chapter 7: Using and evaluating the TeRMEd framework

In line with the pragmatic nature of this PhD research approach, it was important to test the TeRMEd framework in a relevant educational setting. Thus, Chapter 7 considers the use of the TeRMEd framework to help plan and evaluate the integration of the technology tool Matlab into a first-year undergraduate mathematics module.

Chapter 8: Discussion and Conclusions

In Chapter 8, the research questions are answered. The overall findings from the research project are discussed in the wider context of literature in this area. The significance and limitations of these findings are described along with the recommendations for future research projects in this area.

Chapter 2 Literature Review

2.1 Introduction

The role of the literature review within a thesis is multifaceted. In the first instance, it allows the researcher to build an account of the research that has been carried out in the area. This account serves to delimit the research field, identify new areas of research, and support the originality and contribution of the thesis (Boote & Beile, 2005; Hart, 1999; Randolph, 2009). Secondly, it serves to inform the researcher of the theoretical frameworks and research methods that are used in their particular field (Boote & Beile, 2005; Hart, 1999; Randolph, 2009). Finally, the literature review enables the researcher to identify the important research, the seminal articles and the influential researchers in the area (Boote & Beile, 2005; Hart, 1999; Randolph, 2009).

Because of the multifaceted nature of the literature review, it is important that the scope and objectives are well-defined. Effective literature reviews should adhere to a number of criteria such as those outlined in Cooper's (1998, as cited in Randolph, 2009, p. 3) taxonomy of literature reviews and Boote and Beile's (2005) literature review scoring rubric. Criteria to consider are: the focus and goal of the review, the basis for document inclusion and exclusion, the timeframe reviewed, the sources of the material, and the perspective audience (Randolph, 2009). It is also important to acknowledge the implications of the Hawthorne and novelty effects when gathering and reviewing research studies (Franz, 2018; Hochberg et al., 2018). Research studies that attempt to minimise this, for example by using multi-method and multi-measurement research designs, were located when identifying sources (Franz, 2018). Similarly, publication bias can impact on the availability of studies that record no, or detrimental, effects of education interventions (Constantine, 2012). Therefore, articles that reported such outcomes were specifically included in the study.

There are many different forms of the literature review such as narrative, traditional, scoping, methodological and systematic (Baker, 2016; Grant & Booth, 2009; Onwuegbuzie & Frels, 2016). One particular type of narrative review, called a general literature review, is often used for the introduction to a dissertation (Onwuegbuzie & Frels, 2016). This type of review provides the means to analyse relevant and significant aspects of prior research carried out, and to identify the gaps that require further research. The general literature review form was used for the initial investigation into the research area of this project and guided the development of the research questions. The review of relevant literature continued throughout the period of research, and refinements of the articles to be used in the thesis were made along the way. This process resulted in a body of over 300 articles. At various junctures throughout the project, a methodical approach was required to examine the relevant literature. For example, when investigating the types of models and frameworks used to help evaluate the use of technology in education, it was essential to locate all relevant studies; hence a more systematic approach to the literature review was undertaken. Details of the scoping of the literature search and selection of articles are outlined in this chapter, where relevant. Further justification for the types of literature review used is contained in the research methods of Chapter 4.

The research reported on in this thesis is aimed at establishing how and in what way students engage with technology and the factors that influence their engagement, specifically students attending first-year undergraduate non-specialist mathematics modules. Three main inter-related areas of literature were identified that contribute to this research area. These are:

- Student engagement with technology in higher education (and mathematics)
- Technology in education and in mathematics in higher education: what works and what does not
- Evaluating technology use in higher education (and mathematics) and the use of frameworks and models

The outcomes of the literature review are presented in the following three sections of this chapter. In the section 2.5, the conclusions from the literature reviews are drawn together to form the research problem, objectives, and questions that are addressed in this thesis. The research framework which is used to address the research questions is considered in the final section.

2.2 Student engagement with technology in higher education (and mathematics)

Over the last twenty years, higher education institutions have increasingly focussed their attention on student engagement as an indicator of the quality of their educational offerings (Kuh, 2003; Trowler, 2010). This is unsurprising as many studies have shown that student engagement influences student success (M. Bond & Bedenlier, 2019; Fredricks et al., 2016; Henrie, Halverson, et al., 2015; Schindler et al., 2017; Sinatra et al., 2015; Trowler, 2010). In addition, the use of digital technologies has become more pervasive in society and in education (M. Bond & Bedenlier, 2019; Henderson et al., 2015; Schindler et al., 2017). Therefore, there is a growing interest in how the use of technology in higher education impacts on student engagement (M. Bond & Bedenlier, 2019; Coupland et al., 2016; O'Flaherty & Phillips, 2015; OECD, 2015; Schindler et al., 2017). However, specific research into student engagement and technology use is sparse: Schindler (2017) found no systematic reviews that considered the association between the two concepts. Many researchers have stated that studies in student engagement are difficult to identify because the construct of engagement is so loosely defined (M. Bond et al., 2020; Fredricks et al., 2004; Henrie, Halverson, et al., 2015; Kahu & Nelson, 2018). Further, Trowler (2010, p. 3) explained that studies investigating concepts such as student feedback and approaches to learning were in fact examining engagement, without having identified student engagement as a construct in their investigations.

As the main aim of this PhD research is to examine student engagement with technology, in this section of the literature review, studies that examine technology use (and explicitly refer to and define engagement) are reviewed. Studies into the use of technology in undergraduate mathematics education that do not reference engagement are examined in subsequent sections of this chapter. A general review of the literature was carried out to investigate existing research studies on student engagement with mathematics education technology. Databases, including Education Research Complete (ERC) and Web of Science, were used to locate articles using a number of key terms such as 'student engagement', 'technology', 'technology use', 'digital tools', 'higher education', 'undergraduate education', and 'mathematics'. Studies were selected for inclusion based on their relevance to the subject area of this research. Articles, generally peer-reviewed, that explored the concept, definition and measurement of student engagement, or that examined the effect of student engagement with technology, and had a focus on higher education and/or mathematics, were selected. In addition, seminal works were examined for further insights. There were over 45 articles identified that investigated student engagement with technology and 14 of those were related to mathematics learning. The following questions were formulated based on one of the aims of the thesis: why and in what way do students engage with technology to enhance their mathematics learning for first-year undergraduate mathematics modules?

- LRQ2.1: What is meant by student engagement with technology and why is it important?
- LRQ2.2: In what way(s) has student engagement with technology been measured?
- LRQ2.3: What are the factors of implementations that encourage/discourage student engagement with technology?

These questions were then used to examine the body of literature and are answered in the following three subsections.

2.2.1 LRQ2.1: What is meant by student engagement with technology and why is it important?

While many educational studies have reported on student engagement, there is no single definition of the term to be found in the literature. Despite this, there is general agreement in education research literature that the current understanding of the concept of student engagement stems from Astin's (1984) work on student development theory, and Fredricks et al., (2004) seminal paper on school engagement (Coates, 2007; Kahu, 2013; Schindler et al., 2017; Trowler, 2010). The study of Fredricks et al. (2004, p. 59) recognised that a focus on student engagement posed a remedy for the problem of poor academic motivation and success that was prevalent in schools in the USA. In their article, Fredricks et al. (2004) acknowledged the difficulty in synthesising research literature on student engagement:

Because there has been considerable research on how students behave, feel, and think, the attempt to conceptualize and examine portions of the literature under the label "engagement" is potentially problematic; it can result in a proliferation of constructs, definitions, and measures of concepts that differ slightly, thereby doing little to improve conceptual clarity (Fredricks et al., 2004, p. 60).

Nonetheless, they found that the literature was focussed on constructs which relate to one or other of three types of engagement: behavioural, emotional and cognitive. Some researchers refer to emotional engagement as affective engagement, with reference to the psychological approach to emotions (Kahu, 2013, p. 761). Fredricks et al. (2004) collated and discussed the following definitions from the literature:

- Behavioural engagement is generally defined in three ways; positive conduct (following rules and guidelines), involvement in learning tasks (effort, persistence), and participation in school related activities.
- Emotional engagement refers to students' affective responses in the classroom such as being bored, sad, anxious etc. but also students' sense of belonging.
- Cognitive engagement comes from an investment in learning and self-regulation, and being strategic when learning.

(Fredricks et al., 2004, pp. 62–63).

There have been a number of suggestions for further dimensions of engagement such as agentic and social engagement. Agentic engagement is described as students' positive input into how their instruction advances (Reeve & Tseng, 2011). Sinatra et al. (2015, p. 3) described agentic engagement as students' proactive involvement in their learning environment, whereas the other three engagement dimensions are reactions to the learning environment. The final dimension suggested, social engagement, takes into account the increasing role peer and collaborative learning have on education (Fredricks et al., 2016).

In higher education, student engagement has been examined by a number of key authors, many of whom go beyond a definition in terms of dimensions and take a more holistic view that includes engagement's antecedents and outcomes (Coates, 2005; Kahu, 2013; Kuh, 2003; O'Brien & Toms, 2010; Trowler, 2010; Zepke & Leach, 2010). The view that student engagement can be defined in terms of the interaction of influencing factors which produce a number of outcomes has gained a consensus in the literature (M. Bond et al., 2020; Fredricks et al., 2004; Henrie, Halverson, et al., 2015; Kahu, 2013; Trowler, 2010). Reflecting on the National Survey of Student Engagement (NSSE), implemented in universities and colleges in Canada and the USA, Kuh (2003, p. 25) defined engagement as:

'*the time and energy students devote to educationally sound activities inside and outside of the classroom, and the policies and practices that institutions use to induce students to take part in these activities*.'

Similarily, in the reviews of the literature on engagement and technology, authors have highlighted the lack of a definition of student engagment with technology (Bedenlier et al., 2020; Henrie, Halverson, et al., 2015; Schindler et al., 2017; Yang et al., 2018). In their review of the literature on student engagement in online environments, Yang et al. (2018) found that only 16 of the 40 studies contained a definition of engagement: these mainly referred to the Fredricks et al. (2004) definition. Many of the studies that examine technology and engagement refer to the early work of O'Brien and Toms (2008) on analysing user engagement in the context of using a number of web applications. Similar to the holistic view of educational engagement, O'Brien and Toms (2008) proposed that engagement is both a process and a product and that there are certain attributes of a system that influence a user's engagement with that system. This view is reflected in the definition of engagement, in the context of educational technology, given by Bond et al. (2020):

Student engagement is the energy and effort that students employ within their learning community, observable via any number of behavioural, cognitive or affective indicators across a continuum. It is shaped by a range of structural and internal influences, including the complex interplay of relationships, learning activities and the learning environment (M. Bond et al., 2020, p. 3)

In this context, it is within the learning activities and environment that the technology with which students engage resides.

The use of engagement as a window into mathematical learning is also growing (Fabian et al., 2018; Lake & Nardi, 2014; Oates et al., 2014; Pierce et al., 2007; Steen-Utheim & Foldnes, 2018; Trenholm et al., 2019). Many of the mathematics education research studies that can be classified as reporting on student engagement focus on cognitive engagement (Trenholm et al., 2019). One of the early studies on engagement in a mathematical classroom defined engagement as '*the deliberate task-specific thinking that a student undertakes while participating in a classroom activity'* (Helme & Clarke, 2001, p. 136). In their study on the effect recorded video lectures had on student engagement, Trenholm et al (2019) used Skilling et al's (2016, as cited in Trenholm et al., 2019, p. 6) definition of engagment: '*the extent to which students seek deep meaning and understanding as* *well as the cognitive strategies students use to self-regulate their learning'*. Pierce et al (2007) drew the three dimensions of engagement together to focus their attention on cognition while exploring early teenagers' engagement with a mathematical analysis tool. They examined how *'students feel about the subject (…affective engagement, AE) and how they behave in learning the subject (… behavioural engagement, BE)'* within a cognitive realm (Pierce et al., 2007, p. 292).

Students' views on what constitutes engagement have also being investigated (Hong-Meng Tai et al., 2019). Students mainly reported engagement in behavioural terms, though a few students referred to the cognitive aspects of engagement. A strong theme that emerged was the association of engagement with the importance of applying theory into practice: *'Engagement in learning is when you can take the theory and apply it in practice*' (Hong-Meng Tai et al., 2019, p. 1080).

Student engagement is important not least because it has been linked to academic success. Fredricks et al. (2004, pp. 70–71) claim that all three dimensions of engagement have been shown to impact on student success. In an extensive review of published research on engagement, Trowler (2010) refers to a number of studies that found that students' time and effort (or behavioural engagement) impact on their learning; and that *'observed effects of engagement'* include cognitive development, student satisfaction, and influence on student grade (Trowler, 2010, pp. 33–35). Schindler et al. (2017) concluded that the use of technology can impact student engagement, and emphasised the importance of the effective use of technologies. Henderson et al. (2015) suggested that a focus on student engagement can help find which digital technologies work best for students. Student patterns of engagement can be used to examine learning strategies '*that can be used to inform teaching practice, support interventions, and course learning design'* (Mirriahi et al., 2018, p. 59). Bond et al. (2020, p. 21) highlighted the importance of situating individual studies in an overall framework of engagement in order to be able to '*integrate research findings into practice'*.

Within mathematics education research, there is also evidence to suggest that student engagement and the use of technology impacts on learning (Fredricks et al., 2016; Helme & Clarke, 2001; Sinatra et al., 2015; Trenholm et al., 2019). Studies on the use of specific technologies in mathematics education have highlighted benefits of student engagement with technologies such as mobile apps (Fabian et al., 2018); innovative digital tools i.e. GeoGebra and Desmos (Thomas et al., 2017); tablets and screencasts (Galligan et al., 2015); flipped classroom (Steen-Utheim & Foldnes, 2018) and online environments (Kanwal, 2020). In addition, engagement in mathematics and science has been shown to foster long term participation in STEM (Fredricks et al., 2016, p. 5).

While there is a growing body of research available on the impact of technology on student engagement, there is a degree of uncertainty as to what is meant by student engagement with technology. Student engagement has been shown to be an important construct to measure as it impacts on student success. In the next section, student engagement measures used in research studies are examined, which will further illuminate the student engagement concept.

2.2.2 LRQ2.2: In what way(s) has student engagement with technology been measured?

The complexity around establishing a definition of student engagement means that measuring engagement varies considerably from study to study (Sinatra et al., 2015; Whitton & Moseley, 2014). According to Trowler (2010), the USA and Australia traditionally report on engagement from a different perspective than the UK. In the USA and Australia, research on engagement is often based on outcomes of large-scale student surveys, whereas in the UK, research is rooted in small-scale studies that examine the effects of particular tools, techniques and approaches used in teaching (Trowler, 2010, p. 3). These large-scale student surveys, such as the NSSE in the USA and Canada, are generally used to gauge a broad range of engagement indicators, consistent with the view on engagement held by many researchers: that the wider social and institutional interactions and experiences are important components of a holistic approach to engagement (M. Bond et al., 2020; Hong-Meng Tai et al., 2019; Kahu, 2013; Kahu & Nelson, 2018; Kuh, 2003; Trowler, 2010). Indeed, in their seminal work on the characterisation of the dimensions of student engagement, Fredricks et al. (2004) refer to both engagement antecedents, such as community culture and educational context (2004, p. 73), and outcomes of engagement, such as academic achievement (2004, p. 70).

As Trowler (2010, p. 17) said, '*studies tend to measure that which is measurable'*. Within the context of technological interventions, it is the impact on student engagement of use of technology within the learning environment that is often being measured (M. Bond et al., 2020). In order to understand what exactly is being measured, it is important to focus on how student engagement has been operationalised in research studies on engagement (Henrie, Halverson, et al., 2015). Henrie et al. (2015) and Schindler et al. (2017) analysed the literature they reviewed in terms of the behavioural, emotional and cognitive indicators of engagement as defined by Fredricks et al. (2004). Likewise, Bond and Bedenlier (2019, p. 3) drew up a table with engagement indicators for each of these dimensions in order to frame their model of student engagement with technology. Cognitive engagment indicators include aspects of students' beliefs about, and attitudes to, learning; behavioural engagement indicators encompass measures such as time and effort students spend on learning activities; and finally emotional indicators consist of students' perceptions of their happiness in relation to their learning and the support they receive towards learning (Henrie, Halverson, et al., 2015, p. 41). Both Henrie et al. (2015) and Bond and Bedenlier (2019) found that research studies focus mainly on behavioural aspects of engagement with only a few studies considering either affective (emotional) or cognitive engagement.

It has been suggested that the use of scales has been effective in measuring the emotional and cognitive effects of engagement that cannot be observed (Fredricks & McCloskey, 2012; Henrie, Halverson, et al., 2015). Henrie et al. (2015) found that over 60% of the articles they reviewed used a scale or questionnaire to elicit student or teacher perceptions of engagement. However, in line with the difficulty of having a single definition of student engagement, there were 14 different named scales identified in this Henrie et al. (2015) review. Scales that attempt to measure the broad concept of engagement were found as well as scales that measured a single dimension of engagement (Henrie, Halverson, et al., 2015, p. 45). One such scale that focusses on the emotional (or affective) impact of technology in the context of secondary school children's mathematical learning is the Mathematics and Technology Attitude Scale (MTAS) developed by Pierce et al. (2007). Likert scales draw on such indicators as discussed in the previous paragraph to help frame the items in the questionnaires (Coates, 2005; Fredricks et al., 2016; O'Brien & Toms, 2010; Pierce et al., 2007). For example, while investigating the use of innovative technologies in undergraduate mathematics, Thomas et al. (2017, p. 116) used engagement subscales that measured: '*attitude to maths ability; confidence with technology; attitude to instrumental genesis of technology (learning how to use it); attitude to learning mathematics with technology; and attitude to versatile use of technology'*.

Observational methods of estimating student engagement are also found in the literature and vary from notes taken by observers, to log data, video and screen recordings of students' use of the technology under investigation, number of posts made to messaging boards, and the time on task (Bulger et al., 2008; Henrie, Halverson, et al., 2015; Oates et al., 2014; Whitton & Moseley, 2014; Yang et al., 2018). The use of log data is generally facilitated through technologies that students use and is often used to measure behavioural engagement indicators such as: the number of clicks on a resource; activity data relating to multiple choice questions; system features used; and time on task (Beatson et al., 2019; Beer et al., 2010; Cruz-Benito et al., 2015; Henrie, Halverson, et al., 2015; Oates et al., 2014; Trenholm et al., 2019; Yang et al., 2018). When using observational data, engagement is often operationalised in terms of verbal utterances such as phrases 'I'm really into this' (Lake & Nardi, 2014, p. 50), or communication of thinking through questions and explanations (Helme & Clarke, 2001, p. 136). In the Thomas et al. (2017) study on the use of a variety of technologies offered to students, observational notes were used to identify which technology was in use, how it was being used and who within the group was using it. The advantage of such measures is that they report on engagement as it is happening rather than using self-report measures after the engagement has occurred (Henrie, Halverson, et al., 2015). Using computer-generated logs also mitigates against the effects of other observational types of measures that may impact on students' actual engagement (Whitton & Moseley, 2014, p. 441). However, one of the problems with the use of observational data is the lack of a clear connection between what is being observed and the resultant impact of student engagement inferred (Schindler et al., 2017; Sinatra et al., 2015).

Other measures of engagement identified by Henrie, Halverson et al. (2015, p. 44) include interviews, open-ended surveys, academic performance and the use of physical sensors. While many researchers argue that there is a direct link between engagement and academic performance, it is most often used along with other measures, such as rating scales and interviews (Al-Sakkaf et al., 2019; Beatson et al., 2019; Fabian et al., 2018; McMullen et al., 2015; Pardos et al., 2014; Trenholm et al., 2019). When examining students' use of mobile applications for mathematics, Fabian et al. (2018) used pre- and post-tests, a 20-item usability scale, and interviews. Interview data can be useful for inductive analysis, where the nature of student engagement is not predefined (Henrie, Halverson, et al., 2015, p. 46).

Some of the studies used clearly defined theoretical frameworks to investigate student engagement, such as the use of flow theory when considering gaming in education (Al-Sakkaf et al., 2019; Beatson et al., 2019; O'Brien & Toms, 2008, 2010; Whitton & Moseley, 2014; Yang et al., 2018), and instrumental orchestration to examine students' cognitive engagement with technology in first-year undergraduate mathematics modules (Oates et al., 2014; Thomas et al., 2017). In secondary mathematics education, Attard and Holmes (2020) focussed on the pedagogical practices of teachers in terms of their relationships with students and technology, and teachers' repertory of technological tasks when defining a Framework for Engagement with Mathematics (FEM). These types of frameworks are considered in more detail later in the chapter.

There are difficulties associated with measuring engagement, particularly with the lack of consistent definitions and indicators of engagement. Many educators use variables that are not necessarily true indictors of engagement, but perhaps influence engagement (Schindler et al., 2017, p. 5). In their paper on the challenges associated with measuring engagement in science, Sinatra et al. (2015, p. 7) highlighted the following challenges: construct definition, grain size of measurement, individual and developmental differences of students, problems with using a single method, the challenge of observing without disturbing the engagement, and problems pinpointing the source of engagement. They conclude that '*researchers should take care to ensure that construct definition drives their choice of measures rather than the selection of measurement determining how engagement is conceptualized in the research*' (Sinatra et al., 2015, p. 7).

Small-scale investigations on student engagement tend to examine factors such as students' and teachers' rating of a particular intervention being investigated (Trowler, 2010). To date, a number of factors of technology implementations that impact on this engagement have been found. These are discussed in the next section.

2.2.3 LRQ2.3: What are the factors of implementations that encourage/discourage student engagement with technology?

There are a number of models of student engagement that consider the factors that influence engagement, in the overall context of education, discussed in the literature. One of the most cited is Kahu (2013) which was more recently refined in Kahu and Nelson (2018). This model maps student engagement within a sociocultural context and contains three main elements: influencing factors; engagement dimensions and their indicators; and a number of short- and long-term outcomes. This model is reproduced in Figure 2.2.1 below (Kahu & Nelson, 2018, p. 64).

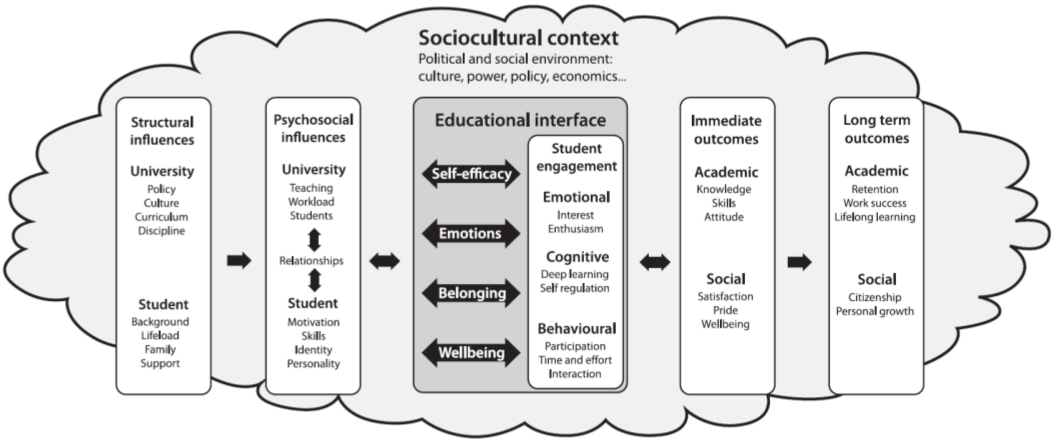


Figure 2.2.1: The refined conceptual framework of student engagement

Copied from Kahu and Nelson (2018, p. 64).

This so called triangle of engagement (influences, contexts and outcomes) s often found in research on student engagement (Yang et al., 2018), though not always as explicitly as in this model. This perspective is in line with the holistic view of engagement taken in the higher education sector (M. Bond et al., 2020; Henrie, Halverson, et al., 2015; Kahu, 2013; Trowler, 2010). In order to determine the influences and outcomes of technology on student engagement, Bond and Bedenlier (2019) drew on the work of Kahu (2013) and others to adapt the Bronfenbrenner and Ceci bioecological model (as cited in M. Bond & Bedenlier, 2019, p. 4). In this model, factors affecting student engagement are considered at a number of levels: the macrosystem level contains factors such as the digitisation of education through national policies; at the exosystem level, institutional factors on the use of technology in education are considered; the impact of students' social and economic background on engagement are contained in the mesosystem level; and finally, the microsystem level contains the more immediate influencing factors such as teachers, peers and educational technologies (M. Bond & Bedenlier, 2019). Bond and Bedenlier (2019) identified a number of the microsystem level influences, such as the individual students' and teachers' acceptance of, and skills in using, technology; the usability and design of the technology-enhanced activities within the curriculum; and the influence of factors such as technical support, usability of the technology and assessment on the learning environment. It is mainly at the microsystem level that the research in this PhD is focussed.

Many of the influencing factors outlined by Bond and Bedenlier (2019) have already been identified in a number of the studies on the use of technology to support student engagement in higher education (Cruz-Benito et al., 2015; Hong-Meng Tai et al., 2019; C. Lai et al., 2012; O'Flaherty & Phillips, 2015; Schindler et al., 2017; Yang et al., 2018) and in mathematics education (Anastasakis et al., 2017b; Coupland et al., 2016; Fabian et al., 2018; Kanwal, 2020; Steen-Utheim & Foldnes, 2018; Thomas et al., 2017; Trenholm et al., 2019). Table 2.2.1 outlines the factors that impact on student engagement as found in studies that are relevant to this PhD, i.e., undergraduate mathematics.

Table 2.2.1: Factors that influence engagement with educational technology in mathematics

Study	**Engagement Dimension and indicator measured**	**Pedagogical Use of technology**	**Factor and/or impact**
Trenholm et al. (2019)	Cognitive engagement: Scale to measure approach to learning (R-SPQ-2F)	Optional use of live versus recorded lectures.	Students used videos because of the self-paced nature of their availability. Students with a high use of the videos were more inclined to take a surface approach to learning than others.
Steen-Utheim and Foldnes (2018)	Affective Engagement: Kahu's (2013) model of student engagement	A flipped classroom approach in a first-year undergraduate mathematics course.	Peer and lecturer relationships, and possibly class size influenced a positive engagement outcome.

Kanwal (2020)	Behaviour engagement: Activity Theory	An automated system to support the solving of mathematical tasks, variety of technology resources including, GeoGebra, MyMathlab, YouTube and online calculators.	Exam preparation encouraged engagement. Using powerful automated calculators diverted students from engagement with the required mathematical operations.
Thomas et al. (2017)	Cognitive Engagement: Instrumental orchestration	Variety of innovative technologies and tasks including Desmos, GeoGebra, KakooTalk.	Engagement was ensured through the sustained intensive use of the technologies; teacher privileging of the technology; ease of use; the ability to visualise mathematics; and integration in assessment.
Anastasakis et al. (2017b)	Behaviour engagement: Activity Theory	Self-selected resources (both digital and non-digital) second year engineering mathematics.	A high mark in their exams was student goal for selecting and engaging in a resource.

The nature of self-paced learning, a focus on assessment, and teachers' use of the technologies are identified as factors that contribute towards student engagement. This view is somewhat consistent with the general mathematics education literature (Coupland et al., 2016; Kahu, 2013). The effective pedagogical use of technology, in the form of appropriate mathematical tasks, has been highlighted as a means to encourage cognitive engagement and develop mathematics learning (Attard & Holmes, 2020; Coupland et al., 2016; Fabian et al., 2018; Helme & Clarke, 2001). Helme and Clarke (2001) identified the following influencing factors on primary school students' cognitive engagement: the classroom environment, the individual, and the mathematical tasks.

In addition, Table 2.2.1 highlights the variety of measures and indicators used when considering student engagement with mathematics education technology.

While a number of factors that impact student engagement with technology within higher education mathematics have been identified, many of these are outcomes from small-scale studies that do not apply an overarching model of student engagement. In order to effectively use technology to support student engagement with mathematics in higher education, research studies need to be examined under a clearly-defined lens of student engagement (M. Bond & Bedenlier, 2019).

2.2.4 Discussion on student engagement

The importance of student engagement in higher education has been well researched and there are many models outlining the influencing factors on, and resultant outcomes of, engagement. Even though there is a lack of a single definition, and many studies do not necessarily give a definition of engagement, the literature tends to focus on the three dimensions of engagement as defined by Fredricks et al. (2004): cognitive, behavioural and emotional. While Bond et al. (2020) acknowledged that definitions may by necessity vary from one project to the next, they highlighted the importance of providing a definition. Within the body of literature on student engagement with technology, a variety of methods are used to measure engagement, such as questionnaires or scales, observations, interviews and logged data. Despite the fact that there has been theoretical consideration given to indicators of measure engagement (M. Bond & Bedenlier, 2019; Fredricks et al., 2004; Henrie, Halverson, et al., 2015), there is often a lack of a clear connection between the measures being used in the studies and engagement indicators (Schindler et al., 2017; Sinatra et al., 2015). Additionally, studies often focus on only one of the three engagement dimensions: cognitive, behavioural or emotional engagement. It has been shown that all three dimensions of student engagement are important as they each impact on student outcomes. It is important to identify these factors, as student engagement is ‘malleable’ and thus targeted ‘interventions’ can be used to increase engagement and hence learning (Fredricks et al., 2016, p. 5). By judiciously using technologies, lecturers can exercise some control over their students’ engagement (Steen-Utheim & Foldnes, 2018).

While factors that encourage student engagement have been identified through the use of models (Kahu & Nelson, 2018; Yang et al., 2018), those factors that influence engagement with technology are less evident (M. Bond & Bedenlier, 2019). To address this issue, Bond and Bedenlier (2019) defined a model that proposed the influencing factors of technology on student engagement. However, within mathematics education research, a limited number of small-scale studies were found that specifically investigated the intersection of engagement and technology: only five studies merited inclusion in Table 2.2.1. These studies identified factors that impact on engagement, such as the affordances of the technology, the pedagogy associated with the use of the tool, and the student's goal in using the technology.

One of the limitations of this section of the literature review is that the focus on the intersection of engagement and technology in undergraduate mathematics education yielded few studies. As indicated by Trowler (2010), there are many studies that investigate approaches to teaching and learning that are not flagged as engagement, but may in fact measure some of the indicators of engagement. In the next section, a review of the literature on the use of technology in higher education mathematics, particularly first-year undergraduate non-specialist mathematics is undertaken.

2.3 Technology in education and in mathematics in higher education: what works and what does not

The use of technology in education, and in mathematics education, has been on the increase over the last few decades. This has been evidenced by the volume of literature available that examines how, and to what effect, technology has been used in higher education (Conole & Alevizou, 2010; Englund et al., 2017; Henderson et al., 2015; L. Price & Kirkwood, 2011; Selwyn, 2011) and in mathematics education (Bray & Tangney, 2017; Buteau et al., 2010; Coupland et al., 2016; Oates, 2016;. Thomas et al., 2017). There are many who argue that the benefits of technology as a teaching and learning resource within higher education have not been fully investigated or exploited (Conole et al., 2008; Conole & Alevizou, 2010; Henderson et al., 2015; Oliver, 2011; Selwyn, 2012b). While evidence exists that technology enhances student learning (Henderson et al., 2015), and there is considerable research on students' experiences of using technology (Conole & Alevizou, 2010), it is not clear how technology should be implemented to achieve maximum benefit (Conole et al., 2008; Conole & Alevizou, 2010; Henderson et al., 2015). As mentioned previously, the effectiveness of using technology in both higher education and in mathematics education is under question (Bray & Tangney, 2017; Drijvers, 2019; Jarvis et al., 2018; Selwyn, 2010). A recent OECD report (2015) identified that an increase in the use of computers in mathematics in schools correlated negatively with student performance in mathematics. While this has been echoed in other studies (Coupland et al., 2016; Drijvers, 2018; Geiger et al., 2016), there are counterclaims. Research reported by Ronau et al. (2014) claimed that the use of digital calculators and computer software does improve student understanding (Drijvers, 2018).

In order to examine how technology has been used and evaluated in undergraduate mathematics education, a traditional literature review was carried out. In this case, the focus of the search was on 'mathematics educational technology' or 'mathematics technology tools', 'evaluations' and ‘investigations’, and ‘undergraduate’ or ‘higher education’. While there is a significant body of research available on the use of technology in school mathematics, there is a lack of such studies focussing on mathematics in higher education (Buteau et al., 2010; Lavicza, 2010). Thus, a body of literature relating to both secondary and higher education, mainly peer reviewed, was built up over the course of the PhD. In addition, seminal articles on technology use in higher education were consulted. This resulted in the review of 49 articles. One of the aims of this research is to establish the factors that influence successful integration of technology-enhanced resources. To address this aim, the following three research questions were used to examine this literature:

- LRQ2.4: What is meant by technology-enhanced resources in undergraduate mathematics education?
- LRQ2.5: What are the benefits of using technology-enhanced resources in first-year undergraduate mathematics modules?
- LRQ2.6: What factors of the technology-enhanced resource implementations impacted on the associated benefits?

These questions are discussed in the following three subsections.

2.3.1 LRQ2.4: What is meant by technology-enhanced resources in undergraduate mathematics education?

The terms technology-enhanced resources and technology-enhanced learning are ill-defined in the literature. King et al. (2014) highlight that authors use different terminology to refer to educational technology and thus it can be difficult to ensure that authors are discussing the same item. In a review of the higher education literature relating to the use of technology for teaching and learning, Kirkwood and Price (2014) examined the types of activities that were considered ‘enhanced’. They found that technology was used in three ways: to mirror existing teaching, to add to current teaching practice, and to alter the student learning experience and/or teaching practices (Kirkwood & Price, 2014, p. 11). These findings are similar to the benefits of technology-enhanced learning as outlined by the Higher Education Funding Council for England (HEFCE): efficiency, enhancement and transformation (HEFCE, 2009). In Ireland, the National Forum for the Enhancement of Teaching and Learning in Higher Education (NF) conducted a survey of higher education teachers’ use of technology to support their teaching activities (NF, 2015a). Participants in the survey rated that classroom management activities, or efficiency, were the most important functions of technology (NF, 2015a). For those who consider that the pedagogical use of technology has not been leveraged to its full in higher education, it is a cause for concern that the main perceived benefit of technology is to promote efficiencies (Bayne, 2014; Conole & Alevizou, 2010; Dimitriadis & Goodyear, 2013;

Selwyn, 2010).These educational researchers call on higher education teachers to carefully consider how technology can be integrated into educational activities so that the student learning experience is altered for the better. One way to support the effective pedagogical use of technology is to put an emphasis on the instructional design processes when integrating technology resources (Conole, 2013; Goodyear, 2015; Laurillard, 2012). Such instructional design principles incorporate many aspects of teaching and learning including the need to identify and the associated pedagogical practices to support students in achieving these objectives (M. Allen & Sites, 2012; Branch & Kopcha, 2014; Dousay, 2017, Goodyear, 2015).

While the use of the term “technology-enhanced resource” is also ill-defined in mathematics education research literature, there has been considerable research on how technology resources influence learning in mathematics education (Drijvers, 2015; Monaghan et al., 2016; Trenholm et al., 2015; Trgalová et al., 2018). In mathematics educational research, a resource is defined as a tool that helps bring about mathematical understanding, as it allows interaction between mathematical objects and human thinking (Trgalová et al., 2018, p. 2). This concept of a resource as a tool, often called instruments or artefacts, has long been discussed in the context of educational theories such as those put forward by Vygotsky and Leontiev (Anastasakis et al., 2017b; Kurz et al., 2005). The resultant work has been used in mathematics education research to develop theories on how these tools mediate learning, and thus enhance student understanding of mathematical concepts and enable new ways of working with and understanding mathematics (Jupri et al., 2016; Kurz et al., 2005; Monaghan et al., 2016; Ratnayake et al., 2016; Trgalová et al., 2018; Trouche & Drijvers, 2014). In addition, some individual studies have focussed on how learning efficiencies such as students working at their own time and pace, or on how students manage to take ownership of their learning, can be achieved using technology (Anastasakis et al., 2017b; Loch et al., 2012; Robinson et al., 2015; Trenholm et al., 2015, 2019; Triantafyllou et al., 2015). Finally, student satisfaction with using technology has been considered in terms of the use of technology to enhance the learning environment (S. O. King & Robinson, 2009b; J. Lee, 2014; Trenholm et al., 2012; Triantafyllou et al., 2015). Within the literature on the use of technology in mathematics education, technology-enhanced resources can therefore be described as technology tools that are used to enhance, or better, the mathematical understanding, learning experience and/or learning environment of students engaged in mathematics learning.

In the next section, the specific benefits of using technology in first-year undergraduate mathematics, as found in the literature, are examined.

2.3.2 LRQ2.5: What are the benefits of using technology-enhanced resources in first-year undergraduate mathematics modules?

The use of technology in mathematics education has been identified as a solution to some of the problems associated with students' levels of mathematical understanding (Bray & Tangney, 2017). The computational power, multiple visual respresentations and diverse ways for students to engage with mathematics have been cited as reasons for an increase in technology use (Bray & Tangney, 2017, p. 256). Educational researchers contend that the affordances of technology, defined as the prescribed, intended, or designed-for use, and possible use (Gibson, 1977; D. A. Norman, n.d.), need to be exploited for successful technology integration in education (Conole & Dyke, 2004; Oliver, 2013). However, educators argue that the term "affordance" should be used with caution, as it suggests that technology shapes learning without giving due respect to existing teaching and learning practices (Oliver, 2013; Selwyn, 2012b). According to Conole and Dyke (2004), technology affordances should include the prescribed, creative, and unintended, educational activities facilitated by technology. In the context of this thesis, technology affordances are taken to be the context-based pedagogical benefits that technology can bring to educational activities.

Many researchers in the field of mathematics discuss the uses and benefits of technology in terms of affordances (Ball et al., 2018; Borwein, 2005; Drijvers, 2016; Kanwal, 2020; Monaghan et al., 2016; Oates, 2010). There are two distinct affordances that technology can bring to mathematical tasks: '*pragmatic and epistemic*' (Artigue, 2002, p. 249). Technology brings pragmatic efficiencies by increasing the speed and accuracy of computations and epistemic value when they help advance students' understanding of mathematical concepts (Artigue, 2002, p. 248). These affordances have been evidenced in the literature on mathematics education technology in higher education (Galligan et al., 2015; Jarvis et al., 2018; S. O. King & Robinson, 2009b; Loch et al., 2014; Trenholm et al., 2012). In addition, many of these researchers have identified benefits that enhance students' mathematical learning, that do not necessarily fall under a pragmatic or an epistemic category, such as enhancing the student learning experience (Galligan et al., 2015; S. O. King & Robinson, 2009b; Trenholm et al., 2012). Table 2.3.1 contains a list of the benefits of using technology in mathematics education categorised under the headings of pragmatic, epistemic and other, as found in mathematics education research studies. The studies included in Table 2.3.1 were selected based on their relevance to the context of this research thesis. Three of the studies are literature reviews; two situated in higher education mathematics (Geiger et al., 2016; Trenholm et al., 2012); and one in general mathematics education (Rakes et al., 2010). The technology under investigation and the context is also given in the table. Some studies examined multiple benefits.

Table 2.3.1: Benefits of using technology in higher education

Cat.	**Benefits**	**Studies**	**Technology Used**	**Context**
Pragmatic	Calculations and graphing	Jarvis et al. (2018)	Sage	Higher Ed. maths
		Varavsky (2012, as cited in Geiger et al., 2016)	Computer Algebra System (CAS)	1st Year undergrad maths
		Thomas et al. (2017)	Multiple technologies	1st Year undergrad maths
Epistemic	Problem Solving	Loch et al. (2014)	Screencast	1st Year undergrad maths
		Takači et al. (2015)	Computer supported collaborative learning (CSCL)	1st Year undergrad maths
	Mathematical Understanding	Galligan et al. (2015)	Tablets	1st Year undergrad maths
		Takači et al. (2015)	CSCL	1st Year undergrad maths
		Triantafyllou et al. (2015)	Multiple technologies	1st Year undergrad maths
		Aventi (2014, as cited in Geiger et al., 2016)	GeoGebra	Year 9 maths (Australasia)
		Thomas et al. (2017)	Multiple technologies	1st Year undergrad maths
		Buteau et al. (2010)	CAS	Higher Ed. maths
	Rote Learning (negative)	Trenholm et al. (2012)	e-lectures	Higher Ed. maths
	Visualisation	Jarvis et al. (2018)	Sage	Higher Ed. maths
		Lavicza (2010)	CAS	Higher Ed. maths
		Takači et al. (2015)	GeoGebra	1st Year undergrad maths
		Jaworski and Matthews (2011)	GeoGebra	1st Year undergrad maths
		Thomas et al. (2017)	Multiple technologies	1st Year undergrad maths

Cat.	Benefits	Studies	Technology Used	Context
	Feedback	Trenholm et al. (Trenholm et al., 2015)	Fully Asynchronous Online (FAO)	Higher Ed. maths
		King and Robinson (2009b)	Audience Response Systems (ARS)	Higher Ed. maths
		J. Lee (2014)	Online quizzes	Higher Ed. maths
	Real World Problems	Jarvis et al. (2018)	Sage	Higher Ed. maths
		Lavicza (2010)	CAS	Higher Ed. maths
	Conceptual Understanding	Rakes et al. (2010)	Various strategies that included technology	Mathematics Education
	Procedural Understanding	Rakes et al. (2010)	Various strategies that included technology	Mathematics Education
Other	Engagement (motivation)	Loch et al. (2014)	Screencasts	1st Year undergrad maths
		Galligan et al. (2015)	Tablets	1st Year undergrad maths
		King and Robinson (2009b)	ARS	2nd year engineering maths
		Thomas et al. (2017)	Multiple technologies	1st Year undergrad maths
		Buteau et al. (2010)	CAS technologies	Higher Ed. maths
	Self-regulated learning, self-paced and self-directed learning	Loch et al. (2014)	Screencast	1st Year undergrad maths
		Trenholm et al. (2012)	Recorded Video lectures	Higher Ed. maths
		Jarvis et al. (2018)	Sage	Higher Ed. maths
		Triantafyllou et al. (2015)	Khan Academy and other online resources	1st Year undergrad maths
		Buteau et al. (2010)	CAS	Higher Ed. maths
		Howard et al. (2018)	Recorded Video lectures	1st Year undergrad maths

Cat.	Benefits	Studies	Technology Used	Context
		Kanwal (2020)	Online learning environment	1st Year undergrad maths
	Satisfaction	Trenholm et al. (2012)	Recorded Video lectures	Higher Ed. maths
		King and Robinson (2009b)	ARS	2nd year engineering maths
		Triantafyllou et al. (2015)	Khan Academy and other online resources	1st Year undergrad maths
		J. Lee (2014)	online learning technologies	Graduate students
	Classroom Management	S.O. King and Robinson (2009b)	ARS	2nd year engineering maths
	Assessment	Oates (2010)	CAS	Higher Ed. maths
	Approaches to learning	Trenholm et al. (2019)	Recorded video lectures	1st Year undergrad maths
		Howard et al. (2018)	Recorded video lectures	1st Year undergrad maths

Table 2.3.1 lists the benefits associated with using technology; however, many studies also reported negative aspects to technology integration. While the use of screencasts and e-lectures are liked by students, they were found to be associated with both rote and surface approaches to learning, with some evidence of a negative correlation with grades (Trenholm et al., 2012, 2019). The use of computer-generated feedback is also under question, as this needs to be carefully designed and integrated into the learning process so that students are obliged to engage with the feedback (J. Lee, 2014; Trenholm et al., 2015). Mathematical discourse is important for students when developing understanding in mathematics and has been found difficult to achieve in online learning environments (J. Lee, 2014; Trenholm et al., 2012). Finally, Jaworski & Matthews (2011, p. 183) found that any evidence of conceptual understanding gain by using GeoGebra was hard to quantify.

In the next section, the literature is examined to determine the factors that impact on the benefits or otherwise of the technology implementations discussed.

2.3.3 LRQ2.6: What factors of the technology-enhanced resource implementations impacted on the associated benefits?

In addition to measuring the benefits or otherwise of using technology in mathematics education, a number of studies investigated factors that impact on successful technology integration. Thomas et al. (2017) attributed the positive impact on students' mathematical understanding and their attitude to, and satisfaction with, the use of technology, to the significant pedagogical changes implemented as part of the study. These pedagogical changes included: teachers designed relevant digital tasks; tools were privileged by the teachers; students were allowed to self-select tools; technology afforded communication between teachers and students; and the use of the digital tools was explicitly linked to the continuous assessment of the modules (Thomas et al., 2017). "Teacher privileging" is a term used to describe the teacher's use and promotion of the tool, within a class setting, to guide and develop students' successful use of the tool (Thomas et al., 2017). Other studies, such as Jaworski & Matthews (2011) and Takači et al. (2015), were clearly embedded in similar significant pedagogical change, though the former questioned whether increased conceptual understanding had actually occurred. Collaborative or peer learning were specific pedagogical changes identified as factors in both the Thomas et al. (2017) and Takaci (2015) studies.

Other factors of success were focused on the technology affordances. For example, technologies like CAS can aid in the visualisation of mathematics, allow multiple representations of concepts and facilitate the automated completion of tasks (Buteau et al., 2010; Takači et al., 2015; Thomas et al., 2017). In addition, online quizzes, and other technological tools, have the ability to give immediate feedback (J. Lee, 2014).

Students reported technical, usability and access issues that prevented them using certain technologies (Galligan et al., 2015; Lavicza, 2010; J. Lee, 2014; Oates, 2010). For example, ease of use was a factor that contributed to students selecting Desmos technology over GeoGebra in the Thomas et al. (Thomas et al., 2017) study. While students often rated technology tools as novel, fun, or convenient, it was not always evident that these ratings influenced greater attendance, engagement or grades (Howard et al., 2018; Jaworski & Matthews, 2011; S. O. King & Robinson, 2009b; Loch et al., 2014; Trenholm et al., 2012).

Similar views are also expressed in a literature review on the use of CAS within higher education. Buteau et al. (2010, p. 61) identified both pedagogical and technical challenges as a barrier to successful CAS integration. In addition, students' educational background impacted on their successful use of CAS (Varavsky, 2012, as cited in Geiger et al., 2016, p. 17). While located in secondary education, Drijvers's (2015) study that examined the factors that supported success is pertinent. He found three such factors: design of the digital technology and the associated tasks and activities; the role of the teacher in synthesising the technology related and other mathematics learning activities; and the educational context.

2.3.4 Discussion from the literature on technology-enhanced resource use in mathematics education

There is appreciable discussion in the literature on what constitutes “enhanced” in terms of the use of technology in higher education and whether the benefits of using technology have been fully exploited (Bayne, 2014; Conole & Alevizou, 2010; Dimitriadis & Goodyear, 2013; M. King et al., 2014; Kirkwood & Price, 2014; Selwyn, 2010). It is also argued that the affordances, or context-based pedagogical benefits, of the technology need to be taken advantage of for successful technology integration (Artigue, 2002; Conole & Dyke, 2004; Oliver, 2013). These pedagogical benefits can be built into the technology resource integration through the use of effective instructional design processes (M. Allen & Sites, 2012; Branch & Kopcha, 2014; Dousay, 2017, Goodyear, 2015). In mathematics education, technology as a tool to mediate learning has been examined in some detail (Drijvers, 2015; Monaghan et al., 2016; Trenholm et al., 2015; Trgalová et al., 2018). There are a limited number of studies that consider enhancement in terms of student satisfaction and self-regulated learning (Anastasakis et al., 2017b; S. O. King & Robinson, 2009b; Loch et al., 2012; Trenholm et al., 2019; Triantafyllou et al., 2015). Benefits of using technology that were identified in the literature included: the epistemic benefits associated with mathematical understanding (Jarvis et al., 2018; Thomas et al., 2017), the pragmatic advantages of outsourcing computational activities (Lavicza, 2010; Takači et al., 2015; Triantafyllou et al., 2015) and other student-centred benefits such as self-regulated learning (Howard et al., 2018; Loch et al., 2014; Trenholm et al., 2019). While a number of factors such as the pedagogical changes implemented (Thomas et al., 2017) and the affordances of the technology (Buteau et al., 2010; Takači et al., 2015) were found to contribute to successful technology integrations, technical challenges and usability issues were identified as barriers (Oates, 2010;Thomas et al., 2017). In addition, some of the approaches to learning adopted by students as a result of technology integration do not appear to foster deep learning (Kanwal, 2020; Trenholm et al., 2019).

It is interesting to note that a number of these studies (see Table 2.3.1), which did not purport to examine student engagement with technology, considered engagement in terms of motivation or satisfaction (Galligan et al., 2015; S. O. King & Robinson, 2009b; Triantafyllou et al., 2015). However, it is not always clear whether the technology affordances or the change in pedagogical practices contributed to these benefits (Drijvers, 2018). Perhaps, as Trowler (2010) suggests, there is a need to establish if some of the indicators of student engagement were examined in these studies. To that end, the methods of evaluation used in the literature are examined in the next section.

2.4 Evaluating technology use in higher education (and mathematics) and the use of frameworks and models

Student engagement has been shown to positively influence student outcomes (M. Bond & Bedenlier, 2019; Fredricks et al., 2004), though the intersection of technology and student engagement has not been adequately investigated (M. Bond & Bedenlier, 2019; Henrie, Halverson, et al., 2015). Evidence exists of the benefits of using technology in small-scale studies (see Table 2.3.1). However, the use of technology at scale in first-year undergraduate mathematics remains problematic, in part due to the lack of studies that have demonstrated the benefits technology can bring to this particular student cohort (Thomas et al., 2017). While factors that contribute to the benefits of using technology have been identified in the previous section, it is not clear how student engagement with technology impacts on the success or otherwise of the implementations. This finding is consistent with the broader literature, where it has been identified that the intersection of student engagement and technology is under-researched (M. Bond & Bedenlier, 2019; Henrie, Halverson, et al., 2015). Added to this is the fact that studies use a variety of methodologies and frameworks to evaluate the integration of technology in education (Drijvers, 2018, 2015; M. King et al., 2014). Furthermore, Coupland et al. (2016) have called for more empirical evidence on the benefits of using technology, as much of the current literature focusses on students' and lecturers' views. They recognise that it is essential to investigate the affordances of technology in terms of student learning, retention and transfer of knowledge, rather than just descriptions and evaluations (Coupland et al., 2016). M. King et al. (2014) have pointed to the need for frameworks of evaluation that can be used to consistently and comparatively examine how technologies have been successfully integrated into education.

Thus, there are two issues to consider here. The first is whether student engagement indicators are used as measures of success in the mathematics education technology literature. To establish this, the studies listed in Table 2.3.1 are further explored to determine the methods of evaluation and the indicators used to measure success. Secondly, further examination of the literature is required to establish what frameworks or models are currently used in describing and evaluating technology integration in mathematics and higher education.

The literature review completed in the previous section was extended to include terms such as 'frameworks', 'models', 'categorisations', 'characterisations', 'typologies' and 'classifications.' In this case a more systematic approach was taken to the literature review in order to ensure that all models and frameworks were captured (Littell & Corcoran, 2010). This body of literature and those listed in Table 2.3.1 were examined to address the research objective of investigating how the effectiveness of resources has been evaluated. The following three research questions were formulated and discussed in the three subsections below.

- LRQ2.7: How have the uses of technology-enhanced resources been measured?
- LRQ2.8: What models or frameworks are available to classify and evaluate technology-enhanced resource implementations?
- LRQ2.9: What features of technology integrations are described/classified within these models and frameworks?

2.4.1 LRQ2.7: How have the uses of technology-enhanced resources been measured?

One of the aims of publishing research on the use of technology in mathematics education is to inform the mathematics education community about practices that have proven effective, so that they can be mirrored in similar contexts (McKnight et al., 2000). In order to ensure a proven intervention can be scaled, it is important to establish what indicators of success have been used, and how they have been measured. In this section studies that focus on the use of technology within undergraduate mathematics are investigated to establish what indicators of engagement, if any, have already been examined in the literature. With this in mind, the studies referenced in Table 2.3.1 are further explored to establish the indicators that were used to measure the benefits of the technologies.

The methodologies and validity varied from study to study. For example, Galligan et al. (2015) completed an exploratory study of the integration of technology in first-year undergraduate mathematics, with little detail on how the data was examined and analysed. On the other hand, Jarvis et al. (2018) used a case study approach to examine the use of Sage within a mathematics course, and used a thematic approach to analysing interviews. Most of the studies reported, or have evidenced, the use of a mixed methods approach, as can be seen in Table 2.4.1, where the different measures for the studies are listed.

Table 2.4.1: Measures taken in the studies

Measure	**Study**
Student and/or teacher views of resources through use of surveys, scales or questionnaires	Jaworski and Matthews (2011), King and Robinson (2009), J. Lee (2014), Lavicza (2010), Loch et al. (2012), Oates (2010), Thiel et al. (2008), Thomas et

	al. (2017), Trenholm et al. (2015,2019), Triantafyllou et al. (2015), Howard et al. (2018).
Test, exam or quiz results for improved students’ mathematical understanding	Jaworski and Matthews (2011), King and Robinson (2009), Loch et al. (2012), Takači et al. (2015), Howard et al. (2018).
Recorded usage of resources	Loch et al. (2012), Trenholm et al. (2019), Howard et al. (2018).
Attendance data	King and Robinson (2009), Howard et al. (2018).
Course artefacts and/or curriculum materials	Jarvis et al. (2018), Lavicza (2010), Thomas et al. (2017).
Student and/or teacher interviews	Jarvis et al. (2018), Jaworski and Matthews (2011), King and Robinson (2009), Lavicza (2010).
Teacher practices, reflections and/or blogs	Galligan et al. (2015), Jaworski and Matthews (2011), King and Robinson (2009).
Class observations	Jaworski and Matthews (2011), King and Robinson (2009), Lavicza (2010), Thomas et al. (2017).
Task analysis	Takači et al. (2015), Thomas et al. (2017).
Scale to measure approach to learning (scale used is R-SPQ-2F)	Trenholm et al. (2015, 2019).
Case Study	Drijvers (2015).

For many of the studies, it is not always clear what indicators were used to measure success. While Trenholm et al. (Trenholm et al., 2015, 2019) used proven scales within their surveys, the development of the questions used in surveys was not always evident (Jaworski & Matthews, 2011; Lavicza, 2010; Triantafyllou et al., 2015), though in some cases, there was a clear link to the literature reviewed (S. O. King & Robinson, 2009b; J. Lee, 2014; Loch et al., 2014). When class observations were used, it was not necessarily clear how the data was interpreted in terms of success or otherwise (Jaworski & Matthews, 2011; S. O. King & Robinson, 2009b).

A number of these measures may also be used to examine student engagement. For example, attendance data and recorded usage of the resources can be used to measure behavioural engagement indicators. Further examination of the inferences made about the recorded use of lectures in the Trenholm et al. (2019) study was that it was used to consider approaches to learning (or cognitive engagement). In contrast, the recorded lecture data used in the Howard et al. (2018) study was used to determine students’ perceived value of self-regulated learning (or affective engagement). Class observations and student interviews may be analysed for indicators of engagement. For example, the S.O. King and Robinson (2009b) study recorded students as saying the ARS technology was fun (associated with affective engagement); however, they did not examine the impact this had on student engagement. Due to the diversity of the inferences made from the same named measures, and the lack of connection between indicators and student engagement benefits, it is difficult to examine if these studies can contribute to our knowledge on student engagement with technology.

Drijvers (2015) suggested that theoretical frameworks are required in order to understand the role of digital technology in mathematics education. Such frameworks can support the evaluation and scaling of technology interventions. Few of the studies explicitly situated their research within theoretical frameworks, but those that did are listed in Table 2.4.2, along with the framework used.

Table 2.4.2. Theoretical Frameworks used in the studies

Theory	**Study**
Community of Inquiry (CoI) and documental genesis	Jaworski and Matthews (2011)
Computer Supported Collaborative Learning (CSCL)	Takači et al. (2015)
Laurillard conversational framework	S.O. King and Robinson (2009b)
Conceptual model of affective and cognitive effects of human and design factors	Piccoli, et al. (2001, as cited in J. Lee, 2014)
Instrumental orchestration	Thomas et al. (2017)
Taxonomy for integrated technology (author's own version from PhD thesis)	Oates (2010)

In conclusion, it is evident that there is little consistency in the design of research studies on the use of technology in undergraduate mathematics. Hence, it may be difficult to compare the outcomes and come to an understanding of what exactly should be measured. Therefore, it may not always be clear if the technologies can be scaled to be used in different contexts (Drijvers, 2015). One way to overcome this is to have frameworks of evaluation that can be used to compare and contrast technology evaluations.

2.4.2 LRQ2.8: What models or frameworks are available to classify and evaluate technology-enhanced resource implementations?

There are a number of issues with the evaluation of technology-enhanced resources within higher education. Amongst these are: the difficulties associated with evaluating this rapidly changing environment, the institutional requirement for cost-effective teaching enhancements, and the lack of appropriate evaluation models or frameworks (Brown et al., 2014; M. King et al., 2014). The importance of frameworks suited for evaluation have been identified by a number of researchers in the field of higher education (Dimitriadis & Goodyear, 2013; M. King et al., 2014; J. Lai & Bower, 2019; Oliver, 2013; Selwyn, 2012b) and in mathematics education (Drijvers, 2015; Geiger et al., 2016). There are a number of elements of technology integration that need to be considered by these types of frameworks. Firstly, studies should incorporate the types of pedagogy or didactical practices that have been used to integrate technology (Drijvers, 2018). Secondly, there needs to be a focus on the types of constructs being measured (J. Lai & Bower, 2019). Thirdly, the context of the study needs to be taken into account, such as the level of education and student attributes (Drijvers, 2018; J. Lai & Bower, 2019). Finally, the affordances of the technology being used need to be made explicit (Ball et al., 2018; Drijvers, 2016; Kanwal, 2020; Monaghan et al., 2016; Oates, 2010). The essential outcome of any evaluation is to establish and explain what technology works under '*which conditions, for whom and why'* (M. King et al., 2014).

A considerable number of models, frameworks, categorisations and typologies were found in the literature on the evaluation or integration of technology in education. For simplicity, these will be generically referred to as frameworks in this section, although the term used by authors will be adhered to when discussing specific frameworks. In this literature review on technology education, four loosely aligned groups of frameworks emerged:

- Technology integration - these frameworks refer to how technology is integrated into teaching and learning.
- Theoretical frameworks – these are used to examine how learning occurs using technology.
- Technology affordances and types – these frameworks categorise different technologies according to functionality or affordances the technology supports.
- User experience frameworks – these refer to how technology is examined from the user, or student in this case, perspective.

A list of the frameworks examined are contained in Table 2.4.3, along with a brief description and/or purpose and an article or website describing their use.

Table 2.4.3: Frameworks used in the integration and evaluation of technology

Group	Framework	Description/Purpose	Study or website
Technology integration	Substitution Augmentation Modification & Redefinition (SAMR)	Model that describes 4 levels of technology integration in tasks	http://hippasus.com/resources/tte/ Puentedura (2006)
	Formative Assessment in Science & Mathematics Education (FaSMEd)*	Characterisation of aspects of classroom integration of formative assessment technology tools	https://microsites.ncl.ac.uk/fasmedtoolkit/theory-for-fa/the-fasmed-framework/ FaSMEd (2020a)
	Technology Acceptance Model (TAM)	Theorises usage behaviour of technology	https://en.wikipedia.org/wiki/Technology_acceptance_model Buchanan et al. (2013) Nikou and Economides (2017) Rabaa'I et al. (2015)
	Technological pedagogical content knowledge (TPACK)***	Framework that considers intersection of teachers' knowledge on technology, pedagogy and content is key to successful technology integration	Mishra and Koehler (2006)
	Classification system* (Bray and Tangney**)	Classification system with 4 components: Technology, Learning Theory, SAMR level, Purpose	Bray and Tangney (2017)
	3E (Enhance, Extend, Empower) Framework	Guidance & examples to exploit technology to enhance, extend, empower teaching & learning	https://3eeducation.org/3e-framework/
	eLearning theoretical framework	eLearning systems theory framework that draws out roles of people, technology and services in learning provision	Aparicio et al. (2016)
	Laurillard Conversational Framework	Framework describes interactions and types of activities that occur between teachers and students for effective learning	King and Robinson (2009b) Laurillard (2013)

	Unified theory of acceptance and use of technology (UTUAT)	Alternative to TAM – 4 key factors in accepting technology: performance expectancy, effort expectancy, social influence, and facilitating conditions	Venkatesh et al. (2016)
	4C (Connection, Communication, Collaboration, Creating) Framework	Framework to organise technology use in higher education	Brown et al. (2014)
Theoretical Frameworks	Instrumental Orchestration*	Converting digital tools into artefacts, connecting technical skills and conceptual understanding required	Artigue (2002) Kieran and Drijvers (2016) Lopes and Costa (2019) Thomas et al. (2017)
	Didactic Tetrahedron*	Examining digital tool use as interactions between (1) tools and knowledge, (2) tools, knowledge and learner, and integration of (3) tools in curriculum or classroom	Trgalová et al. (2018)
	Mathematical Proficiency*	5 strands of mathematical proficiency required to learn maths successfully	National Research Coucil (2001)
	Pedagogical Opportunities*	10 pedagogical opportunities grouped into 3 levels: task that has been set, classroom interaction, maths topic	Pierce and Stacey (2010)
	Didactical Functions*	3 didactical functions supported by technology: (1) Do, (2) Learn – Practice Skills, and (3) Learn-concepts	Drijvers (2015)
Technology Affordances and Types	Mobile App Categorisation* (Handal**)	Categorises use of mobile apps for schools based on instructional roles and media richness as: Productive, Explorative and Instructive. Uses Goodwin's classification – see below	Handal et al. (2011)
	Web 2 typology (Bower**)	Typology of web 2 tools suitable for teaching and learning; includes what they have been used for, their pedagogical uses and examples	Bower (2016, p. 772)

	Evaluation Grid for multimedia tools (Abderrahim, Mohamed and Azeddine**)	Checklist to ascertain quality of multimedia tools, in terms of pedagogical, didactical and technical quality. Derived from tools used in secondary education in Morocco	Abderrahim et al. (2013)
	Classification of Mobile Apps (Goodwin**)	Precursor to Handal's categorisation mainly concerned with users' level of control over tasks and activities, for school-based apps: Instructive, Manipulative, and Constructive	Goodwin (2012, p. 26)
	Typology of mobile apps (Pechenkina**)	Typology of mobile apps used in higher education institutions in Australia by order of most used types: Organiser, Navigator and Instructive	Pechenkina (2017, pp. 139–140)
	Categories of digital tools* (Hoyles and Noss**)	4 categories of tools: (1) dynamic and graphical tools, (2) tools that outsource processing power, (3) new representational infrastructures, and (4) implications of high- bandwidth connectivity on nature of maths activity	Hoyles and Noss (2009)
	Experimental mathematician* (Borwein**)	Use or affordances of a computer in mathematics, focussing on mathematical proofs	Borwein (2005)
User Experience	User Experience Honeycomb	7 attributes of technology deemed desirable to enhance student experience of using technology	Morville (2016)
	Universal Design for Learning (UDL)	Framework used to provide a fully inclusive learning environment for all students. 3 main elements: Engagement, Representation, and Action & Expression, where multiple means to achieve these should be considered	Center for Applied Special Technology (CAST) (2018)
	Online Course Design Learning Checklist (OCDLC)	Before, during and after checklist, with 3, 6 and 10 items respectively, for online courses in higher education	Baldwin and Ching (2019)
	Student-Owned Learning-Engagement (SOLE) model	Theoretical Framework on eLearning systems that has 3 dimensions: users, technology, and services	Atkinson (2011)

	FEM Framework for Engagement in Mathematics (FEM) *	3 aspects: Pedagogical Relationships (between students and teachers), Pedagogical Repertoires (teacher day-to-day teaching practices), and Student Engagement (factors that support engagement)	Attard and Holmes (2020)

** Indicates framework designed specifically for mathematics education studies.*

*** Where framework does not have associated distinguishable name, author(s) have been included with name.*

****This framework was originally called TPCK by Mishra and Koehler (2006) but is now commonly referred to as TPACK.*

In addition to those listed in Table 2.4.3, more generalised frameworks were found that encompass a number of aspects of evaluations and integration (Aparicio et al., 2016; Kirkpatrick & Kirkpatrick, 2006; Pickering & Joynes, 2016; Rodríguez et al., 2012). For example, Pickering et al. (2016) proposed an holistic model of technology enhanced learning TEL evaluation based on the Kirkpatrick model, one of the most cited models used in the evaluation of training. This model focusses on learner satisfaction, learner gains, and learner and institutional impact, with a view to establishing a cost-benefit analysis (Pickering & Joynes, 2016, p. 1244). In their literature review on how technology use is evaluated in education, J. Lai and Bower (2019) suggested that education researchers should use the classifications they developed to better focus the design of educational technology research. Firstly, researchers can reflect on which aspects of evaluation and its associated construct they intend to investigate, and then select their methodology from the methods and instruments that have already been similarly used (J. Lai & Bower, 2019, p. 38). Secondly, they proposed that a generalised model for technology evaluation could be developed based on the themes and subconstructs they identified (J. Lai & Bower, 2019, p. 38).

As can be seen from Table 2.4.3, the frameworks vary in which aspects of technology integration and evaluation are characterised. In the next section, the different features categorised by the most relevant frameworks will be considered in more detail.

2.4.3 LRQ2.9: What features of technology integrations are described/classified within these models and frameworks?

In this section, the frameworks in Table 2.4.3 will be examined in more detail in order to elicit which features of technology integration have been classified. Those that came from mathematics education will be discussed first and this will be followed by an examination of other relevant frameworks.

2.4.3.1 Mathematics Specific Frameworks

Pedagogical Opportunities

Pierce and Stacey examined the use of technology in mathematics education in terms of the pedagogical opportunities that can be supported by the affordances of Mathematical Analysis Software (MAS) (Pierce & Stacey, 2010). In their pedagogical map, they identified three levels where educational transformation can be enacted by the teacher: mathematical tasks; classroom dynamics and didactical contract; and the subject area, such as mathematical thinking or applications (Pierce & Stacey, 2010, p. 6). The didactical contract is the set of implicit or explicit responsibilities and commitments that the teacher and student agree to use within the learning environment (Gueudet & Pepin, 2018). Geiger et al. (2016) used these three areas to classify the studies they examined in a critical synthesis of research on mathematics educational technology in Australasia. While the pedagogical map was useful, they pointed to areas where it needed to be extended, such as the inclusion of other technology types. Drijvers (2015) referred to the benefit of the pedagogical map as a way to define the educational context and mathematical practices of a technology intervention, which are important in determining the success of a technology intervention.

Didactical Functions

Drijvers (2015) defined pedagogical functionality in terms of didactical functions (Drijvers, 2015, p. 136). In the Drijvers' (2015) model, there are three main didactical functions that are supported by technology: (1) Do: the functionality related to doing mathematics, where work that could be done by hand is completed by the technology; (2) Learn – practice skills: the functionality provided to practice skills; and (3) Learn – concepts: the functionality that supports the development of conceptual understanding (Drijvers, 2015, p. 136). Drijvers uses this framework to position the pedagogical use of technology in the studies he subsequently examines.

Instrumental Orchestration

Instrumental orchestration is a term that is used to describe how a teacher orchestrates the use of a digital tool. It stems from Artigue's work (2002) on an instrumental approach to using digital tools in mathematics where the technological and conceptual affordances of the tools are exploited to foster mathematical understanding. This theoretical framework has been used in mathematics education research in order to investigate and compare students' mathematics learning using different technologies and settings (Jupri et al., 2016; Kieran & Drijvers, 2016; Thomas et al., 2017).

Didactic Tetrahedron

The Congress of the European Society for Research in Mathematics Education (CERME) group adopted a didactic tetrahedron, inspired by Tall (1986, as cited in Trgalová et al., 2018, p. 1), to examine the interactions between teachers, students, knowledge, and tools (resources and technology) (Trgalová et al., 2018, p. 2). See Figure 2.4.1 Cognitive processes are described by the interactions between the technology or resource, knowledge and the learner (student). The learning theories enacted in the classroom are described by the teacher's integration of the technology or resource in the classroom and the associated knowledge interactions.

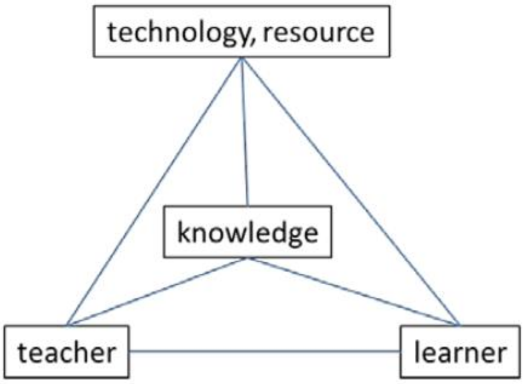


Figure 2.4.1: Didactical Tetrahedron

Copied from Trgalová (2018, p. 2)

Categories of tools (Hoyles & Noss, 2009)

Hoyles and Noss (2009) identified four categories of tools '*that distinguish different ways that digital tools have the potential to shape mathematical cognition*' (Hoyles & Noss, 2009). First are dynamic and graphical tools that allow students explore mathematical representations from different perspectives. Secondly, outsourcing processing power allows a machine to take over processing that would previously have been done by the student. Third are tools that enable the creation of new mathematical representations and symbols. The final category are tools that allow connectivity and the ability to share mathematics within the community. This framework has since been modified and extended to include newly available digital tools and influenced Bray and Tangney's (2017, p. 259) work on classifying technology mathematics research studies.

Classification System of research studies (Bray & Tangney, 2017)

Bray and Tangney (2017) classified the current literature on mathematics education technology in order to give an overview of the field and enable a comparative analysis of the interventions. The studies were classified into four components described below: (Bray & Tangney, 2017, fig. 4).

- Technology which describes the type of technology in use. They used a refinement of the Hoyles and Noss (2009, as cited in Bray & Tangney, 2017, p. 261) categorisation of tools (described above) which also took into account the types of technology use observed in the literature review. There were seven final classifications within the technology type.
- Learning Theory. Studies were classified according to whether they adopted a Behaviourist, Cognitive, Constructivist, Social Constructivist, or Constructionist teaching and learning approach.
- Technology Adoption. They used the SAMR model to describe how technology is integrated, because it pertains to the level of technology adoption specific to tasks and activities. This model will be discussed in more detail below.
- Purpose. Each of the studies was classified based on the aim of the study: for example, to change students' mathematical attitude, improve performance or engender collaboration and discussion.

In their analysis of these studies, Bray and Tangney (2017, p. 270) conclude that while tools are increasingly being used to enable visualisations, and to promote collaborative problem-solving, they are not yet transforming the student learning experience.

Formative assessment in Science and Mathematics Education (FaSMEd)

The FaSMEd project team developed a theoretical framework to characterise aspects of the classroom use of formative assessment technology tools they developed for post-primary education (FaSMEd, 2020a). The FaSMEd framework consists of three interrelated dimensions developed from the relevant literature and the teams' educational experience. The three dimensions are:

- Agents (student, peers, teacher) that intervene in formative assessment processes in the classroom and that can activate formative assessment strategies.
- Strategies for formative assessment activated by the agents, based on the work of Wiliam and Thompson (2008).
- Functionalities of technology within the formative assessment processes: Sending and Displaying; Processing and Analysing; and Providing an Interactive Environment
- (FaSMEd, 2020a).

Mobile Apps Classifications (Handal et al., 2011)

Handal et al. (2011) examined over a hundred mathematics educational apps while developing a framework for categorising mobile applications. The apps were initially categorised into nine types based on their instructional roles and subsequently clustered into three broad classifications:

explorative, productive and instructive (Handal et al., 2011). Explorative apps allow simulations and guided discovery; productive apps enable the student to construct content such as graphs; and instructive apps are generally focussed on drill and practice. These classifications are a modified form of the Goodwin pedagogical classification of tablet apps (Handal et al., 2011). Handal et al. (2011) added the concept of media richness to describe the ability of the app to provide a '*high level of problem solving and low prescription'*. Each of the three classifications can have a lower, in-between, or higher level of media richness. For example, Guided-Discovery-type apps which allow '*exploration and experimentation within a pre-determined framework'* are Explorative with a high level of media richness; thus allowing the student a high level of control over the task in hand and requiring a high cognitive investment (Handal et al., 2011).

Framework for Engagement in Mathematics (FEM) (Attard & Holmes, 2020)

Attard and Holmes (2020) examined how exemplary mathematics teachers take advantage of the affordances of educational technology through the lens of the FEM. According to Attard and Holmes (2020), there are two main factors that encourage student engagement: pedagogical relationships and pedagogical repertoires. They define pedagogical relationships as the educational relationships between students and teachers that support engagement and pedagogical repertories as the routine educational practices used by the teacher (Attard & Holmes, 2020, p. 2). This framework outlines a number of elements, such as determining students' backgrounds and the use of student-centred technology, needed to achieve the required pedagogical relationship and repertories that encourage student engagement with the technology provided (Attard & Holmes, 2020, p. 3). These elements were based on the practices of exemplary teachers' use of technology, and Attard and Holmes (2020, p. 10) conclude that technology used in this way can engage students with mathematics.

2.4.3.2 General frameworks of relevance

A number of the other frameworks listed in Table 2.4.3 have been used to investigate technology integration in higher education and in mathematics education. The SAMR and TPACK models are described below because of the frequency with which they appear in the mathematics education technology literature. Due to their increasing relevance in educational technology, user experience models and the universal design for learning framework are also described. Furthermore aspects of user experience that are traditionally seen in the context of software should be incorporated into the of the instructional design process design (Adnan & Ritzhaupt, 2018; Svihla, 2018) and support the effective integration of technology into education (Conole, 2013; Laurillard, 2012).

Substitution Augmentation Modification Redefinition (SAMR) model (Puentedura, 2006)

The SAMR model is used to characterise how technology tools are adopted into existing education environments, either through the enhancement or transformation of teaching and learning processes or activities. This model, Figure 2.4.2, depicts a hierarchical structure of two broad levels, each with two subcategories (Bray & Tangney, 2017, p. 260). The lowest level of integration is to substitute existing activities without making functional changes, followed by augmentation where the technology tools are used to augment existing activities and make functional improvements. At the transformative level, the tasks are either significantly modified through task redesign or the technology allows the redefinition of tasks that enable activities that were previously unavailable.

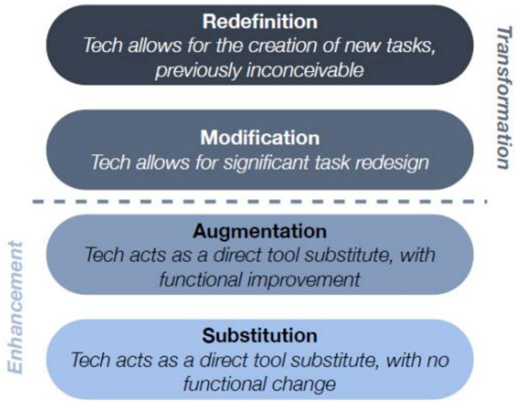


Figure 2.4.2: SAMR model for technology integration in education

Copied from Puentedura (2010, p. slide 3)

Bray and Tangney (2017, p. 269) classified mathematics education technology using the SAMR model and found that the majority of tool use fell under the augmentation part of the SAMR model, suggesting that classroom practices are not utilising the affordances of the technologies so that they can transform practice.

Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006)

Mishra and Koehler (2006) drew on their experiences working in higher education to develop a framework that captured the knowledge required by teachers to effectively integrate technology. This framework, TPACK, has been widely used and/or referred to in research on the integration of technology in mathematics education (Drijvers et al., 2014; Handal et al., 2012; Oates, 2016; Trgalová et al., 2018). The framework highlights the connections between the content, pedagogical, and technological knowledge required by teachers for successful integration of technology in teaching. Mishra and Koehler (2006, pp. 1019–1020) used the framework in three ways: (1) to investigate teacher knowledge with a view to enhancing it, (2) to apply a pedagogical approach of learning by design to help teachers achieve TPACK, and (3) to guide research and analysis on the effectiveness of pedagogy associated with technology integration. They conclude that the TPACK framework can help describe, make inferences, and inform, how to apply practices of technology enhanced education.

SAMR versus TPACK

In a case study, located in a school context, teachers were asked to reflect on their use of technology from both the SAMR model and TPACK framework perspectives (Hilton, 2016). They discussed TPACK in terms of technology integration throughout the year whereas they reflected on individual activities when discussing SAMR (Hilton, 2016, p. 71). Hilton (2016, p. 72) suggested that the SAMR model is more focussed on student-centred activities whereas TPACK is more aligned with teacher-centred design. TPACK has become popular amongst researchers whereas SAMR is more popular amongst practitioners (Kimmons & Hall, 2018, p. 29).

User Experience Models

In the studies examined in section 2.3, there is a lack of focus on the usability of the educational technology as experienced by the students. While many of the studies explored teacher and student views, there are only a few that specifically reference a measure for usability (Fabian et al., 2018; Galligan et al., 2015; S. O. King & Robinson, 2009b). It has long been recognised that the usability of educational software needs to be investigated in the context of its use, as opposed to the software as a standalone product (Reeves et al., 2002; Squires & Preece, 1999). Recent investigations by Slade and Downer (2020), reveal the importance of the user experience for students when using ePortfolios. Many of the early usability techniques used checklists and rubrics, but these have been proven to be problematic (Squires & Preece, 1999, p. 471). One way to overcome problems with checklists is with the use of heuristic evaluations: '*Heuristic evaluation is done by experts (in this case, expert teachers) using a set of guidelines, known as 'heuristics'* (Squires & Preece, 1999, p. 468). The notion of heuristic evaluation was first introduced by Molich and Nielsen (1990), with the associated usability guidelines available on the Nielson Norman group website (J.Nielsen, 2020). Squires & Preece (1999, p. 479) combined these heuristics with the notion of learnability of educational technology to produce a set of 'learning with software' heuristics. Reeves et al. (2002) also used the Nielsen guidelines to define a set of 15 heuristics for eLearning.

More recently JISC, the UK digital education organisation, combined the notions of usability and user experience to map out the attributes of educational technology that influence a positive user experience (JISC, 2015). This framework is based on Morville's honeycomb, see Figure 2.4.3.

Figure 2.4.3: Morville’s Honeycomb

*Copied from (*https://www.jisc.ac.uk/guides/usability-and-user-experience*)*

Universal Design for Learning (UDL)

Dimensions such as accessibility and findability have become increasingly important in education and are reflected in the Universal Design for Learning (UDL) framework as described by Meyer et al. (2014), part of the Centre for Applied Special Technology (CAST) project in the USA (CAST, 2018). The principles associated with UDL account for the ways in which the different users’ access and use technology. For example, they include the provision of audio files to support learners that are visually impaired. The UDL guidelines (Rose & Meyer, 2002), suggest there should be multiple means of:

- Representation, to give learners various ways of acquiring information and knowledge;
- Expression, to provide learners alternatives for demonstrating what they know; and
- Engagement to tap into learners' interests, challenge them appropriately, and motivate them to learn.

There is limited research on how the use of the UDL framework has impacted on student engagement with technology. One such study, however, reported that the deliberate design of a first-year undergraduate science module using multiple means of representation, expression and engagement, resulted in a more positive experience for the teacher, despite an increased workload (Kumar & Wideman, 2014, p. 137). In addition, students were positive about the increase in control of their learning and in the sense of social presence achieved (Kumar & Wideman, 2014, p. 138).

2.4.4 Discussion on evaluations and frameworks/models in higher education

An examination of the research methods used in the mathematics educational technology literature has revealed that most studies used mixed methods. A variety of measuring instruments were used such as scales, interviews and class observations. Indicators of success included students’ grades, students’ and lecturers’ views on the resources, and the analysis of curriculum materials (See Table 2.4.1). While data with respect to behavioural engagement was gathered, it was not always analysed in terms of student engagement (Howard et al., 2018; S. O. King & Robinson, 2009b; Trenholm et al., 2019). Thus, it is difficult to establish the factors of technology implementations that impact on student engagement. While the use of frameworks of evaluation are recommended in order to allow the scaling of implementations, there was limited use of such frameworks found in the literature (Drijvers, 2015; M. King et al., 2014).

There are considerable challenges associated with evaluating technology integration (Brown et al., 2014; M. King et al., 2014). The use of frameworks of evaluation can help overcome these challenges (Drijvers, 2015; Geiger et al., 2016). Four main categories of framework were found in the literature on educational technology in higher education: technology integration; theoretical frameworks; technology affordances and types; and user experience frameworks. The focus on mathematical understanding in the literature on educational technology in mathematics education is also reflected in the number of frameworks that describe how mathematical learning is achieved using technology as a tool (Artigue, 2002; Trgalová et al., 2018) and how the pedagogical affordances of technology can be leveraged (Drijvers, 2015; Handal et al., 2011; Hoyles & Noss, 2009; Pierce & Stacey, 2010). Both the Bray and Tangney's (2017) system of classification and the FaSMEd framework (2020a) encompass a number of aspects of technology use such as the type of technology, the learning theory used and the level of technology integration. None of the mathematical frameworks considered usability or user experience, which is increasingly recognised as a factor in student engagement (Hong-Meng Tai et al., 2019; O'Flaherty & Phillips, 2015), and has been identified as a factor in the success of technology integration in mathematics education (Fabian et al., 2018; Galligan et al., 2015; Lavicza, 2010; J. Lee, 2014; Oates, 2010). While there were a number of frameworks that claimed to describe all aspects of technology education in general (Aparicio et al., 2016; Pickering & Joynes, 2016; Rodríguez et al., 2012), no holistic framework for technology integration was found in the mathematics education literature.

2.5 Conclusion on the literature review

Student engagement has been shown to be an important construct due to its impact on student success (Fredricks et al., 2016; Helme & Clarke, 2001; Sinatra et al., 2015; Trenholm et al., 2019). Additionally, there is an increasing use of holistic frameworks to examine both the influencing factors and resultant outcomes of student engagement, within the students' sociocultural context (M. Bond & Bedenlier, 2019; Kahu & Nelson, 2018). While there is a growing body of research available on the impact of technology on student engagement, there is a degree of uncertainty as to what is meant by student engagement with technology and how it should be measured (M. Bond et al., 2020; Henrie, Halverson, et al., 2015; Schindler et al., 2017). In addition, this literature review found a dearth of studies in undergraduate mathematics education that specifically focus on student engagement with technology. Although factors relating to the pedagogical integration of technology have been identified in mathematics education literature (Drijvers, 2019; Galligan et al., 2015; Thomas et al., 2017), there are few studies that examine technology use from the perspective of the student or student engagement. Those that do are mainly concerned with students' goals (Anastasakis et al., 2017b; Kanwal, 2020) and do not necessarily consider the impact of the usability and design of the technology on student engagement, factors that have been highlighted in the general education literature (M. Bond & Bedenlier, 2019). In order to effectively use technology to support student engagement within higher education, research studies need to be examined under a clearly-defined lens of student engagement (M. Bond & Bedenlier, 2019). This research need is addressed within this thesis, where a clearly defined lens of student engagement (see Section 2.6.1 below) will be used to explore student engagement with technology in the context of undergraduate non-specialist mathematics modules.

Few studies on education technology define technology-enhanced resources; however, it is clear from the mathematics literature that such resources can be described as technology tools that are used to enhance, or improve, the mathematical understanding, learning experience and/or learning environment of students engaged in mathematics learning (Anastasakis et al., 2017b; Jupri et al., 2016; Ratnayake et al., 2016; Triantafyllou et al., 2015). In mathematics education, considerable work has gone into examining the use of technology as a tool to enhance mathematical understanding (Drijvers, 2015; Monaghan et al., 2016; Trenholm et al., 2015; Trgalová et al., 2018). Other, more pragmatic benefits have been explored to a lesser extent (Lavicza, 2010; Takači et al., 2015; Triantafyllou et al., 2015). While indicators associated with student engagement were measured, it is not clear how pedagogical changes rather than technology use affected engagement. Only a limited number of studies considered student satisfaction with, and motivations to use, mathematics education technology (Howard et al., 2018; S. O. King & Robinson, 2009b; J. Lee, 2014; Trenholm et al., 2019; Triantafyllou et al., 2015). While satisfaction and motivation are clearly linked to engagement (Fredricks et al., 2004), it is not clear what factors impact on student engagement with mathematics education technology. Bond and Bedenlier (2019) identified a number of the micro-layer influences on student engagement with technology, such as: the individual student and teacher acceptance of, and skills in using, technology; the design of the technology-enhanced activities within the curriculum; and the influence of factors such as technical support, usability of the technology and the assessment on the learning environment. In order to examine student engagement with technology in mathematics education, research needs to focus on establishing if these or other factors influence student engagement with technology.

This research need has been identified as the first issue that this research study will address (see Section 2.5.1 below)

Factors that contribute to the success of technology integration in mathematics education were identified, such as the need for significant pedagogical change and the student's technical skill in using technology (Drijvers, 2015; Thomas et al., 2017). The pedagogical challenges associated with integrating technology require careful consideration, and teachers need support to successfully use technology in mathematics education (Buteau et al., 2010; Drijvers et al., 2013; Mishra & Koehler, 2006; Monaghan et al., 2016). One way to overcome these challenges is to have frameworks available to guide teachers with the integration and evaluation of technology (Drijvers et al., 2013; Lopes & Costa, 2019; Mishra & Koehler, 2006). There are many frameworks found in the mathematics literature that describe various aspect of technology integration, such as those that describe the types of technology in use, how learning is mediated using technology and how technology can be integrated into tasks or settings – see Table 2.4.3. However, there is no overarching framework that describes both the pedagogical aspects and the educational context of technology integration. Thus, this is the second issue that this research study will address (see Section 2.5.1 below)

2.5.1 Research Problem

Two issues have emerged from this literature review, as outlined in the previous section. First of all, it is important to establish the factors that affect student engagement with technology, due its impact on student success. While few studies in the use of technology-enhanced resources in undergraduate non-specialist mathematics courses have investigated how students engage with mathematics educational technology, evaluations have identified some of the pedagogical features and technology affordances that impact on the success of technology implementations. However, studies have not focussed on determining which factors of the technology integrations encourage students to engage with the resources to support their learning. In this study a clearly defined lens of student engagement will be applied to the evaluation of technology use. The second issue is that evaluations have revealed a number of challenges to successful technology integration, such as the technical skills and pedagogical changes required. One way to overcome these challenges is to use frameworks of technology evaluation that include aspects of the pedagogical, technical and educational context of technology implementations. These frameworks can then be used to guide teachers in the successful integration of technology. No such framework was found in the literature.

2.5.1.1 Research aims

The aim of this research is to explore why, and in what way, first-year undergraduate students engage with selected technology-enhanced resources to support their learning of mathematics for non-specialist mathematics modules and to determine what factors of the learning environment impact on this engagement.

Research Objectives based on this aim:

1. To review the current literature on the use of technology-enhanced resources by first-year undergraduate students in supporting their mathematics learning.
2. To investigate how the effectiveness of such resources has been evaluated.
3. To evaluate the effect the learning environment has on students' engagement with selected technology-enhanced resources.
4. To develop a research-based evaluation framework that can be used by practitioners to determine the effectiveness of technology-enhanced resources that they develop for their students.

2.5.1.2 Research Questions

Three research questions have been identified to address the aims and objectives of this PhD study. The first two research questions are used to examine student engagement with lecturer-developed technology-enhanced resources. The third research question relates to the evaluation of technology-enhanced resources. The three research questions are listed below:

RQ1: What are the key factors of technology-enhanced resources and their implementations that influence students' engagement with these resources?

RQ2: What are the key pedagogical features of technology-enhanced resource implementations that impact on student engagement with these resources?

RQ3: How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?

In the next section the research framework that is used to address these questions is discussed.

2.6 Research framework

The selection of a research framework for a particular study depends both on the ontological (nature of being) and epistemological (nature of knowledge) outlooks that are embedded in the study (Cohen et al., 2007). Ontological positions in educational research are used to define the phenomena under investigation and epistemological perspectives help shape the methods of generating knowledge for the study (Farrow et al., 2020). In addition, a researcher's own viewpoint, or value system, impacts on how the research is conducted and interpreted (Farrow et al., 2020; Lincoln & Guba, 1985). These three elements, ontology, epistemology and axiology (one's own value system), form the theoretical foundations of the research paradigm adopted for a study (Farrow et al., 2020). Different research paradigms may be used in different branches of research, and a number of distinct paradigms are evident in educational research (Farrow et al., 2020; Lincoln & Guba, 2000). Positivism and interpretivism have been the two most commonly used paradigms (Lincoln & Guba, 2000), though more recently post-positivism, critical and pragmatic approaches, which build on these two, are often applied (Farrow et al., 2020; Kivunja & Kuyini, 2017).

- **Positivism:** A positivist approach to research generally relies on using empirical evidence to arrive at a truth. By gathering quantitative data about our experiences of the world, one can analyse and classify them to describe a fact about the world. Positivists aim to find a hard fact, which is one of the downsides of this approach when used in the social sciences. Gathering data about human experiences in this manner is difficult (Farrow et al., 2020).
- **Post-positivism:** While still valuing an objective truth, post-positivists recognise that human experiences are influenced by individual and societal values and backgrounds. Mixed methods and triangulation of both qualitative and quantitative data are often used in a post-positivist approach (Farrow et al., 2020).
- **Interpretivism:** Interpretivists, on the other hand, regard certain aspects of human experiences, such as emotions, values, and social and cultural influences, as factors that cannot be measured objectively. The researcher derives an understanding of the phenomena through interpreting the subject's viewpoint. Qualitative methods are employed for this approach, where the findings rely on the different perspectives of the subjects (Farrow et al., 2020; Kivunja & Kuyini, 2017; Lincoln & Guba, 2000).
- **Critical:** In a critical perspective, the researcher does not remain neutral in the research, the outcomes aim to transform a social phenomenon. There are certain methodologies specifically developed to support this critical paradigm, such as action research and field research (Farrow et al., 2020).
- **Pragmatic:** Pragmatic approaches are aimed at establishing what works. Pragmatists are not centrally focussed on establishing one truth, but more on solving a real-world problem. This method can be used to assess and remodel educational activities. Research

methods are chosen expediently to match the requirements of the project (Duram, 2012; Farrow et al., 2020; Weaver, 2018).

It is important to reflect on one’s own position within the context of the research and to determine what values and experience one brings to the study (Agee et al., 2013; Morrison, 2007). This research is situated in a higher education context, specifically involving a student cohort who are enrolled in non-specialist mathematics modules. While this cohort of students self-select support resources (Anastasakis et al., 2016; Ní Shé et al., 2016), there is little known about how they engage with technology. It is also apparent that, in order to leverage the affordances of technology effectively in mathematics education, frameworks of evaluation are required (Conole & Alevizou, 2010; Drijvers, 2015; M. King et al., 2014). The value system that I bring to this research is based upon my experiences as a higher education tutor working with students who have traditionally struggled with mathematics. In addition, I have been actively involved in supporting lecturers in higher education to take advantage of technology affordances to enhance their teaching. While recognising elements of interpretivism in the research undertaken regarding student engagement with technology, a pragmatic and somewhat positivist approach was taken to determining the factors that need to be included in an evaluation framework. Pragmatism involves solving a problem (Farrow et al., 2020); in this case how to effectively evaluate technology in mathematics education. However values, past experiences and the sociocultural environment impact on the students’ motivations and actions in relation to using technology and, thus, are best researched through an interpretivist framework (Farrow et al., 2020). Hence, this research takes a pragmatic approach to developing a framework for evaluating technology use in mathematics education and an interpretivist one for understanding how students engage with technology.

2.6.1 Research Definitions

While the initial research area of interest will inform the research paradigm and ensuing methodologies (Cohen et al., 2007; Farrow et al., 2020), the topic under investigation, engagement, must also be defined (Farrow et al., 2020). The methodological considerations are contained in Chapter 4, the definition of engagement that used in this thesis is outlined below.

2.6.2 Definition of engagement for my thesis

From an ontological viewpoint, it is important to have a definition of a phenomenon before one examines it (Farrow et al., 2020, p. 10). Indeed, Bond and Bedenlier (2019) assert that, due to the varied definitions of engagement found in the literature, and the difficulty in measuring all aspects of engagement, it is important to define what is meant by engagement at the start of the research study.

The definition and framework of engagement taken for this study is founded on the literature review, as outlined in Chapter 2. It is broadly based on the widely-used definitions discussed by Fredericks et al. (2004), with a focus on technology, and relies on the work of both Kahu and Nelson (Kahu, 2013; Kahu & Nelson, 2018) and Bond and Bedenlier (2019). The three dimensions and their associated influencing factors are defined immediately below. This is followed by a discussion of the engagement framework used in the study.

Behavioural

- concerned with students' actions in relation to using technology, such as: use/non-use; duration they used it; or effort in trying to use it.
- factors influencing this behaviour such as: recommendation by lecturer; required in class; or in assessment.

Affective *

- concerned with students' emotions prior to or as a result of using the technology, such as: satisfaction; annoyance; confusion; or frustration.
- factors that influence this emotion: ease of use; aligned with own or course objectives; or familiarity.

Cognitive

- concerned with students' learning from using the technology, such as: developing understanding; or achieving competence in methods.
- factors that influence this include: behavioural and affective engagement; being positive; or tasks within the technology being designed to achieve this cognition.

*Note that the term 'affective' was chosen rather than 'emotional' as it is more commonly used in higher education literature.

The use of the Fredericks et al. (2004) definition for this study is justified in that mathematics educators have also used this definition. For example, Attard (2012, p. 10) said that engagement manifests through a person's thoughts, behaviours, and actions which is a reflection of the Fredericks et al. (2004, p. 60) notion of engagement as how students 'behave, feel and think'. Attard (2012) considers that engagement and motivation are interlinked in such a way that when a student is engaged in mathematics, they have been influenced by motivational factors and vice versa. These factors of influence are reflected in conceptual frameworks of engagement which are discussed below.

One of the most quoted holistic frameworks of student engagement, which includes both the antecedents (or influences) and consequences of engagement, was proposed by Kahu (2013). In this framework, student engagement is framed within a sociocultural context with both structural and psychological factors influencing engagement (Kahu, 2013). Subsequent student engagement is manifested in either short-term and/or long-term consequences. In a refinement of the framework, Kahu and Nelson (2018) added the notion of students transitioning to higher education and included an educational interface in their model. They also moved from the term 'consequences' to 'outcomes' of student engagement, which reflects the wider higher education focus on student outcomes. This latter model is depicted in Figure 2.6.1 below.

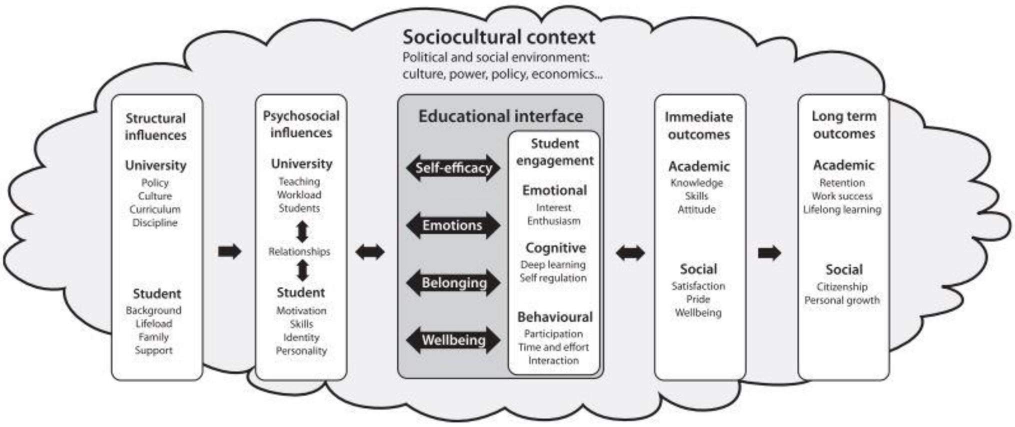


Figure 2.6.1: Refined conceptual framework of student engagement

Developed by Kahu and Nelson (2018) and copied from Kahu and Nelson (2018, p. 64)

While Kahu and Nelson's (2018) framework is useful, it lacks a focus on technology. Attard and Holmes (2020) explored student engagement with mathematics technology in primary and secondary education and utilised a Framework for Engagement with Mathematics (FEM). This framework focusses on the pedagogical relationships between teachers, students, technology and content, and the pedagogical repertories of the teachers (Attard & Holmes, 2020, p. 3). However, the focus is on teachers and pedagogy in secondary education rather than on students in higher education. The most relevant framework of student engagement with technology in higher education that was found, in the literature, is the biological student engagement framework proposed by Bond and Bedenlier (2019). They used the work of Kahu and Nelson (2018) along with a review of the relevant literature to propose a framework that operates at a number of levels: macro, exo, meso and micro (M. Bond & Bedenlier, 2019, p. 3). It is at the microsystem level that this PhD study resides. The microsystem level is concerned with the relationships between the student, peers, teacher and content, and the interactions with technology (M. Bond & Bedenlier, 2019, p. 5). Their model of the factors that influence student engagement with technology is shown in Figure 2.6.2.

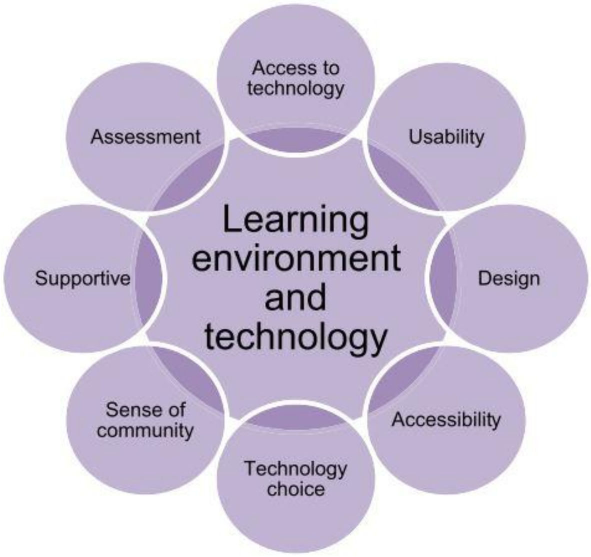


Figure 2.6.2: Learning environment and technology influences on student engagement

Copied from Bond and Bedenlier (2019, p.5)

Bond and Bedenlier (2019, p. 3) mapped out a list of engagement indicators for each of the three recognised dimensions of engagement. These indicators are measurable manifestations of engagement actions and reactions (M. Bond & Bedenlier, 2019, p. 3). In addition, Lai and Bower (J. Lai & Bower, 2019, p. 33) compiled a list of the indicators, or subconstructs, used to evaluate technology engagement in education as found in a literature review across all levels of education. While recognising that these are not exhaustive lists, they have been be used as a reference in the analysis later in the thesis.

2.6.3 Addressing the research questions

RQ1 and RQ2, as outlined in Section 2.5.1.2, were investigated using the evaluations of the technology-enhanced resources developed as part of the NF-funded project and the review of relevant literature. The outcomes of RQ1 and RQ2 were used to address RQ3 and develop a framework for practitioners to evaluate the effectiveness of their implementations of technology-enhanced resources. This framework was then tested within the context of a specific technology-enhanced resource implementation in a first-year engineering mathematics module. The context of the NF-funded project will be discussed in Chapter 3.

Chapter 3 The National Forum funded project

3.1 Introduction to the National Forum funded project

The need for research on student engagement with mathematics educational technology, and for effective means of evaluating the use of such technologies, was established in Chapter 2. The initial impetus for this PhD research was in a National Forum for the Enhancement of Teaching and Learning in higher education in Ireland (NF) funded project: 'Assessment for Learning Resources for First-Year Undergraduate Mathematics Modules' (NF, n.d.-b). The resources developed for this project were aimed at addressing a widely-reported problem: that first-year undergraduate students in Ireland are under-prepared for the non-specialist mathematics modules they encounter (Faulkner et al., 2010; Gill & O'Donoghue, 2007a). Technology-enhanced formative assessment techniques were used to design and build a number of support resources that were then made available to selected first-year undergraduate students attending non-specialist mathematics modules. As part of the project, the resources were evaluated and then modified before they were made generally available on the project website (NF, n.d.-d). It was within the evaluations of these resources that the work in this PhD began. The initial evaluations revealed the importance of a number of factors that impacted on student engagement with the resources. In an attempt to classify these factors, it became apparent that no framework currently existed that encompassed all of the factors. Thus, the research focussed on the development of such a framework. In addition, interviews with students revealed that their engagement with technology was a complex issue. Following a review of the literature, it was evident that students' engagement with technology-enhanced resources in first-year undergraduate non-specialist mathematics modules had not been fully explored. Hence, the research was refined to focus on factors that impact student engagement with technology-enhanced resources and widened to include the development of an evaluation framework that practitioners can use to support their planning and evaluation of such resources. The purpose of Chapter 3 is to explain the context in which the project resources were developed. The chapter contains five sections as follows:

- The first section contains an overview of higher education and the NF in Ireland.
- The background and rationale for the NF-funded project are given in the second section.
- In the third section, the project objective and the role of this researcher within the project are described.
- Details of the different NF-funded resources are outlined in the fourth section.
- The final section contains the particulars relating to the NF-funded resource implementations.

3.2 Higher Education in Ireland

In order to situate the student cohort who partook in this research project, a brief description of higher education in Ireland is given in the first subsection below. This is followed by an overview of the functions of the NF.

3.2.1 Universities and Institutes of Technology

Prior to 2019, undergraduate education in Ireland was mainly provided by two types of institutes: Universities and Institutes of Technology (IoTs). Traditionally they play distinct roles in undergraduate education in Ireland, with IoTs mainly providing certification at Higher Certificate level, Ordinary degree and Honours degree, while Universities focus mainly on Honours and postgraduate degrees (DES, 2005). IoTs tend to have a greater percentage of mature students (students over the age of 23), part-time students and students from disadvantaged areas than Universities (O'Sullivan et al., 2015). In 2015, at the time the project was funded, there were 21 Higher Education Institutes (HEIs) in the Republic of Ireland: seven universities and 14 IoTs. In addition, there are a number of private colleges, some of whom receive public funds towards primary undergraduate education. In 2018, the Irish government enacted legislation for the provision of Technological Universities envisioned to occur mainly through the amalgamation of existing IoTs (Higher Education Authority, n.d.).

Access to higher education in Ireland is via a centralised application system that allocates places based on entry requirements and a student score, called "points", calculated from six subjects taken at Leaving Certificate (CAO, n.d.). The Leaving Certificate is the terminal post-primary state examination in Ireland and is taken by 96% of the student cohort at the end of a five or six-year secondary school programme (O'Sullivan et al., 2015, n. 1). Entry requirements and points obtained tend to be lower for the IoTs than the universities (DES, 2011). Almost all students study mathematics at leaving certificate although they can opt for three different levels in the mathematics examination: Higher, Ordinary and Foundation Level with Higher Level (HL) being the highest rated in terms of level of subject matter covered and difficulty (Faulkner et al., 2010, p. 77). There are more points allocated to HL grades than Ordinary Level (OL). Students who take Foundation Level (FL) mathematics generally do not have direct entry into higher education (CAO, n.d.; Faulkner et al., 2010). Between 2010 and 2015, a new mathematics curriculum was gradually introduced in post-primary education in Ireland. "Project Maths" places a greater emphasis on mathematical understanding, real word applications and encourages greater problem solving skills (DES, 2011). In tandem with its implementation, students who take HL mathematics now receive bonus points towards entry into higher education (CAO, n.d.). Entry requirements in mathematics for access to higher education depend both on the HEI and the student's course of choice (CAO, n.d.) .

3.3 The National Forum for the Enhancement of Teaching and Learning in Higher Education in Ireland

The NF is the Irish national body with responsibility for promoting and leading teaching and learning policies and initiatives in higher education (NF, n.d.-a). The Department of Education and Skills (DES) has highlighted the significance of a positive first-year student experience: *'failure to address the challenges encountered by students in their first year contributes to high drop-out and failure rates, with personal and system-wide implications*' (DES, 2011, p. 56). The NF selected 'Teaching for Transitions' as their first enhancement theme. They identified the '*need to integrate approaches to building digital capacity across the sector'* as one of the principles of their roadmap for enhancement in a digital world (NF, 2015b, n. vii). In line with these policies, they funded a number of cross-sectoral research projects that aimed to support digital innovation and collaboration across 25 HEIs (NF, n.d.-c). A subset of these research projects focussed on learning more about how students' transitions can be supported with digital resources. The Assessment for Learning Resources for First Year Undergraduate Mathematics Modules, which was the starting point for this PhD, was one of these NF Projects. The overarching aim of the project was the development of digital formative-assessment techniques to improve the teaching and learning experience of first-year undergraduate non-specialist mathematics modules (NF, n.d.-b). Details of this project are outlined in the next section.

3.4 The Assessment for Learning Resources for First Year Undergraduate Mathematics Modules project

This NF-funded project was kick-started in 2015 and had a two-year duration. Its focus was on those students attending non-specialist mathematics modules, sometimes referred to as service mathematics (Faulkner et al., 2011). Service mathematics, practiced worldwide in higher education, is defined as '*mathematics as taught to non-mathematics specialists and students studying science, engineering, and other technical subjects'* (Artigue et al., 2007). The students involved in this project were attending either Engineering, Computer Science, Business or Science degree programmes. The prior mathematics required for these courses varies across programme and institution.

The resources developed for this NF-funded project were aimed at addressing a widely-reported problem: that first-year undergraduate students in Ireland are under-prepared for the non-specialist mathematics modules they encounter (Faulkner et al., 2010, 2014; Gill & O'Donoghue, 2007b). This has been found to impact on their ability to successfully complete their first year at higher education (Liston et al., 2018), which has consequences for the targets for higher education set out by the Department of Education and Skills (DES, 2011). The lack of basic mathematical skills on entering higher education, and the resultant impact on progression and retention, has also been identified in an international context (J. Allen et al., 2008; Galligan et al., 2015; Liu & Whitford, 2011; Loughlin et al., 2015; OECD, 2015; Trenholm et al., 2019; Wang, 2009). As a consequence, Mathematics Learning Support Centres (MLSCs) have been put in place in a large number of higher education institutes, across Europe, Australia and the USA (Ahmed et al., 2018; Cronin et al., 2016; Grove et al., 2020; Lawson et al., 2012; Mac an Bhaird et al., 2011; MacGillivray, 2009; Mills et al., 2020; Rylands & Shearman, 2015; Schürmann et al., 2020). Lecturers have also sought to address this issue through the provision of technology-enhanced resources (Coupland et al., 2016; Kay & Kletskin, 2012; Loch et al., 2012; Mac an Bhaird et al., 2020; Trenholm et al., 2019). In addition, students attending first-year undergraduate mathematics modules self-select and use technology-enhanced support resources such as YouTube videos, Khan Academy and Wolfram Alpha to support their mathematics learning (Anastasakis et al., 2017a; Kanwal, 2020; Ní Shé et al., 2017b).

As a cross-sectoral project, this NF-funded project had members from two universities, Maynooth University (MU) and Dublin City University (DCU) and two IoTs, Dundalk Institute of Technology (DkIT) and Athlone Institute of Technology (AIT). Dr Ann O'Shea, from MU, was the project lead. The members of the project team, along with the main roles they had, are shown in Table 3.4.1 below.

Table 3.4.1: Assessment for Learning Resources for First Year Undergraduate Modules

Team Members	**Institution**	**Discipline**	**Main role (s) within the project**
Dr. Ann O'Shea	MU	Mathematics	Project Lead and co-developed interactive tasks using GeoGebra.
Dr. Ciarán Mac an Bhaird	MU	Mathematics	Joint responsibility for overseeing research and developing a list of recommended freely available technology-enhanced resources.
Dr. Seamus Mc Loone	MU	Engineering	Joint responsibility for the development of the audience response system UniDoodle App.
Christina Kelly (Joined April 2015)	MU	Software Developer	UniDoodle app software development.

Dr. Eabhnat Ní Fhloinn	DCU	Mathematics	Joint responsibility for overseeing research and the development of the initial student and lecturer survey.
Dr. Brien Nolan	DCU	Mathematics	Co-developed a playlist of relevant Khan Academy (KA) videos and quizzes.
Dr. Sinéad Breen	DCU	Mathematics	Co-developed interactive tasks using GeoGebra.
Dr. Conor Brennan	DCU	Engineering	Joint responsibility for the development of the UniDoodle App.
Caitríona Ní Shé (Joined April 2015)	DCU/MU	PhD candidate	Project researcher (under joint supervision of Dr. Ciarán Mac an Bhaird and Dr. Eabhnat Ní Fhloinn).
Dr. Fiona Lawless	DkIT	Mathematics/ Computer Science	Co-developed a playlist of relevant KA videos and quizzes, developed KA mastery challenges and student authored screencast teaching activity.
Dr. Frank Doheny	AIT	Mathematics	Developed Moodle lessons.

Each of the project members selected the resources that they developed for their students and were responsible for the implementation of those resources within their institution. The initial funding period was from January 2015 to December 2016, with a no-cost extension granted until April 2017.

3.5 Objective of the project and role of this researcher

As discussed earlier, the NF's objective in funding the project was based on the need to learn more about how students can be supported in transitioning from secondary education to undergraduate level. As outlined above, the target population for the project were those students who have problems with first-year undergraduate non-specialist mathematics modules (Faulkner et al., 2010; Gill & O'Donoghue, 2007b). The aim of the project, as set out in the initial stages, was to identify mathematical topics and concepts that are problematic for those students, and to use this information in the development of formative assessment techniques and resources. It was intended that these resources, consisting of online activities and interactive tasks, would improve student understanding of the topics identified. A further aim was to evaluate the effectiveness of these resources before developing a shared digital platform for all the HEIs in Ireland (NF, n.d.-b). From the outset, it was envisaged that technology-enhanced formative assessment techniques would be employed within the resources in order to encourage students to monitor and develop their understanding of the relevant problematic topics.

Prior to the development of the resources, the project team explored the literature for definitions of mathematical understanding and formative assessment. The term 'mathematical understanding' is not well-defined, and many authors have attempted to describe it in different ways (Pirie & Kieren, 1994; Skemp, 1976). As there was no single definition for mathematical understanding found in the literature, the NF-funded project group chose to work with the concept of 'mathematical proficiency', as defined by the National Research Council (NRC) (NRC, 2001, pp. 115–145). The NRC defined mathematical proficiency as encompassing five interwoven and interdependent strands which are summarised as follows:

- *'Conceptual understanding: comprehension of mathematical concepts, operations, and relations*
- *Procedural fluency: skill in carrying out procedures flexibly, accurately, efficiently, and appropriately*
- *Strategic competence: ability to formulate, represent, and solve mathematical problems*
- *Adaptive reasoning: capacity for logical thought, reflection, explanation, and justification*
- *Productive disposition: habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy.'* (NRC, 2001, p. 116).

The project team identified conceptual understanding and procedural fluency as the most important strands for their students, and so chose to focus on these within the resources.

As stated, one of the objectives of using the resources was to use formative assessment techniques. In the consideration of how to support formative assessment it was first necessary to determine what is meant by formative assessment. While formative and summative assessment have been used in educational contexts since 1967, it is the work of Paul Black and Dylan Wiliam since 1998 that has promoted the concept of formative assessment as a means of improving student learning (Wiliam & Thompson, 2008). In their original work, Black and Wiliam defined formative assessment as the teaching and learning activities that provide information on students' current understanding that can be used by either the lecturer and/or the student as feedback to modify subsequent activities (Black & Wiliam, 1998). In their work on integrating assessment with learning, Wiliam and Thompson (2008) developed a framework to help integrate formative assessment into teaching and learning. They drew on Ramaprasad's (1983, p. 4) definition of feedback: *'feedback is information about the gap between the actual level and the reference level of a system parameter which is used* *to alter the gap in some way*'. Based on this definition, they identified three instructional processes that are necessary for effective feedback: (1) determine where the learners currently are, (2) plan where the learners are going, and (3) inform the learners of how to get there. They outlined five key strategies that can be used to provide effective formative assessment:

1. '*Clarifying and sharing learning intentions and criteria for success*
2. *Engineering effective classroom discussions, questions, and learning tasks that elicit evidence of learning*
3. *Providing feedback that moves learners forward*
4. *Activating students as instructional resources for one another*
5. *Activating students as the owners of their own learning*' (Wiliam & Thompson, 2008, p. 64)

The issue of using formative assessment in higher education has been examined and discussed (Boud, 2000; Gibbs, 2010; Sadler, 1998; Yorke, 2003). Nicol and MacFarlane-Dick (2007, p. 205) outlined seven good feedback practices that can be used to help achieve formative assessment in higher education. The project team decided to use the Wiliam and Thompson (2008) framework as it has been well researched within the literature and the strategies align with the Nicol and MacFarlane-Dick (2007, p. 205) good feedback practices. The use of this framework informed the development of Formative Assessment section of the TeRMEd framework and is further referenced in Section 6.5.

Using technology to support formative assessment is not new. Indeed, as discussed in Chapter 2, the FaSMEd project focussed on the use of technology in post-primary classrooms to support the formative assessment strategies described in the Wiliam and Thompson (2008) framework (FaSMEd, 2014). In higher education, Yorke (2001) noted the possibility of using technology as a less time-consuming method for implementing formative assessment than by hand, thus freeing up valuable lecturer time. In a review of the literature on online formative assessment in higher education, Gikandi et al. (2011) found three functionalities of technology-supported formative assessment: (1) provision of formative and immediate feedback, (2) supporting engagement with critical learning processes, and (3) promoting equitable access. Using the affordances of technology to support assessment has been shown to support the following educational benefits: provision of a range of different types of assessments; flexibility on timing and location of assessment; improved student engagement especially with interactive tasks which incorporate instant feedback; and timely evidence on the effectiveness of course design and delivery (JISC, 2010, p. 9). The need to provide instant feedback to students was taken into consideration when selecting the resource types to be used in the NF-funded project.The first stage of the project, carried out between January and April 2015, consisted of surveys of first-year students and their lecturers, who were involved in non-specialist mathematics modules. The objective was to establish both the mathematical concepts and procedures with which students have difficulty, and the resources they use or would like to use, to help overcome these difficulties. This survey was designed and carried out by the team prior to the arrival of this researcher. Subsequently, this researcher carried out an analysis of the data gathered during the surveys and two published papers emerged: “Problematic topics in first-year mathematics: lecturer and student views” (Ní Shé et al., 2017a), and “Students’ and lecturers’ views on mathematics resources” (Ní Shé et al., 2017b). The outcomes of this research were used to inform the topics covered in the NF-funded project resources and the types of technologies used.

The next stage of the project involved the development, implementation and trialling of the resources, with a view to their modification and subsequent re-trialling. During this phase, the team members were responsible for the selection and implementation of the resources they had developed. This researcher had responsibility for the design and development of the research instruments to be used. In addition, she coordinated all research activity and worked with the individual team members to fine-tune and finalise the research questions and instruments for each resource implementation. All the data was analysed by this researcher and fed back to the individual team members. Subsequently, some of the team members made modifications to the resources and second trials were implemented. In addition, one of the team members, Dr. Conor Brennan, facilitated this researcher to carry out further research on student engagement with technology at a later stage of the PhD. This will be described in more detail in Chapter 4. Once the evaluations were completed, the team members had no further involvement with this PhD research, other than Dr. Ann O’Shea who contributed to aspects of the classifications of the resources in the early stages of the development of a classification framework. This framework will be discussed in Chapter 6. In addition, Dr. Ciarán Mac an Bhaird and Dr. Eabhnat Ní Fhloinn were involved, as PhD supervisors.

As indicated above, the two strands of mathematical proficiency, formative assessment and the affordances of technology, formed the basis of the design and implementation of the NF-funded project resources. The focus was on developing conceptual and procedural understanding of the topics identified from the initial survey (Ní Shé et al., 2017a). These NF-funded project resources will be described in the next section.

3.6 The NF-funded Project Resources

As outlined above, one of the aims of the NF-funded project was to develop technology-enhanced formative assessments for use in first-year undergraduate non-specialist mathematics modules. The resources developed enable assessment for learning by providing feedback for students to improve their learning. The outcome from the surveys carried out in April 2015 indicated that students considered that the most problematic topics encountered in their first-year mathematics modules were integration, differentiation, functions, logs and limits, and that they had difficulty with the procedures rather than the concepts (Ní Shé et al., 2017a). However, their lecturers pointed to students' lack of ability in some basic algebraic skills such as the manipulation of formula and fractions, and solving linear and quadratic equations (Ní Shé et al., 2017a). Lecturers considered that the problems students reported with calculus were related to the absence of these essential skills, though both students and lecturers agreed that calculus procedures and using logs proved difficult (Ní Shé et al., 2017a, pp. 720–722). The topics covered in the NF-funded project resources focussed on many of these essential skills along with the understanding of the concept of functions. In order to align with the objectives of the NF-funded project, which was to provide technology-enhanced resources that support the development of conceptual and procedural understanding, using formative assessment strategies that align with the Wiliam and Thompson (2008) framework and provide instant feedback, the following four different resources were selected and developed by the lecturers involved in the project:

1. An audience response system called UniDoodle
2. Khan Academy playlists and mastery challenges implemented via Moodle
3. A suite of interactive tasks using GeoGebra and Numbas
4. Online lessons and quizzes designed in Moodle

These first three resources are described in more detail in the subsections below. The online lessons and quizzes designed in Moodle were discontinued after the first use, and are not further outlined here. The trial carried out on this resource was used to pilot the student survey which is further discussed in Chapter 4.

3.6.1 UniDoodle

UniDoodle is a smart device student-response system designed for use in mathematics lectures. It currently operates on all devices running either iOS or Android. The system consists of a student application that allows for freeform input, through sketching capabilities; a lecturer application that allows easy viewing and editing of multiple sketch-based responses; and a Google App Engine cloud-based service for co-ordinating between these two applications. Lecturers create questions which are displayed via the overhead projector to the class. Students prepare individual responses which are uploaded to the lecturer tablet. The lecturer then selects relevant responses, both correct and incorrect, to display and discuss with the class. Figure 3.6.1 shows a sample of UniDoodle screens.

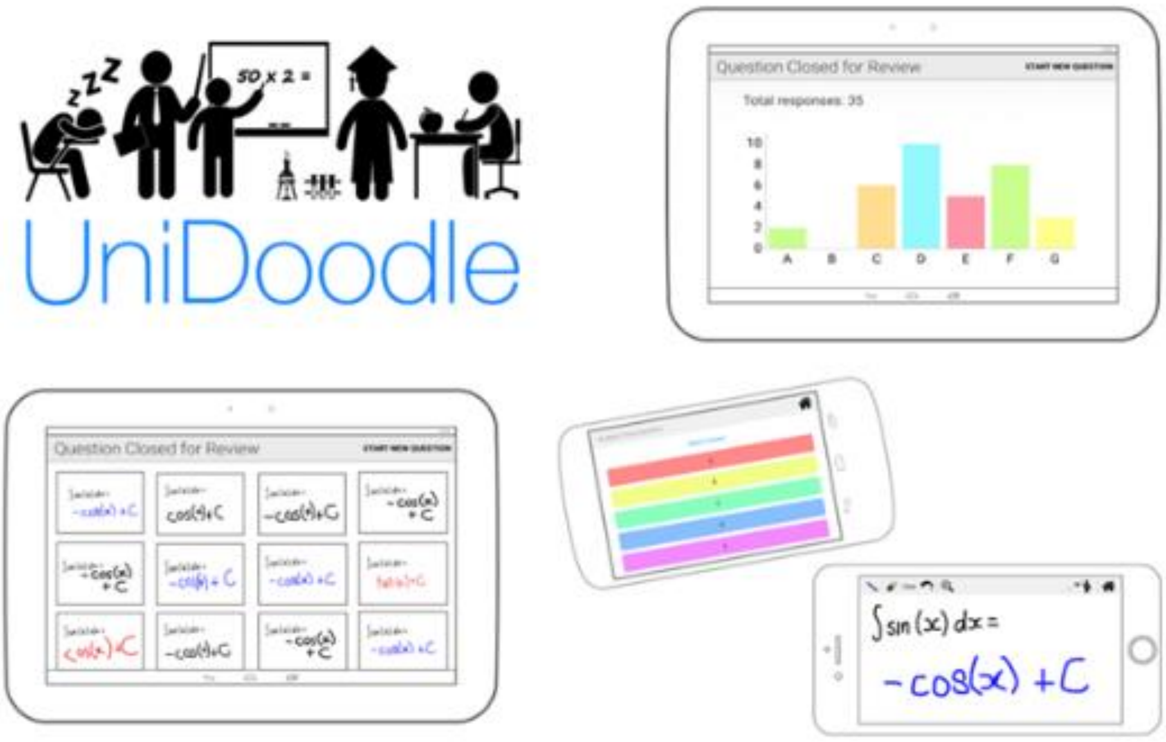
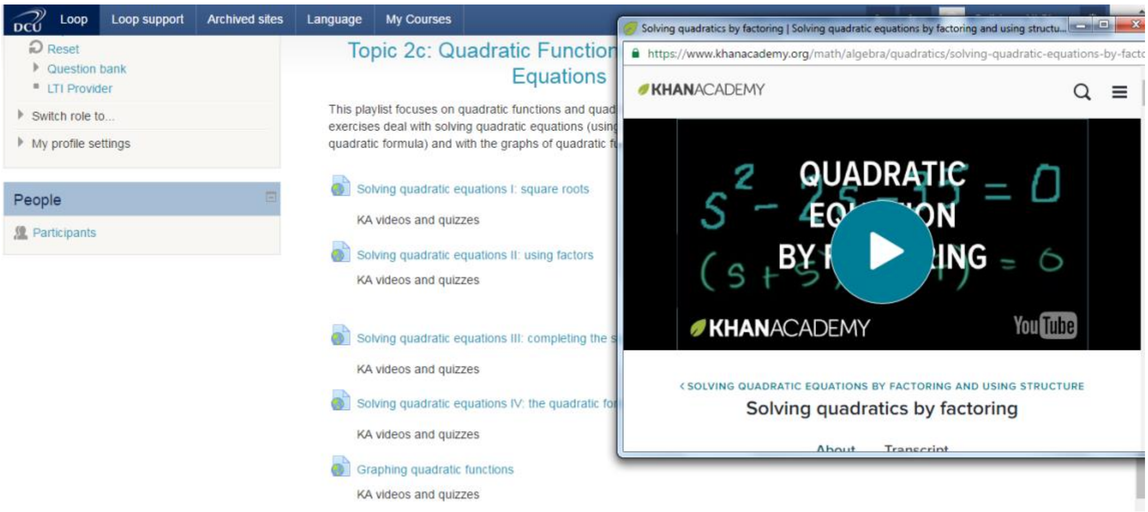


Figure 3.6.1: The UniDoodle screens

3.6.2 Khan Academy Playlists

Khan Academy (KA) is a freely-available learning resource which provides practice exercises, instructional videos, and a personalized learning dashboard (Khan Academy, 2020). The KA Playlist was implemented in this project in two specific ways. In the first implementation, the KA material was used to provide students with a learning path that enabled them self-test and subsequently develop the most problematic mathematical skills that had been identified by the project team. The second implementation was used to provide a flipped classroom approach, in which the lecturer monitored student progress through a learning pathway, designed by the lecturer, and subsequently modified in the face-to-face lectures. The KA Playlists are made available through the institutional Virtual Learning Environment (VLE) and allow students to link directly to quizzes and videos on relevant topics. Background information on KA and how it should be used is also provided. Figure 3.6.2. is a screengrab taken from the DCU implementation and shows the VLE interface and the KA video that a student has selected.

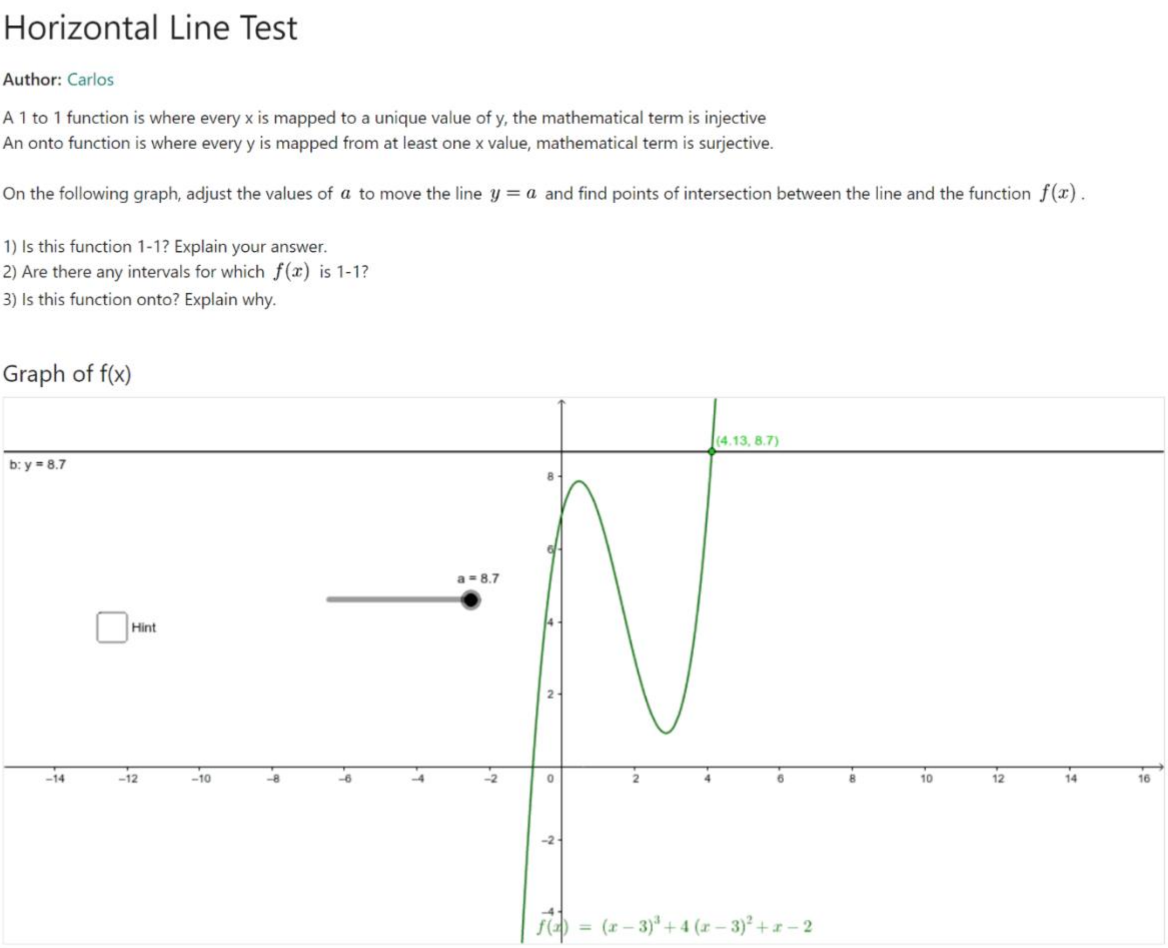


This playlist focuses on quadratic functions and quad
exercises deal with solving quadratic equations (usin
quadratic formula) and with the graphs of quadratic f

Figure 3.6.2: Khan Academy as implemented in DCU

3.6.3 Interactive tasks using GeoGebra and Numbas

GeoGebra is a freely-available dynamic mathematics software that enables the development of interactive mathematics resources for use in the teaching and learning of mathematics (GeoGebra, 2020). Numbas is a web-based e-assessment system developed at Newcastle University with a focus on producing exam quiz packages in mathematics (Newcastle University, 2015). These two applications were used to develop interactive GeoGebra tasks and interactive Numbas assessments that were made available to students via the student VLE. Students were made aware, in class or via the VLE, of the availability of the relevant resource as they progressed through the mathematics module. These resources, referred to as tasks, are interactive; students can vary and manipulate variables to determine the effect on given graphs or other artefacts, thus enabling them to develop deeper mathematical understanding. The e-assessment allows students assess their understanding and provides them with opportunities to adjust this understanding. In addition, some tasks provided mathematical instruction and posed probing questions. Figure 3.6.3 and 3.6.4 show examples of an interactive GeoGebra task and a Numbas e-assessment respectively.



Horizontal Line Test

Author: Carlos

A 1 to 1 function is where every x is mapped to a unique value of y, the mathematical term is injective
An onto function is where every y is mapped from at least one x value, mathematical term is surjective.

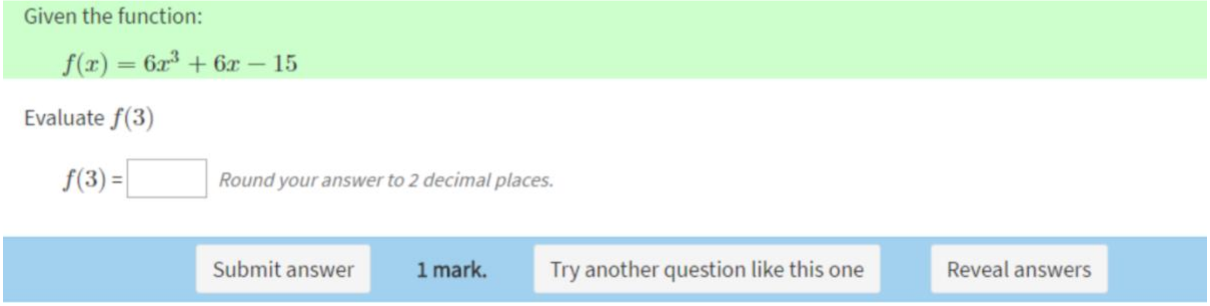
On the following graph, adjust the values of a to move the line $y = a$ and find points of intersection between the line and the function $f(x)$.

1) Is this function 1-1? Explain your answer.
2) Are there any intervals for which $f(x)$ is 1-1?
3) Is this function onto? Explain why.

Graph of f(x)

Figure 3.6.3: Investigating the Horizontal Line Test using GeoGebra

(https://www.geogebra.org/m/RrWWmS63)



Given the function:

$$f(x) = 6x^3 + 6x - 15$$

Evaluate $f(3)$

$f(3) =$ ☐ *Round your answer to 2 decimal places.*

Figure 3.6.4: Numbas e-assessment on functions

3.7 The NF-funded Project resource trials

In order to assess the NF-funded project resources, they were trialled and evaluated during the academic years of 2015/2016 and 2016/2017. Table 3.7.1 outlines the trial details. Throughout the rest of the thesis, the trials will be referred to by their Trial Name, as indicated in this table.

Table 3.7.1: Details of the NF-funded project resources trials

Trial Location	**Trial Name**	**Trial Dates**	**Modules and Students**	**Context & Resource**
Maynooth University	UniDoodle1	2015/2016	2nd year engineering (12 students). Circuit Analysis (Karnaugh maps).	UniDoodle was used regularly in tutorial classes.
Dublin City University	UniDoodle2	Spring 2016	1st year engineers. Engineering Mathematics II (165 students) & Numerical Problem Solving for Engineers (151 students).	UniDoodle was used in 4 one hour sessions in total, two per module.
Dundalk Institute of Technology	KA1	Autumn 2015	1st year computing programming students (175 students). Diagnostic Test/ Retest cycle.	Students completed a diagnostic test (DT1) in early September, were given access to mathematics supports and selected KA resources, via a Mathematics Learning Centre (MLC) Moodle module. They completed a second diagnostic test (DT2) approximately 5 weeks later.
Dundalk Institute of Technology	KA2	Spring 2016	1st year computing programming Linear Algebra module taken by a subset of the original	KA Masteries were incorporated as a Continuous Assessment (CA) component (10% of overall grade). The class/coach functionality in KA was used to

			KA1 student cohort (80 students).	make recommendations, assess student engagement with targeted material, monitor student progress and identify specific problem tasks to be addressed directly in class or through mathematics learning support.
Dublin City University	KA3	Autumn 2015	1st year Business Mathematics (335 students).	KA resources were made available to the students via a dedicated module on Loop, the institutional VLE. Links were provided from the Business Mathematics module on Loop. Note Loop is the DCU brand name for the VLE, Moodle, and other student resources.
Maynooth University	GeoGebra1	Autumn 2015	1st year science students. Differential Calculus module (476 students).	Ten interactive GeoGebra tasks, two GeoGebra applets, and a Numbas quiz were integrated into the Moodle module and some were referred to in the relevant assignment and/or in class.
Maynooth University	GeoGebra2	Autumn 2016	1st year science students. Differential Calculus module (396 students).	A modified set of interactive tasks and quizzes were integrated into Moodle; six GeoGebra tasks and two Numbas quizzes. Both quizzes were graded. One task was directly linked to an assignment.

3.8 Conclusion

The NF-funded project resources were developed as part of an overall NF strand of funding that aimed to address some of the difficulties encountered by students as they transition from secondary school to higher education (NF, n.d.-c). This particular project ‘Assessment for Learning Resources for First-Year Undergraduate Mathematics Modules’ (NF, 2018) was designed to meet the needs of a specific cohort of students: first-year students attending non-specialist mathematics modules who are known to face difficulties with some of the mathematics that they experience (Faulkner et al., 2010; Gill & O’Donoghue, 2007a). The topics covered in these resources were based on the results of surveys carried out in April 2015 (Ní Shé et al., 2017a, 2017b). The NF-funded project resources focussed on conceptual and procedural mathematical proficiencies as defined by the NRC (2001) and used formative assessment strategies that leveraged the affordances of technology (JISC, 2010; Wiliam & Thompson, 2008). Both purpose-built software and existing applications were used in the development of the resources. These resources were trialled in the four institutions involved in the project during the period from Spring 2015 to Spring 2017. Modifications to the resources were made based on the evaluations before they were made more widely available to the higher education community in Ireland (NF, n.d.-d).

This researcher had responsibility for the evaluations of the resources, which included the design of the methodology and the subsequent analysis of the data. In addition, she was responsible for the analysis of the initial survey data which led to two publications that were subsequently used to inform the development of the NF-funded project resources (Ní Shé et al., 2017a, 2017b).

This research formed the starting point for the PhD. Evaluations of the NF-funded project resources revealed the lack of a framework of evaluation for technology integration in higher education mathematics. In addition, it became clear that there is a lack of information on how students engage with technology-enhanced resources in first-year undergraduate mathematics. Thus, the research was refined and extended to include these aspects. In the next chapter, Chapter 4, the rationale, and design of the methodology associated with the research project is explained in detail.

Chapter 4 Research Methodology

4.1 Introduction to the chapter

The purpose of this chapter is to describe and rationalise the research methodology and methods that were used for this PhD study. Educational research is generally aimed at gathering knowledge and understanding that can be used to improve educational actions and decisions (Bassey, 1999). Similarly, the purpose of mathematics education research is to understand mathematical thinking and the ways of teaching and learning in order to enhance the teaching of mathematics (McKnight et al., 2000; Schoenfeld, 2000). Schoenfeld (2000) and McKnight et al. (2000) both note that, unlike mathematics research, there are no proofs in mathematics education research. Educational questions, such as what works and which approach is better, are not answerable in the abstract (Schoenfeld, 2000). For mathematics education research to be successful, there is a need to establish the context of the research such as: which cohorts of students are under investigation, what does onemean when one says that something works, and what evidence is needed to support this (Schoenfeld, 2000). According to McKnight et al. (2000, p. 3), mathematics education research is '*inquiry by carefully developed research methods aimed at providing evidence about the nature and relationships of many mathematics learning and teaching phenomena*'. In order to contribute towards the validity and reliability of a study, it is crucial that the researcher justifies their methodological choices (Glatthorn & Joyner, 2005; Wallace & Louise, 2003). The research methodology is therefore the rationale for the research methods that have been chosen to elicit evidence about the phenomena under investigation (Howell, 2013). In this thesis, the research methodology decisions and choices were made with the final outcome in mind – that is, to increase our understanding of how technology can best be implemented in undergraduate mathematics education to encourage student engagement. In this chapter, the research design and methods are described and justified. The chapter contains the following sections:

- Research methodology and design
- Research methods
- Validity, reliability, and trustworthiness of this study
- Ethical consideration during the research

The research framework, questions and definitions that have been discussed were used to select the methodology and methods used in this research. The research design and its rationale are described in the next section.

4.2 Research methodology and design

Once the research framework has been established, the methodology can be chosen and particular data-gathering methods selected to address the research questions (Creswell & Plano Clark, 2018; Farrow et al., 2020). It is important to judiciously select the methods that will answer the final research questions. The subsequent research design provides the guide for the research study: it outlines what was done, and how it was done, in order that the study can be replicated (Wiersma & Jurs, 2009); in other words, it provides the blueprint for the 'collection, measurement and analysis of the data' (University of Southern California (USC), n.d.-b, para. 1). In the following sections, the rationale for the choice of methodology is explained, along with details of the research design that outlines the methods of data collection and analysis.

4.2.1 Choice of methodology

As noted in Section 2.6, this study is rooted in both pragmatic and interpretivist research frameworks. The choice of methodology has a bearing on the research design and therefore should reflect the paradigm (Kivunja & Kuyini, 2017; Lincoln & Guba, 2000) In this study, a pragmatic approach was taken to solving the problem of evaluating technology-enhanced resource implementations. In order to understand a problem, pragmatic studies involve investigating multiple factors that influence human actions and converting the results of this research into practical applications (Duram, 2012; Farrow et al., 2020; Weaver, 2018). Pragmatic approaches to research allow for relevant methods to be chosen to address particular research questions and often use a mixed-methods methodology (Duram, 2012; Farrow et al., 2020; Morgan, 2014; Morrison, 2007). Mixed methods involve the gathering and analysing of data using both quantitative and qualitative research methods (Cohen et al., 2007; Creswell & Plano Clark, 2018; Farrow et al., 2020; Morgan, 2014). Quantitative research is generally concerned with using numerical and statistical methods of gathering and analysing data and has been traditionally associated with a positivist approach to research, where cause and effect are investigated (Cohen et al., 2007; Farrow et al., 2020; Morrison, 2007). On the other hand, qualitative research methods are focussed on describing entities, and the relationships between them, in order to understand social and human experiences (Norman K. Denzin & Lincoln, 2005; Farrow et al., 2020; Morrison, 2007). Qualitative research is traditionally associated with an interpretivist paradigm, and relies on descriptive data gathered from observations and personal accounts, and the use of inductive analysis (Farrow et al., 2020; Morrison, 2007). While epistemologically it may appear that quantitative and qualitative research draw from opposing paradigms, there is increasing agreement in the literature that it is not just the data and analysis methods that define the paradigm, but the way they are used (Creswell & Plano Clark, 2018; Morgan, 2014). Increasingly, a mixed methods approach to research design is being taken which makes use of the strengths of both quantitative and qualitative methods (Creswell & Plano Clark, 2018; Farrow et al., 2020). In a pragmatic approach to research design, careful and complementary use of both qualitative and quantitative methods allows exploration of the complexity of human situations, leading to a solution for a problem (Duram, 2012; Farrow et al., 2020; Morgan, 2014).

An interpretivist approach was taken to investigating how students engage with technology-enhanced resources. Interpretivists recognise that certain '*emotions; understandings; values; feelings; subjectivities; socio-cultural factors; historical influence; and other meaningful aspects of human being*' cannot be gathered objectively (Farrow et al., 2020, p. 15). The research generated from an interpretivist approach relies on the meanings the researcher implies from the observations (Lincoln & Guba, 2000; Morrison, 2007). Qualitative research methods are used to gather data, and inductive analysis is commonly used to generate theory from the documented real-life social experiences (Farrow et al., 2020; Kivunja & Kuyini, 2017). Key components of an interpretivist approach include the recognition that there is interaction between the researcher and the research participants, that the context of the study has a bearing on the outcomes, and that '*causes and effects are mutually interdependent*' (Kivunja & Kuyini, 2017, p. 34). Interpretivist approaches generally rely on qualitative research methods such as observations, interviews and conversations (Farrow et al., 2020; Kivunja & Kuyini, 2017; Lincoln & Guba, 2000).

Why then is the use of a mixed methods methodology the best approach to answering the research questions for this PhD study?

This study necessitated the gathering of evidence from students about their use of specially-designed technology-enhanced resources implementations. According to Cohen et al. (2007, p. 205) this type of evidence is best acquired through surveys, since '*… surveys gather data at a particular point in time with the intention of describing the nature of existing conditions…*'. On the other hand, there was a need to get both a richer description and a depth of understanding of student use of the resources, which indicated that a qualitative approach was needed (Creswell & Plano Clark, 2018). In order to develop a framework of evaluation, this mixed-methods approach facilitated the gathering of factors that influence student engagement with technology and determining what works, a central tenet of a pragmatic approach. As the intersection of student engagement and technology has had little investigation in higher education (M. Bond & Bedenlier, 2019; Henrie, Bodily, et al., 2015), there is little evidence of how first-year undergraduate students engage with technology-enhanced resources provided by their lecturers to support them in non-specialist mathematics modules. An interpretivist approach using qualitative methods, allowed the generation of a rich description of how first-year undergraduate mathematics students engage with technology.

Therefore, a mixed-methods approach was used in this study. According to Creswell and Plano Clarke (2018), there are many advantages to using mixed methods in research. First of all, numerical data can be used as a starting point for gathering narrative data, confirming and adding meaning to the numerical data. This in turn leads to an enriched understanding of the problem, which increases the generalisability of the findings. Finally, by using mixed methods, data triangulation is enabled, which enhances the validity and reliability of the study.

Mixed methods recognise that reality is complex and cannot be explained by using quantitative or qualitative methods alone, and as many instruments as possible should be used (Creswell & Plano Clark, 2018). For a successful mixed methods study, the quantitative and qualitative data must be combined and connected in order to gain a deep understanding of the problem (Creswell & Plano Clark, 2018; Farrow et al., 2020). In the next section, the instruments selected along with the design implementation are outlined.

4.2.2 Research Design

There were five stages in the research that was carried out in this PhD study. These are illustrated in Figure 4.2.1 and then described in more detail below.

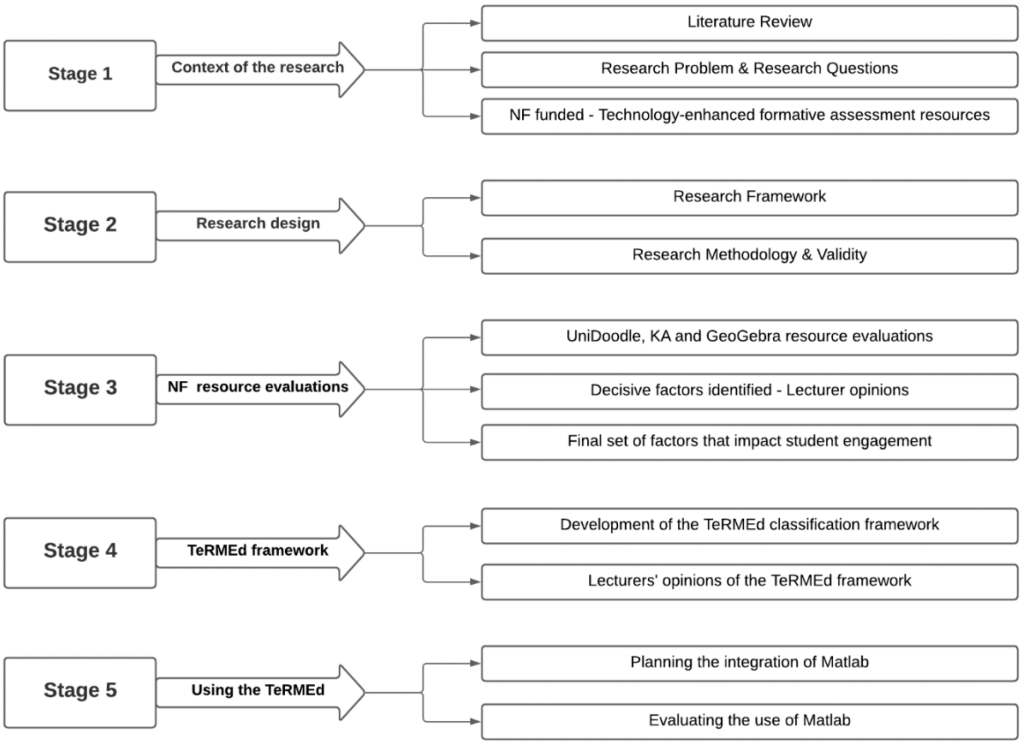


Figure 4.2.1: The five stages of the research

Stage 1: Literature Review. Stage 1 of the research consisted of a review of the literature with respect to students' use of, and engagement with, technology-enhanced resources in undergraduate mathematics, and on the ways the use of such resources have been evaluated. A literature review was necessary in order to both situate the evaluations of the resources within the larger field, and to provide a critical evaluation of the scholarly work already completed in this area (Fink, 2010). The exploration and examination of the literature was initially conducted in the autumn of 2015 but continued throughout the five years of the PhD project in order to examine new insights that emerged as a result of the research and to keep abreast of similar relevant studies. This review helped to orientate the research project, identify gaps in the literature and refine the research questions (Farrow et al., 2020; Fink, 2010). Chapter 2 contains a discussion and exploration of the relevant elements of the literature review. The literature review methodology and rationale for its use are discussed in the research methods section below.

Stage 2: Research Design. This stage of the research concerned the design of the research project, and the development of instruments that were used in later stages of the research. During this stage, the literature on research methodology was consulted extensively in order to develop the research design and methods that were to be used in the study. The discussion of the development of the research framework and selection of the methodology are outlined in Section 4.2 and 4.3 of this chapter. The details of the research design are contained in the remaining sections of this chapter.

Stage 3: NF-funded project resource evaluations. In Stage 3, the NF-funded project resources were evaluated. The process of the development of the NF-funded project resources and a description of the resources are contained in Chapter 3. Table 3.7.1 contains a list of the trials that were carried out along with the dates of the trial and a brief description of the context of the trial. Stage 3 was an iterative process in that the different resources were trialled separately and some of the NF-funded project resources were evaluated and subsequently re-trialled. Figure 4.2.2 outlines the various iterations of the resource evaluations. The evaluations consisted of a number of methods of data gathering, consistent with a mixed methods approach. These methods will be outlined in the section on research methods below, Section 4.3.2.

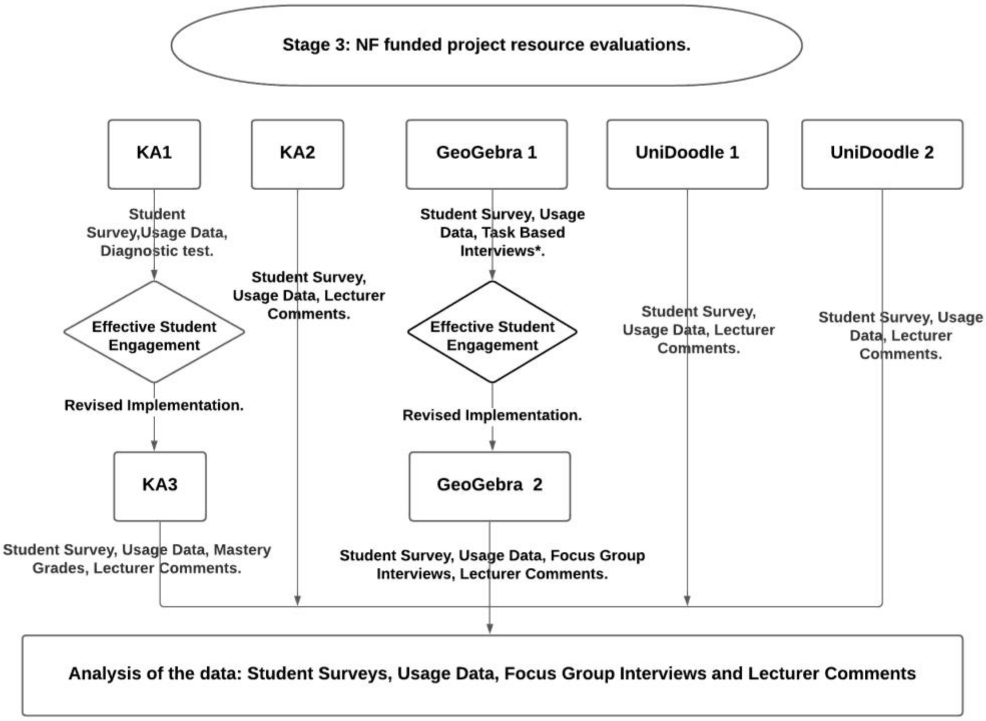


Figure 4.2.2: Stage 3 - iterative evaluation of the NF-resources

See Table 3.7.1 for a match between trial name and its details. *Note that Task Based Interviews were conducted after the first GeoGebra trial in order to determine what type of learning paths students took through the tasks. The analysis of these do not form part of this thesis study.

Stage 4: TeRMEd classification framework. Stage 4 consisted of the development of the TeRMEd classification framework. The analysis of the data gathered during Stage 3 identified a number of factors of technology-enhanced resource implementations that impacted on students' engagement with technology. These outcomes, along with a methodological review of the literature, were used to develop a framework of evaluation that can be used by practitioners to plan and evaluate resources they develop for use in first-year undergraduate mathematics modules. This stage of the research, aimed at finding a solution to the problem of evaluating technology implementations, is an outcome of the analysis in Stage 3 and literature review from Stage 1. A survey of lecturers involved in the NF-funded project was used to verify the framework and is described in the research methods section below, Section 4.3.3.

Stage 5: Using the TeRMEd framework to plan and evaluate student engagement. This stage of the research was conducted after the evaluation and analysis of the NF-funded project resources, and the development of the TeRMEd classification framework. A technology-enhanced resource, Matlab, was integrated into a first-year engineering module, EM114, in Spring 2018. The TeRMEd classification framework was used in the planning and evaluation of this technology integration.

The lecturers and students involved in this module facilitated this researcher in conducting the associated research. The context for this integration of Matlab in the EM114 module is given in Chapter 7. There were three steps involved in this stage of the research:

1. The classification of Matlab within the TeRMEd framework prior to its use within the first-year engineering mathematics module.
2. The collection and analysis of the User Experience values for the TeRMEd framework, taken as part of the evaluation of the module.
3. The conducting of focus group interviews to further explore the students' opinions on the use of Matlab within the module.

In the first instance, the TeRMEd framework, developed in Stage 4, was used to classify the planned integration of Matlab within the first-year engineering module. This allowed the lecturer to design the use of Matlab in such a way as to enable students to achieve the learning outcomes of the module, while effectively engaging with Matlab. After the module, data was gathered and analysed to determine the effectiveness of the TeRMEd framework in the planning and subsequent evaluation of the use of Matlab within EM114. This element of the research used a mixed methods approach.

The methods used to implement this research design, along with a rationale for their use, are outlined in Section 4.3.4 below.

4.3 Research Methods

The research methods are the set of techniques and strategies that are required to gather and analyse the data that responds to the chosen research design. As indicated earlier in this chapter, careful consideration was given to the methodology and methods selected for this study. Using a mixed methods methodology necessitates the use of both quantitative and qualitative methods (Cohen et al., 2007; Creswell & Plano Clark, 2018). There are a wide variety of data gathering and analysis methods that can be used in a mixed methods study (Creswell & Plano Clark, 2018). For example, when gathering quantitative data, numerical data such as polls, tests, surveys and questionnaires are often used (Babbie, 2010, as cited in USC, n.d.-a, para. 1). In addition, logged data, such as analytics gathered via a virtual learning environment, have been employed to gather quantitative data on students' usage of technology (J. Lai & Bower, 2019; Pickering & Joynes, 2016; Yang et al., 2018). Similarly, there are many statistical tools available to help analyse quantitative data (J. Lai & Bower, 2019; Babbie, 2010, as cited in USC, n.d.-a, para. 1). This diversity of data gathering and analysis is also found in qualitative methods (Creswell & Plano Clark, 2018; Wiersma & Jurs, 2009).

A number of software tools were used in the organisation, analysis and gathering of the research data, as is common in modern research (Farrow et al., 2020, p. 29). The software tool MS Excel was initially used to organise and analyse the survey data. In most cases, this data was then imported into SPSS for further statistical analysis. The quantitative software tool NVivo was used to manage and analyse qualitative data such as responses to open survey questions, interview data, and documents. The interviews were transcribed by this researcher either using a tabulated Word document, or the transcript facility of NVivo. Many of the diagrams, figures and tables used to display the data and its analysis were generated using these and other software tools.

The data gathering and analysis methods used in this study are discussed in the sections below under the different stages of the research. Note that Stage 2 is not included as it refers to this research design phase which has been used to validate the choices made.

4.3.1 Stage 1: Literature review

Literature reviews are used to situate the research study in the broader context of research in the area and to justify the identification of the research problem and subsequent research questions (Fink, 2010). There are a variety of types of literature reviews used depending on the research context, such as narrative (or traditional), systematic, meta-analysis and meta-synthesis (Baker, 2016). A number of common literature review types are briefly described in Table 4.3.1 along with a rationale for the two that were used in this study: traditional and systematic.

Table 4.3.1: Literature review types - and those used in this study

Review Type	Definition	Reason used or not
Traditional	Provides a comprehensive overview and objective analysis of current research in an area. Used to identify any research gaps that need to be addressed (Baker, 2016; Fink, 2010).	Used in this study to support formulation of research questions and to set context of the research.
Narrative	Similar to a traditional literature review, though generally a standalone research article (Baker, 2016).	Not applicable, as literature review was not a standalone article.
Systematic	Aims to establish and critically analyse literature pertinent to a particular research question. Methodology used is meticulously recorded in terms of key search phrases, research databases used, and processes used to select relevant literature. Often	Was beneficial in establishing the existing frameworks used in evaluating technology in mathematics education.

	used to identify all sources that reference a particular phenomenon and were traditionally used in medical research (Littell & Corcoran, 2010).	Can be difficult to conduct systematic reviews in education, in part due to lack of agreed definitions of terminology, use of broad versus narrow question, and lack of informative abstracts (Bedenlier et al., 2020).
Theoretical	Focus on finding theories and frameworks associated with a particular phenomenon. Often used to illustrate lack of adequate theoretical frameworks in research (Randolph, 2009).	Not applicable. Was considered for the review on evaluation frameworks, but ruled out due to its emphasis on theory.
Focussed	Used to examines one particular aspect of a body of literature (Frederiksen et al., 2018; Randolph, 2009).	Used to determine pedagogical features of technology-enhanced resources that impact on student engagement.

The detailed description of the key phrases and databases used for the literature reviews are given in the context of the literature analysis and synthesis in Chapter 2. The outcomes of the focussed review are discussed in Chapter 5.

4.3.2 Stage 3: NF-funded project resource evaluations

Stage 3 of the research was used to address RQ1 and RQ2. In addition, this stage contributed to answering RQ3. See Section 4.2.1.2 for these questions. A mixed methods approach was taken during this stage of the research. Quantitative data in the form of surveys, student grades and logged usage were used and statistically analysed. Focus group interviews and open responses to questions formed the basis of the qualitative data gathered. In addition, lecturer descriptions of, and observations during, the NF-funded project resource trials were noted. Table 4.3.2 contains a list of the data gathered and associated analysis. Each of these are discussed in more detail in the subsections below.

Table 4.3.2: Stage 3 - Research methods

Research Stage	**Data Collection Instrument**	**Data Analysis Techniques**
Stage 3	Survey (Likert Scale)	Frequencies, percentages, Rasch analysis, Mann-Whitney, Chronbach alpha, etc.
	Survey (open questions)	Inductive Analysis
	Usage	Frequencies and Percentages
	Pre and post Tests, CA	Grades
	Focus Groups	Inductive Analysis
	Lecturer Descriptions and Comments	Narrative Analysis

4.3.2.1 Survey

Questionnaire data can be used to determine useful information regarding student background experiences, attitudes and perceptions, and the usefulness of teaching and learning interventions (Galbraith & Haines, 1998; McKnight et al., 2000; Pierce et al., 2007). While there are drawbacks associated with students' perceptions of teaching effectiveness, such as that their attitudes may be influenced by their own motivations and desires, there are plenty of studies that have established the validity and reliability of questionnaires (Gorsky & Blau, 2009). In fact, Pierce et al., (2007, p. 288) suggested that requesting students to '*pause and reflect briefly*' may illicit valuable information that cannot be easily observed.

As with any instruments used in research, the validity and reliability of the questionnaire must be considered. In the case of a questionnaire, both face and content validity should be examined prior to its implementation (MacGeorge et al., 2008; McKnight et al., 2000; Pierce et al., 2007). Face validity is achieved when a question item appears to measure what it purports to measure, and is often considered insufficient to measure validity (Laerd, 2012). Stronger validity is accomplished using content validity: in this case experts agree that all variables or constructs requiring measurement are included and that all questionnaire items are relevant to the study (Haynes et al., 1995). In order to ensure content validity, it is essential to select dimensions and items based both on prior research and expert opinion (Haynes et al., 1995; MacGeorge et al., 2008). Blair et al., (2014) suggest that a valid questionnaire contains clear questions that are authentic measures of the factors of interest, elicit reliable information and encourage participant responses.

The project team agreed that items on the dimensions of background, usability, engagement, learning and confidence should be included in a Likert scale survey in order to evaluate the NF-funded project resources. Likert scale surveys are often used to measure the effectiveness of a teaching intervention and students are familiar with these types of evaluation ratings (Penny, 2003; Risquez et al., 2015; Uttl et al., 2017). Indeed, the response rate to such questionnaires is improved when students understand the significance of the value of the questionnaire (Nair et al., 2008), a factor that was taken into account when seeking responses from students. The first step in the development of the items was to examine the literature in the area (Fogarty et al., 2001; Han & Finkelstein, 2013; S. O. King & Robinson, 2009a, 2009b; MacGeorge et al., 2008; Ní Shé et al., 2017b, 2017a; Richardson et al., 2014; Strachota, 2006; Zaharias & Polymenakou, 2009). This examination led to the identification of items that corresponded to the dimensions agreed by the team, and these items were refined before being included in the questionnaire.

Usability was a key focus of this study. When measuring effectiveness of a technological teaching intervention, many researchers do not always consider the usability of the technology (Fabian et al., 2018; Squires & Preece, 1999; Zaharias & Polymenakou, 2009). Usability is in fact a very important measure when considering students' engagement with technology, as was discussed in Chapter 2 (Fabian et al., 2018; JISC, 2015; Squires & Preece, 1999). Zaharias and Poylymenakou (2009) suggested that usability alone is not enough and that usability and instructional design go hand-in-hand. They used this idea to develop a questionnaire to measure the functional usability of technology: in other words, how effective the technology is in motivating students to learn (Zaharias & Polymenakou, 2009). The project team considered using this questionnaire, however it was deemed too long (64 items) and that there was too great a focus on usability (54 items). Instead, a number of the items relating to motivation to learn and usability were included in our questionnaire. Each of the questionnaires found in the literature were examined in a similar way until a list of possible questionnaire items was collected. This list was then examined for both face and content validity by the project team, and a final list of 48 question items were compiled. A pilot evaluation of the questionnaire was carried out in AIT, one of the institutions involved in the NF-funded project. A set of technology-enhanced resources had been developed using teaching elements of the institution's VLE. First-year students, attending a gaming programme, were given access to these resources as a part of a non-specialist first-year undergraduate mathematics module, and the questionnaire was piloted at the end of the module. The final set of questionnaire items, along with their sources and the dimension that was measured are shown in Appendix A.

All students involved in the evaluations were asked to complete the questionnaire; in some instances, they were handed a paper-based survey and in others, an online survey was made available through their VLE. It is known that there is a greater rate of completion for paper-based surveys (Risquez et al., 2015) but due to the nature of the project, paper-based questionnaires were not possible for all trials. During the evaluations, the project members, in consultation with this researcher, adjusted the number and wording of the questions according to their specific needs. Thus, the final items asked in each trial varied. Details on which items were asked in which trials are available in Appendix A.

4.3.2.2 Statistical analysis of the survey

Statistical analysis of survey responses can be used for a number of purposes (Farrow et al., 2020; Groves et al., 2011). In this case, the responses were used to determine factors that students perceive to affect their engagement with the NF-funded project resources. As this was an exploratory phase of the study, no inferential statistics were required. Instead, descriptive statistics were used, such as percentage of students who responded positively or negatively to the items in the questionnaire.

The questionnaire responses were initially transcribed into Excel sheets and then imported into SPSS for statistical analysis, one file per trial. As indicated above, not all items were asked in all surveys, hence the commonly-asked items across all the surveys were amalgamated into one Excel file and imported into a separate SPSS file. An identifier for each trial was included in the file. In addition, trials of the same resource, such as UniDoodle1 and UniDoodle2, used the same questionnaire items. Hence, the questionnaire responses for these files were amalgamated and imported into another SPSS file. At each stage during this process, the researcher was careful to check that the data was entered correctly, and that no data entry errors occurred. Finally, this researcher compiled a report on the evaluations for each of the trials. The lecturer involved in the trial and this researcher checked the reliability of the data during this process. These reports are beyond the scope of this project and will not be further discussed.

In addition to examining the frequency and percentage of positive responses to the Likert Scale items, Mann Whitney and Fisher exact tests were used to compare responses to particular items across the different trials. In the case of the two UniDoodle and GeoGebra trials, Rasch analysis was used to compare the categorical data. The Rasch analysis was completed by Dr. Ann O'Shea, the team lead for the project, and is included in the analysis in Chapter 5.

Note that the open questions in the surveys were analysed using inductive analysis based on Thomas' (2006) grounded inductive analysis techniques. This technique will be further discussed in the context of the analysis of the focus group interviews in Section 4.3.2.7.

4.3.2.3 Usage data

The use of learning analytics in education is increasing. Institutions and researchers are using this type of data to investigate student engagement with various aspects of college life. As discussed in Chapter 2, recorded usage of resources is used by many researchers when investigating the use of technology in education (Howard et al., 2018; Inglis et al., 2011; J. Lai & Bower, 2019; Loch et al., 2014; Pickering & Joynes, 2016; Trenholm et al., 2012; Yang et al., 2018). Usage data generally relies on the use of the VLE to record students' access to resources (Howard et al., 2018; Inglis et al., 2011; Yang et al., 2018), and while this data in itself is reliable, the researcher needs to be careful about the inferences taken from the recorded usage (Howard et al., 2018; Inglis et al., 2011). It is possible that, although students access a particular link, they do not engage any further with the resource and this needs to be considered when making inferences from the logs (Howard et al., 2018; Inglis et al., 2011).

Use of the GeoGebra tasks and the KA, in the KA1 and the KA3 implementations, was voluntary. The resources were made available via the students' institutional VLE, in both cases Moodle. Moodle retains a log of all user activity with respect to access to the course materials, hence all students' clicks (or hits) on the URL's to the KA playlists or GeoGebra tasks were collected. The log files can then be downloaded to Excel for analysis.

The type of data available via Moodle will depend on the particular report downloaded. In the case of the NF-funded project evaluations, data obtained through the event file log, as illustrated in Table 4.3.3, is indicative of the data gathered for this study. As instances of Moodle may vary from one institution to another, so too may the names of the reports and fields within the reports. Hence, the types and names of data fields in the Moodle logs obtained from the various trials may differ, as shown below.

Table 4.3.3: Moodle event log file - example of a GeoGebra task

Data Field	**Value in field**
Time	18/11/15, 15:02
User full name	User 21: name anonymised
Affected user	-
Event context	URL: Finding limits for piecewise functions
Component	URL
Event name	Course module viewed

Description	The user with id '21199' viewed the 'url' activity with course module id '53744'.
Origin	web
IP address	149.157.96.7

The username is given, but, in line with ethical guidelines, has been anonymised. The event context lists the name of the URL accessed by the student which, in this case, refers to ‘Finding limits for piecewise functions’. This is one of the GeoGebra tasks. Similar data was logged for both the KA1 and KA3 trials, where students accessed KA URLs via the Moodle platform.

In the case of KA2 trial, the KA software application itself also provided access to learning analytics. The lecturer set up KA classes within the KA application and asked students to log into the KA application, rather than accessing the KA playlists via Moodle. Within the KA class application, the lecturer set up a number of missions, related to the module content, that students were required to pursue. Each mission contained videos and quizzes, and were aimed at developing a particular skill. Thresholds for successful completion of a mission were set in relation to the number of quiz questions answered correctly. A number of related missions were grouped as a challenge, and students reaching the threshold for these missions were then recorded as having achieved mastery of the challenge. Students were allocated points and badges for completion and partial completion of the different missions and challenges, thus adding a gaming element. See Figure 4.3.1 for an overview of this process.

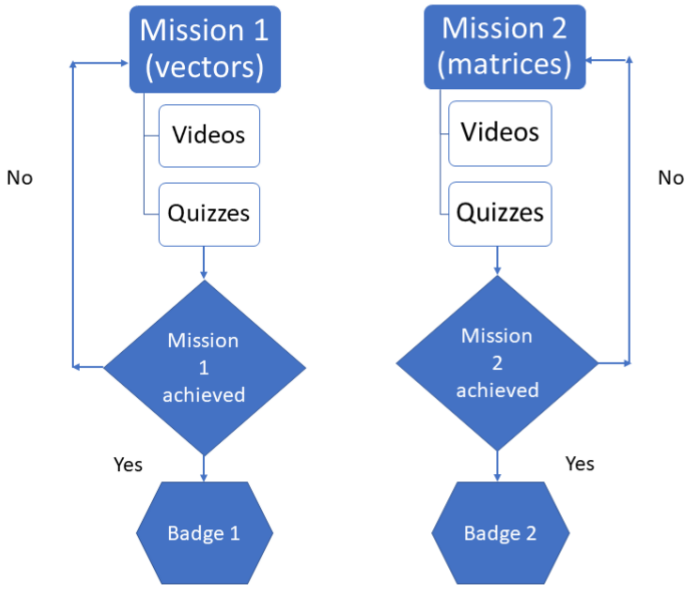


Figure 4.3.1: KA class setup showing two missions

Different sets of data are made available to the lecturer via the KA class applications. The data fields used in this analysis, only for the KA2 trials, are illustrated in Table 4.3.4.

Table 4.3.4: Moodle data from KA2 class application logs

KA Field Name	**Data contained**	**Examples**
Student	Student name as per login	Tríona Bloggs
Mastered	The number of challenges for which the student has received sufficient points to have achieved mastery of this skill	53
Time Spent (min)	The amount of time they have spent on the challenge in total	92.91666667
Time Spent on Videos (min)	The amount of time they have spent running the videos	3.733333333
Time Spent on Exercises and Challenges (min)	The amount of time they have spent in the exercises and challenges sections	156
Badges Earned	Number of badges earned. These are gaming badges that they receive based on their engagement	6
Points Earned	This is the total number of points earned in this KA class	36709
Classes	These are the list of the KA classes (or groups) to which they are assigned within KA and reflect the student groups as organised by the institute	Digital Systems 1C1, DT Group Semester 1 2015, Maths 1 2016, all classes
Student Profile	The KA identifier for that individual student	www.khanacademy.org/profile /kaid_811527419924388207024000 (as an example)

In the KA1 and KA2 trials, permission had been received to link the KA usage data to the students' grades; therefore, the data was not anonymised until after the data analysis.

4.3.2.4 Usage data analysis

All data analysis of the usage statistics was completed using the software application MS Excel. The usage log files obtained for usage analysis had first to be filtered to remove non-student users who accessed the resources, such as the lecturers or tutors involved in the module delivery.

In the case of the Moodle logs, the date and time, user full name and the event context, see Table 4.3.3 above, were used to filter the file and identify student access to the different GeoGebra tasks or KA URLs. Descriptive statistics such as the number of students hits or clicks per task and the distribution of hits across the term were compiled from these logs.

In the KA class application, the data illustrated in Table 4.3.4 was filtered from the logs. Descriptive statistics such as student time spent on videos and exercises versus their points scored were tabulated.

4.3.2.5 Grades

The use of student grades as part of analysis with respect to establishing cause and effect is problematic, as there can be many variables that influence the outcome of student tests (Howard et al., 2018; S. O. King & Robinson, 2009b; Loch et al., 2014). However, if tests are administered that are strictly aligned with the associated teaching, it may be possible to correlate students' learning with the use of specific resources (Howard et al., 2018; S. O. King & Robinson, 2009b; Loch et al., 2014). Notwithstanding this, it is possible to gain some general information about student learning through administering pre and post-tests (Howard et al., 2018; Loch et al., 2014; McKnight et al., 2000; Pickering & Joynes, 2016). Hence careful consideration was given to the use of the grades data gathered in this thesis in an attempt to gain insight about students' ways of engaging.

In the KA1 trial students completed an initial diagnostic test DT1 and were individually informed by the lecturer (and/or the MLSC staff) which topics and procedures they needed to improve on. They were then given access to the KA playlists via Moodle, shown how to log in and also given details about the availability of support through the MLSC. Six weeks later, this same group of students retook the diagnostic test (DT2).

In the KA2 trial, the lecturer used the class/coach functionality within the KA class application to align the missions with the week-by-week course material of the relevant module. Students were allocated 10% of their overall grade towards the completion of the KA element of the course, named the Khan Academy Masteries or KM. The overall assessment contained five elements: Class Test 1 (CT1) worth 10%; Class Test 2 (CT2) worth 10%; Tutorial attendance and Test (TT) worth 10%;

KM worth 10%; and a terminal exam worth 60%. The grade data was recorded for all 80 students attending the associated module.

In the end, the analysis of the grades data did not provide sufficient reliable evidence of students' engagement with technology to merit inclusion in the main body of this work and is therefore contained in Appendix B.

4.3.2.6 Focus group interviews

Interviewing students allows more in-depth probing on student attitudes and their thoughts (Cohen et al., 2007; Farrow et al., 2020; McKnight et al., 2000). These types of interactions between students and researchers can provide useful insights into the research problem (Cohen et al., 2007). The carefully designed focus group interviews were used to elicit further information, in the form of qualitative data, on students' engagement with the NF-funded project resources and with other support resources.

There were two focus group interviews carried out after the Geogebra2 trials. Each focus group had three participants from first-year undergraduate science.

A semi-structured approach was taken to the interview. There were specific questions that required answers, such as the students' reasons for using or not using the GeoGebra tasks that were made available on a voluntary use basis. As indicated in the survey, there was a particular focus on usability so that issue was also pursued. However, this PhD was not solely focussed on the use of GeoGebra, so a more general conversation about the use of technology resources was pursued in the focus groups. A copy of the interview protocol sheet is available in Appendix C. Prior to analysis, the interviews were transcribed by this researcher, either as Word documents uploaded into NVivo, or transcribed usng the inbuilt transcription editor in NVivo.

4.3.2.7 Focus Group Interview Analysis

As the focus of this research was on exploring the factors that influence students' engagement with technology, a phenomenon that has not been widely examined or conceptualised, inductive analysis was considered to be the best approach. The aim of inductive analysis is to develop an understanding of a phenomenon through the methodical examination of empirical observations (P. Johnson, 2011; D. R. Thomas, 2006). On the other hand, deductive analysis relies on using an a priori theory to test the data (P. Johnson, 2011; D. R. Thomas, 2006). While many researchers consider that inductive analysis allows objective analysis, in that the meanings inferred from the exhaustive coding processes are inherent in the data, others consider that the researcher will naturally influence the questions asked of the data, and thus meaning is socially constructed (Charmaz, 2000, as cited in P. Johnson, 2011, p. 5). According to Denzin (1971), inductive analysis is akin to the '*logic of naturalistic inquiry'* where the researcher enters the native world of people to make their worlds understandable through observation of their actions, behaviours and feelings (Denzin, 1971, as cited in P. Johnson, 2011, p. 2). This pragmatic study acknowledges that the researcher's own beliefs have a role to play in generating knowledge. In addition, no a priori theory was evident in the literature. Hence inductive analysis was used to socially construct the natural world of students' engagement with technology.

There are a number of different approaches taken to inductive analysis (P. Johnson, 2011), one of which is a general inductive approach, as outlined by Thomas (2006). This approach provides a systematic analysis method that is easy to follow and implement (D. R. Thomas, 2006). According to Thomas (2006, p. 238), inductive analysis uses '*detailed readings of the raw data to derive … themes …. through interpretations made from the raw data by … the researche*r'. The purpose of the generalised inductive approach is to:

- abbreviate the raw data into summary form
- make and demonstrate clear transparent links between the research objectives, the raw data and the findings
- provide a theory about the experiences that are apparent in the data

There are five procedures used for inductive analysis outlined by Thomas (2006, pp. 241–242) which are similar to those commonly found in the literature on inductive analysis (P. Johnson, 2011; Miles & Huberman, 1994). These five steps were rigorously adhered to by this researcher during the analysis and coding stages. This process resulted in the development of codes that summarised the raw data into themes relevant to the research objectives and questions. The use of NVivo facilitated this approach. In NVivo, raw data is coded to nodes, and sets of nodes can be linked through themes, subthemes and/or hierarchies. Nodes were created and identified with descriptive names and contained explanations and examples of data coded to those nodes. In addition, further coding of the data within the parent nodes was used to create sub-themes coded into child, or sub-nodes. Finally, links between different nodes and sub-nodes were established to display the relationships between them. As described by Thomas (2006, p. 242), the same text from the raw data was sometimes coded to more than one node. Where relevant, whole "segments" of student comments were coded to nodes and the count of segments coded to a specific node was reported, where a segment is an uninterrupted phrase, sentence or paragraph spoken by the student. Coding focus-group data in this way allows the identification of the strength of a theme within the data. The category of nodes and sub-nodes created through this system was continuously revised and refined until the most important and relevant themes were identified. Trustworthiness of the coding system was checked using stakeholder checks (D. R. Thomas, 2006, p. 244). Members of the team and the PhD supervisors were consulted to ensure the validity of the findings. Informal conversations were held with the team members as the outcomes emerged and reports were sent to individual lecturers. In addition, formal sessions were held with the PhD supervisors to check, modify and verify the coding system used and the inferences subsequently written in the findings. Examples of the code descriptions for the Encourage GeoGebra use and the relationships between nodes are shown in Table 4.3.5. Child or sub-nodes are illustrated in ***bold italics*** and grandchildren, or sub-sub-nodes in normal text.

Table 4.3.5: Code description and examples

Node Name	**Description**	**Example text coded at this node**
Encourage GeoGebra use	Factors that students consider encourage or discourage them to use GeoGebra.	Yeah, I think it's a better idea if they did that more if they said it was on the assignment because people actually do it then
GeoGebra purpose	References to lack of knowledge on the purpose of GeoGebra	For someone like coming in doing their first assignment if they told us like this is a really very helpful resource like obviously that pattern would follow as well
GeoGebra value	References to the value of GeoGebra within the module and/or for mathematics learning	Or what it can be used for as well, I thought it was just going to visualise just one graph
Usefulness	Where students mention how useful GeoGebra was or might be	I didn't know where to use it like I know you were given graphs but …I didn't think it was very useful
Graded assessment	Where reference to GeoGebra and assessment occurred	Honestly like unless it says on the assignment do this most people won't to be honest
Improvements	References to making improvements on the use of GeoGebra	You could plot your points and have this graph
Instructions on use	References to the need for instructions, or further	And to improve it I think maybe just have more instructions on like to get what you want from.

Node Name	Description	Example text coded at this node
	instructions on the use of GeoGebra	
Clarity	References where clarity of how to use GeoGebra might have helped	But again it wasn't very clear to me how to use it but that it is just me maybe cos I might not be able to use technology well but I think if it's a little bit more clear how to get the horizontal line test or the vertical line test I think it would be better
Tutorial on use	References to the possible value of having tutorials on its use	I think it would be good to have more like I do think they are useful but even to have like a tutorial in a computer room with tutors and that there
Use or demo in lectures	Any reference to value in lecturer using GeoGebra in class	Or if they are doing examples because they have the projectors if they want to do an example of something that they are explaining they can do an example on GeoGebra and then
Using alternatives	Explicit alternative resources students used where GeoGebra should have explicitly helped	.. I just used to go onto like Wolfram Alpha or any of those and type in like that kind of works to see a graph or like if I ever just wanted to see or compare my own answers.

4.3.2.8 Lecturer resource descriptions and comments

In order to set the context of the project, and to fulfil one of the outputs of the NF-funded project, it was necessary to create descriptions of the resources. These descriptions were initially intended as a resource that would be made available on the project website for wider HE access (NF, n.d.-d). As a result of the evaluations, described above, factors that influenced student engagement with these resources were identified. It was then necessary to characterise these resources with these factors in mind. A form of narrative analysis was used for this process.

Narrative analysis is generally used by researchers to interpret stories that are told about everyday life and can be reported on in a number of diverse ways (Parcell & Baker, 2018). While narrative analysis is often used to study traditional stories to analyse their structure, function and/or substance (Parcell & Baker, 2018), in this case it has been used to analyse the structure or characteristics of the NF-funded project resource trials. In a general sense, structural narrative analysis is used to analyse plot elements of a story (Parcell & Baker, 2018), but in this case it is used to identify elements, or characteristics, of the NF-funded project resource trials.

This was an iterative process where the lecturers were consulted about the various characteristics until a final agreed set were produced. The final agreed characteristics are: Trial name; Type of Technology; No of students; Context of use; Type of Task; Type of Formative Assessment; Grade for its use. A table of these is contained in Appendix D. These characterisations along with further comments from the lecturers were used in the description of the NF-funded resources in Chapter 3, the trial details in Chapter 5 and the classification of the resources within the TeRMEd in Chapter 6.

Narrative analysis of the lecturer comments with regard to their opinions of the success or otherwise of the trial of their resource was also used to help identify the factors that impact on student engagement as a response to RQ1. The discussion on this analysis is contained in Chapter 5.

4.3.2.9 Conclusion of Stage 3

Stage 3 of the research was used to identify implementation factors and pedagogical features of the NF-funded project resources that impacted on student engagement with these resources, thus providing evidence to address RQ1 and RQ2. The measures used to evaluate the NF-funded resources were analysed within the context of student engagement, as defined in Section 4.2.2. These research outcomes are further discussed in Chapter 5.

The outcomes from Stage 3 of the research were used to inform Stage 4 of the research. The methodology used in Stage 4 is outlined in the next section.

4.3.3 Stage 4: TeRMEd framework development

One of the aims of this PhD is to address the issue of a lack of a framework for the evaluation of technology-enhanced resources within first year non-specialist mathematics modules. RQ3, see Section 4.2.1.2, was formulated to address this problem. The theoretical foundation for the development of the TeRMEd framework was the detailed descriptions of the NF-funded project resource trials, the outcomes of the evaluations of the NF-funded project resources and the literature review outlined in Chapter 2 and in Section 5.7. The methodology followed for this process is shown in the flowchart in Figure 4.3.2.

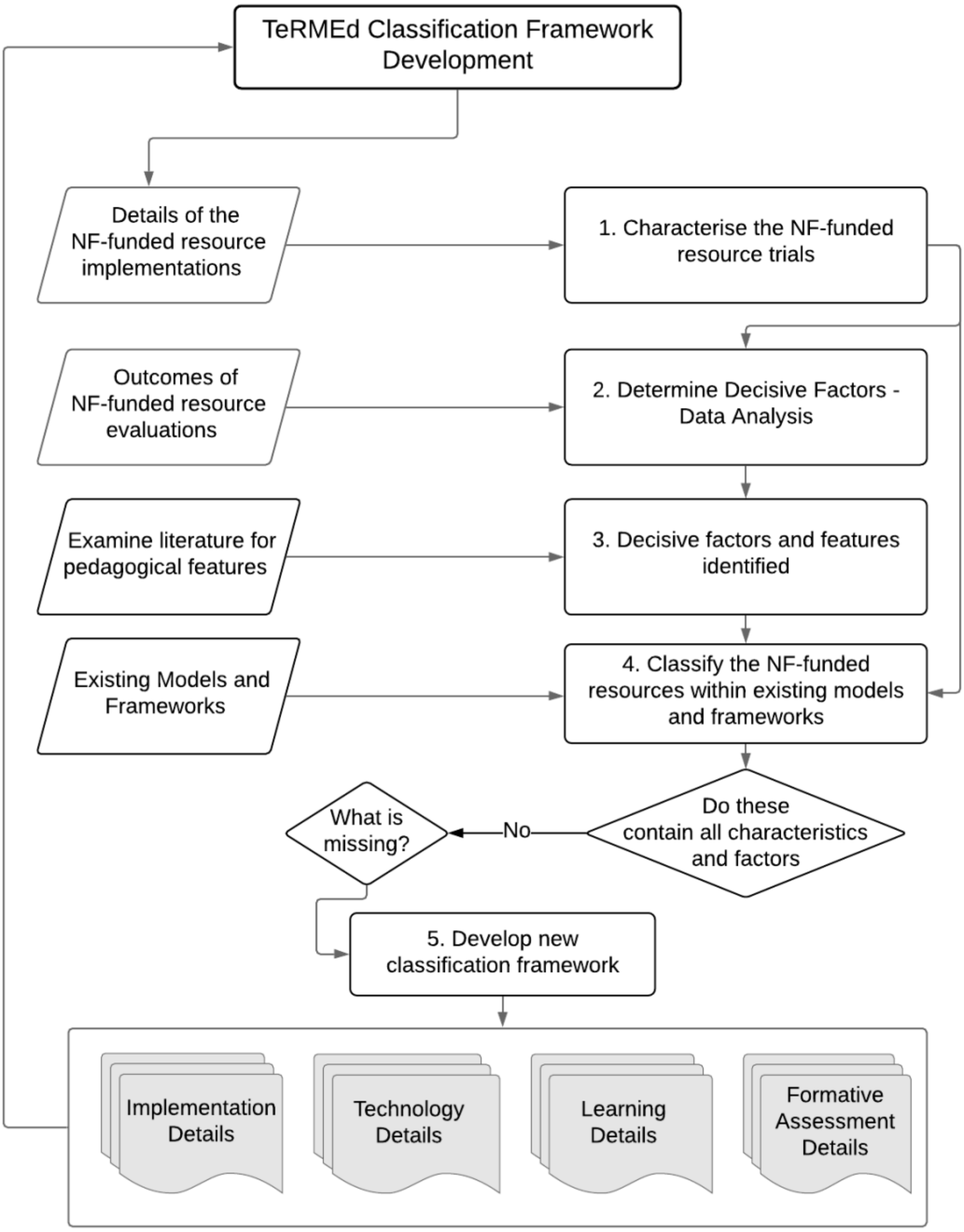


Figure 4.3.2: Process involved in the development of the TeRMEd framework

There were five iterative steps to the development of the TeRMEd framework. The first step involved the characterisation of the NF-funded project resource descriptions which were agreed with the lecturers involved in the project, and have already being discussed in Chapter 3, and Section 4.3.2.8. The outcomes of the evaluations in Stage 3 of the research led to the identification of factors that influenced student engagement with the NF-funded project resources, step two. Step 3 involved the identification of pedagogical features from the literature. In step 4, existing evaluation frameworks were investigated in order to determine how technology integration is currently classified, and whether all the factors identified during Stage 3 research, and the literature review, were contained within these frameworks. As all the factors were not contained, a new classification system was developed, the TeRMEd classification framework, which was the final step in the process

As part of the pragmatic nature of this research, a number of steps were taken to validate this framework and ensure its pragmatic validity. These steps are outlined in Figure 4.3.3.

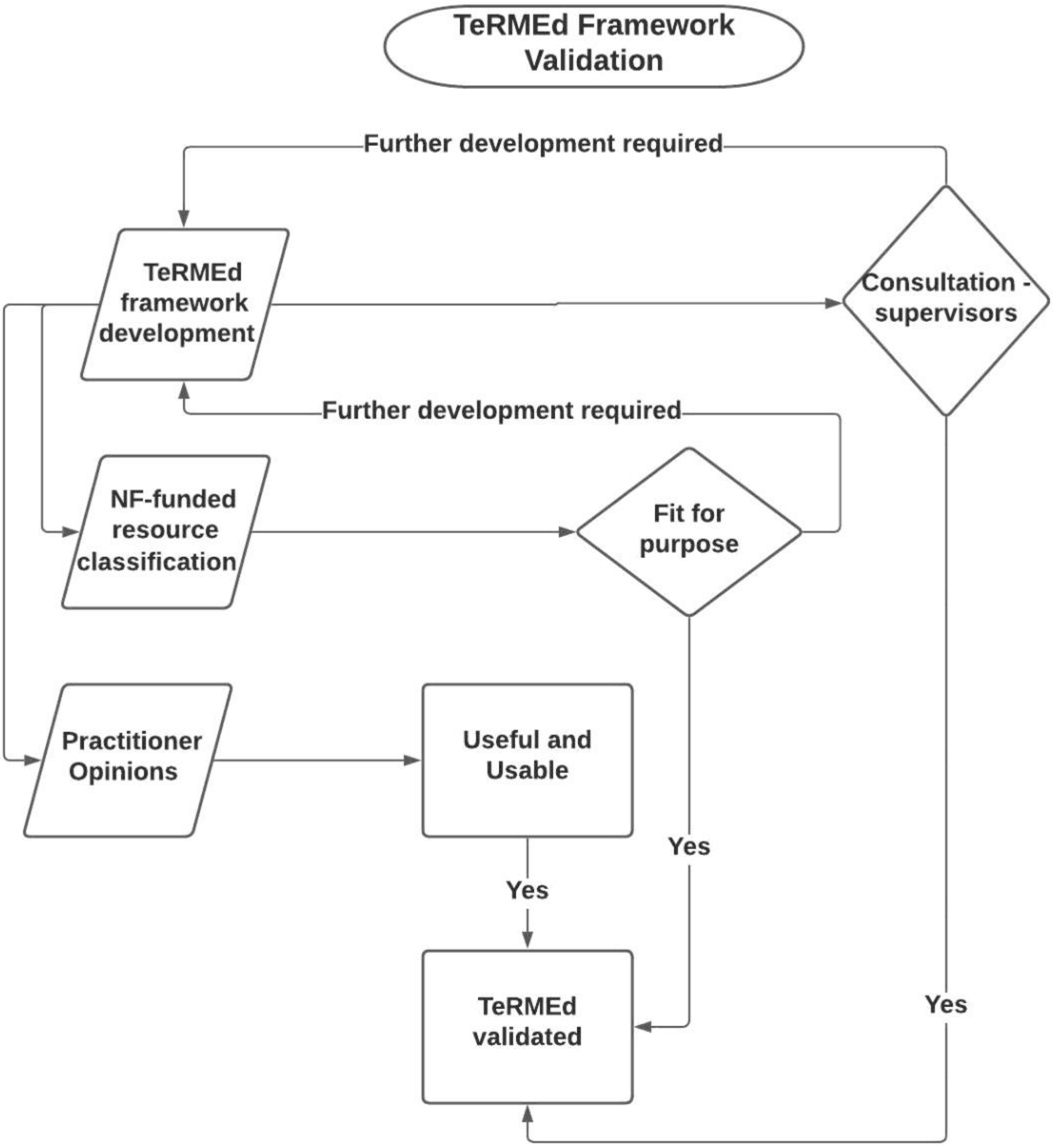


Figure 4.3.3: Validating the TeRMEd classification framework

In the first instance, this researcher, the two PhD supervisors, and the NF-funded project team lead, met formally to discuss the framework. This was an iterative process; as discussions progressed, this researcher repeatedly reviewed the outcomes of Stage 3 and the literature to ensure nothing had been overlooked. This aligns with the processes required for validity in mixed method studies (D. R. Thomas, 2006; Worren et al., 2002).

Secondly, the NF-funded project resources were classified within the TeRMEd framework. This process served to investigate if the TeRMEd framework was fit for purpose, in that a number of technology-enhanced resources could be classified within the TeRMEd framework. This process supports the pragmatic nature of project, in that the constructs encompassed within the TeRMEd framework were operationalised (Worren et al., 2002)

After the development of the TeRMEd classification framework, the third and final validation process was conducted. Lecturers involved in this project were asked for opinions of the framework and its potential value within their own practice. A detailed questionnaire was sent to the eight lecturers involved and the analysis of their responses were used to confirm the framework as an instrument for practitioners in the field. This evaluation process provides validity in terms of a pragmatic study as suggested by Worren et al. (2002). The questionnaire was carefully designed to elicit responses about all aspects of the framework and structured to ensure face and content validity as discussed in Section 4.3.2.1. In order to facilitate the lecturers in engaging with the TeRMEd framework, they were given a document describing the TeRMEd framework sections, categories and subcategories, and the classification of their particular resources within the framework. This narrative and visual representation of the TeRMEd classification framework provided an extra level of validity to the study, which Worren et al., (2002) noted as lacking in many pragmatic studies. Six of the members of the project team completed this survey; those members directly involved in the development and trialing of the resources. The project lead, who co-developed the GeoGebra tasks, did not complete the survey as she had been involved in early discussions of the framework. One of the lecturers was responsible for two trials, KA1 and KA2, and she completed one survey for both trials. The quantitative aspects of the completed surveys were analysed in MS Excel and the qualitative data was imported into NVivo for general inductive analysis, as described in Section 4.3.2.7. Details of the survey instrument and associated documents are contained in Appendix E.

A detailed description of the TeRMEd framework, its genesis, and subsequent validation is given in Chapter 6.

The third and final process of the pragmatic nature of this study was to test the system in a real setting. This testing was completed in Stage 5 of the research which is outlined in the next section.

4.3.4 Stage 5: Using the TeRMEd framework in a first-year engineering mathematics module

The aim of this stage of the research was to evaluate the TeRMEd classification framework within a context that was outside the scope of the original NF-funded project. The selected research context was a first-year engineering group who completed two mathematics modules, EM114 where Matlab was used by students to help solve numerical problems, and EM122 where matrices and vectors are covered. Further details of the research context are contained in Chapter 7.

A mixed-methods approach was taken during this stage of the research. Quantitative data in the form of a survey was used and statistically analysed. Focus group interviews and open responses to questions formed the basis of the qualitative data gathered. Table 4.3.6 contains a list of the data gathered and the associated analysis. Each of these are discussed in more detail in the subsections below.

Table 4.3.6: Research methods - stage 5

Research Stage	Data Collection Instrument	Data Analysis Techniques
Stage 5	TeRMEd Classification Framework	Narrative
	User Experience Survey	Frequencies, percentages
	Focus Group	Inductive Analysis & Case Study Analysis

4.3.4.1 TeRMEd framework evaluation

There were a number of steps taken to provide the data for evaluating the TeRMEd framework. The steps consisted of:

1. Classifying Matlab within the TeRMEd framework as part of its planned use
2. Conducting a post-use survey in order to complete the Implementation section* of the classification of Matlab within the TeRMEd framework
3. Running focus group interviews to ensure the TeRMEd framework contained all identifiable factors that impact engagement

These are discussed in more detail below.

*The TeRMEd classification framework and its various sections will be explained in detail in Chapter 6.

Step 1: Matlab was classified within the TeRMEd framework, as a first step in the evaluation process. As described in Section 4.3.2.8, this is a form of narrative analysis, where the relevant elements of the Matlab integration were identified and classified within the TeRMEd framework in discussion with the lecturer involved in the integration of Matlab.

These classifications, and the factors that impact student engagement determined in Stage 3 of the research, were used to analyse and determine how students would engage with Matlab during the EM114 module.

Step 2: After the module had been completed, students were asked to complete a short survey on its use. The questions in this survey were aimed at providing the necessary user experience data to complete the Implementation section of the TeRMEd framework. To that end, students were asked selected questions from the original survey, discussed in Section 4.3.2.1. These particular questions were used to calculate values for the TeRMEd framework and are shown in Table 4.3.7 below. In addition, students were asked to provide comments on the use of Matlab within the module. Frequencies and percentages of students who rated questions 2 to 5 as either Strongly Agree (SA) or Agree (A) were calculated for input into the Implementation section of the TeRMEd framework.

Table 4.3.7: User experience Likert scale items

Questions	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1. I used the Matlab application regularly, even when it was not assigned as part of the EM114 module					
2. For me it was easy to use Matlab					
3. Using Matlab enhanced my learning of the mathematics required in EM114					
4. I was easily able to navigate the content in Matlab					
5. I found that Matlab is a useful resource for solving mathematics problems					

6. It was clear to me what I needed to accomplish when using Matlab within the EM114 module					
7. Using Matlab increased my confidence in my ability to complete 1st year mathematics successfully					

This student survey was completed in Autumn 2019 by students who had attended the EM114 module in the previous Spring. The survey was distributed while students were attending a second year Mathematics module lecture. All 99 students attending class that day completed the survey in full (total cohort 120).

The analysis of the survey data and the open response questions was used to evaluate the module and determine if the students' engagement was as predicted in Step 1.

Step 3: The final step in the evaluation of the TeRMEd framework was to conduct focus group interviews with the students who had attended the module. The focus groups were used to elicit responses from the students regarding the use of Matlab within their mathematics modules. These, along with the responses to open questions in the survey, were analysed using inductive analysis as oulined in Section 4.3.2.7. An example of the codebook used can be found in Appendix F.

The analysis of this data was used to determine two things: one was to establish if the students who partook in the focus groups corroborated the evidence from the survey, and the second was to determine if further evidence emerged regarding student engagement with Matlab during the EM114 module.

The focus groups were conducted shortly after students had completed the module, and prior to their end-of-year exams. Two focus groups were held: one with three students and the other with two. All five students were male.

Appendix F contains the details of the data gathering instruments for Stage 5 of the research.

4.4 Validity, reliability and trustworthiness of this study

The rationale behind the chosen research methodology, as discussed in this chapter, is an essential element when considering the accuracy and authenticity of the outcomes of a study (Farrow et al., 2020). The research paradigm associated with the research has a part to play in determining the validity and reliability of a study, for example a positivist approach aspires to '*high standards of* *validity and reliability supported by evidence*' (Farrow et al., 2020, p. 14). On the other hand, an interpretivist approach often relies more on the trustworthiness of the study in terms of the outcomes being credible, dependable, confirmable, and transferable (Kivunja & Kuyini, 2017). However, Morse et al. (2002) argue that qualitative researchers should pay attention to both validity and reliability throughout all stages of the research in order to ensure its trustworthiness. According to Guba (1981), credibility and dependability within an interpretivist approach are akin to internal validity and reliability in a positivist approach (Guba, 1981, as cited in Kivunja & Kuyini, 2017). Reliability in this study has been achieved through this researcher's careful construction of the coding schemes as described earlier in the chapter. The validity of the study is discussed further below. The PhD supervisors provided the necessary confirmability by being critical friends who challenged this research, and indeed the entire PhD study. Transferability of the outcomes has been supported through the detailed documentation of the research context which allows readers to apply the findings to their own circumstances.

The pragmatic researcher is not necessarily looking for a truth, but rather relies on finding a value in the application of the research, an output that works at this time (Farrow et al., 2020; Weaver, 2018). Pragmatic validity can be considered in terms of how the use of the research output steers activity to achieve an objective in the real world (Worren et al., 2002). Worren et al. (2002) suggested three approaches to ensuring pragmatic validity: the first is to consider the degree to which the instrument is adopted; the second, to test the system within a real context; and the final one is to ask the users their opinions of the system. Within this study, the factors that affect student engagement with the NF-funded project resources were used as a basis to develop a framework that practitioners can use in their 'real world' when planning technology implementations. The first approach to validity has yet to be tested, though the TeRMEd framework was received positively when presented at the September 2019 CETL conference (Ní Shé et al., 2019b). The TeRMEd framework was applied successfully in an experimental situation in Stage 5 of the research, reported on in Chapter 7, and thus fulfils the second approach to pragmatic validity. The third approach was achieved through the survey that was completed by the team members involved in the NF-funded project. Each of the team were positive about using the framework within their own contexts, as discussed in Chapter 6.

Finally, it is worth mentioning the concept of triangulation. Many researchers refer to the value of triangulation in achieving validity in mixed methods studies (Cohen et al., 2007; Creswell & Plano Clark, 2018; Norman K. Denzin & Lincoln, 2005; Farrow et al., 2020). In this study, two of the most common triangulation methods were employed. Methodological triangulation is provided by using a mix of research methods during the project, and in this study both qualitative and quantitative methods were used. Data triangulation refers to the gathering of data using different strategies at various stages throughout a study. In this project, two main strategies were used. Data was gathered from students in the form of surveys and subsequent interviews during Stage 3 and Stage 5 of the research. Lecturer data was gathered using a different strategy, conversational data was gathered in earlier parts of the research and survey data gathered once the TeRMEd framework was completed.

The integrity of a research study not only lies with its trustworthiness but also in the due regard given to ethical standards. In the next section, the ethical considerations of the study are described.

4.5 Ethical considerations during this work

There are certain risks, such as ethical issues, that need to be managed, regardless of the type of research that has been undertaken. Maintaining research integrity has become key to the management of research projects, and as a result research institutions have introduced regulatory committees and procedures that must be adhered to (Cohen et al., 2007). For example, when using human participants, there is an onus on the researcher to make sure the participants are fully informed and have given their consent (Cohen et al., 2007; Farrow et al., 2020). As this project involved the gathering of data from students attending four HEIs, it was important to ensure that the four ethics committees' guidelines were correctly adhered to. In all four institutions, the ethics applications involved the submission of documents containing the following:

- details of the project and its intended outcomes;
- the specific students who were going to be asked to be involved in the project;
- a copy of the survey and interview questions;
- particulars relating to the intention to record and use student data such as grades and usage statistics; and
- details of the risks involved to the students and the steps taken to mitigate them.

With regards to the latter point, a plain language statement and informed consent form was drafted and either handed to students prior to the face-to-face research or made available online in the completion of online surveys. In all instances of data gathering, students were given the time to read the plain language statement, ask any questions, and then sign an informed consent form. In addition, only those students over 18 were allowed participate in the surveys. All participation was voluntary and did not impact on the student module outcomes. Access to students for the completion of surveys was made available by the team members involved in the project during a ten or fifteen-minute slot at the beginning or end of a scheduled class. In addition, where access for interviews was required, this researcher was given permission to attend a scheduled class and seek volunteers. This was followed up by an email, which the module lecturer distributed to the students attending the module, outlining the project and seeking volunteers. A small monetary voucher, of ten euro, was made available to students who volunteered for interview, as a thank-you for their time and effort in participation. Copies of the approved participant information sheets, consent forms and emails that this researcher submitted, are available in Appendix G. There were no instances where students refused to participate in the research nor where they followed up with any issue(s) subsequent to the research.

4.6 Discussion

At the outset of this chapter, the importance of selecting the correct research framework to address the research questions was discussed. In addition, the researcher's own paradigm was taken into account and considered in terms of the validity and reliability of the research.

A mixed methods research methodology was chosen for this project as it supports the pragmatic approach taken by this researcher. In addition, an interpretivist approach was taken to investigate factors that impact on student engagement with technology. The use of triangulation of the data and methods that mixed methods facilitate, also contributed to the trustworthiness of the project.

Details of the rationale behind the development of the surveys, interview questions, usage data, and lab experiments have shown how they were used to address the research questions and ensure sufficient data was gathered. The analysis methods were judiciously chosen in-line with best practice in educational research as determined from the literature. Finally, research integrity was ensured, and ethics approval carefully considered and sought during each stage of the research.

The research outcomes of Stage 3 of the research will be considered in the next chapter.

Chapter 5 Student engagement with the NF-resources

5.1 Introduction

The NF-funded project resources, described in Chapter 3, were trialled and evaluated in a number of different settings. One of the objectives of this PhD study is to evaluate the effect different learning environments have on student engagement with technology-enhanced resources. The results of the evaluations of the NF-funded project resources were used to identify factors of the learning environment that impact on student engagement. The relevant outcomes of these evaluations are described in this chapter.

Prior to the implementation of the NF-funded project resources, it was not possible to be sure if, how, and why, students would engage with them. Hence, the aim of the evaluations was to determine the level of use of the NF-funded project resources and students' opinions of them. These evaluations, completed by this researcher, resulted in the production of a report on each of the NF-funded project resources. The lecturers involved in the NF-funded project used the report outcomes to modify subsequent implementations of the resource. Outcomes of the evaluations that were pertinent to two of the research questions of this study, RQ1 and RQ2, were used to identify factors that impact on student engagement with technology-enhanced resources. In addition, comments made by the lecturers on receipt of the reports were used to corroborate or dispute some of these findings. In order to focus the analysis of the NF-funded project resource evaluations, the following research questions, relating to RQ1 and RQ2, were formulated:

- RQ5.1: What usage of the NF-funded project resources was made by students involved in the project?
- RQ5.2: What are the similarities/differences found in students' opinions of the impact of the various trials of the NF-funded project resources?
- RQ5.3: What evidence emerges from the focus group interviews that contributes to identification of factors that encourage student engagement with technology?
- RQ5.4: What are the opinions of the lecturers regarding the use of the NF-funded project resources they developed?
- RQ5.5: What are the factors, if any, found in the literature that need to be considered in addition to those identified through the resource evaluations?

The first section of this chapter is used to illustrate how the evaluation instruments contributed to the final set of factors identified from the data. In the subsequent sections, each of the research questions listed above is addressed. The final section contains a discussion and conclusion on the results of the analysis.

5.2 Methodology revisited – factors identified

In Chapter 3 and 4, details of the NF-funded project resources' trials and associated evaluations were discussed. The characterisation of these trials, along with the evaluation details, are shown in a single table, Table 5.2.1, below.

Table 5.2.1: Trial implementation and evaluation details of the NF-resources

	UniDoodle		**Khan Academy**			**GeoGebra**	
	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2
Dates	2015/16	Spring 2016	Autumn 2015	Spring 2016	Autumn 2015	Autumn 2015	Autumn 2016
Course	2nd yr. Eng (Uni1)	1st yr. Eng (Uni2)	1st yr. Comp (IoT1)	1st yr. Comp (IoT1)	1st yr. Business (Uni2)	1st yr. Science (Uni1)	1st yr. Science (Uni1)
Module	Circuit Analysis	Eng. Maths; Problem-solving	Diagnostic testing	Linear Algebra	Business Maths	Diff. Calculus	Diff. Calculus
# Students	12	165	175	80	335	476	396
# Surveys (# items in the survey)*	12 (100%) (42 items)	98 (59.4%) (42 items)	115 (65.7%) (48 items)	37 (46.3%) (27 items)	108** (32.2%) (13 items) 37 (further 13 items)	46 (9.6.%) (14 items)	221 (55.8%) (14 items)
# Usage Stats	12 (100%)	137 (83%)	175	80	335	467	396
#Focus Groups	---	---	---	---	---	---	2 (n=6)
Context	Regularly in tutorials	Four 1-hr classes (2 per module)	After diagnostic test, access given to	KA Masteries as continuous assessment (10% of final grade).	KA resources available via Moodle	Interactive GeoGebra tasks (10), GeoGebra applets (2),	Interactive GeoGebra tasks (6), Numbas quizzes (2)

			selected KA resources via Moodle	Class/coach functionality used		Numbas quiz (1) in Moodle	in Moodle. Both quizzes graded; 1 task linked to an assignment

**As discussed in Chapter 3, each of the project members who developed and/or implemented a resource selected the number of items used in the survey, hence the numbers vary across implementations.*

*** In the KA3 trial, only those students who had selected that they had actually used the KA resource were asked to complete the second part of the survey. Hence 37 of the 108 students completed the second part of the survey.*

The analysis of the data gathered using the research instruments, and the characterisation of the NF-funded project resources listed in Table 5.2.1, led to the identification of a number of factors that influenced student engagement with the resources. Figure 5.2.1 illustrates which research instruments contributed to the development of the factors. The factors are coloured grey and numbered, for ease of reference, in order of their first mention within the chapter. Some factors identified early in the analysis were subsequently redefined and renamed, so both labels are shown. For example, factor number 4 was originally identified as ‘ease of use’ but subsequently expanded to ‘user experience’.

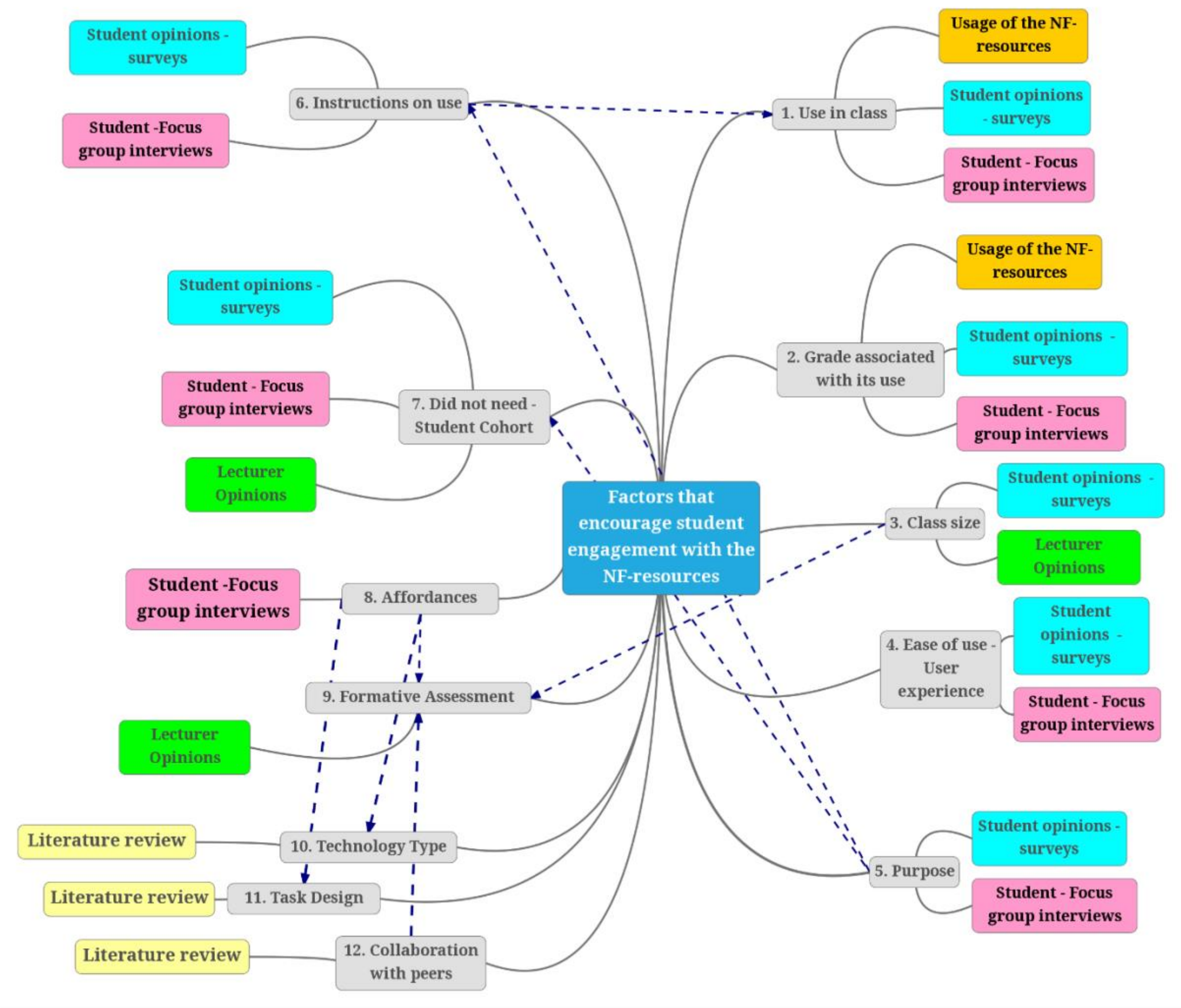


Figure 5.2.1: Final research instruments that contributed to the identification of the factors

Grey – Factors that impact student engagement; Orange – resource usage; Blue – Student surveys; Pink – Student focus group interviews; Green – Lecturer opinions; Yellow – Literature review; Continuous black line – connect factor to identifying research instrument; Dashed navy lines - connect factor that impacts on another factor.

The identification of the factors from the analysis of the data gathered by each of these research instruments is discussed in following sections.

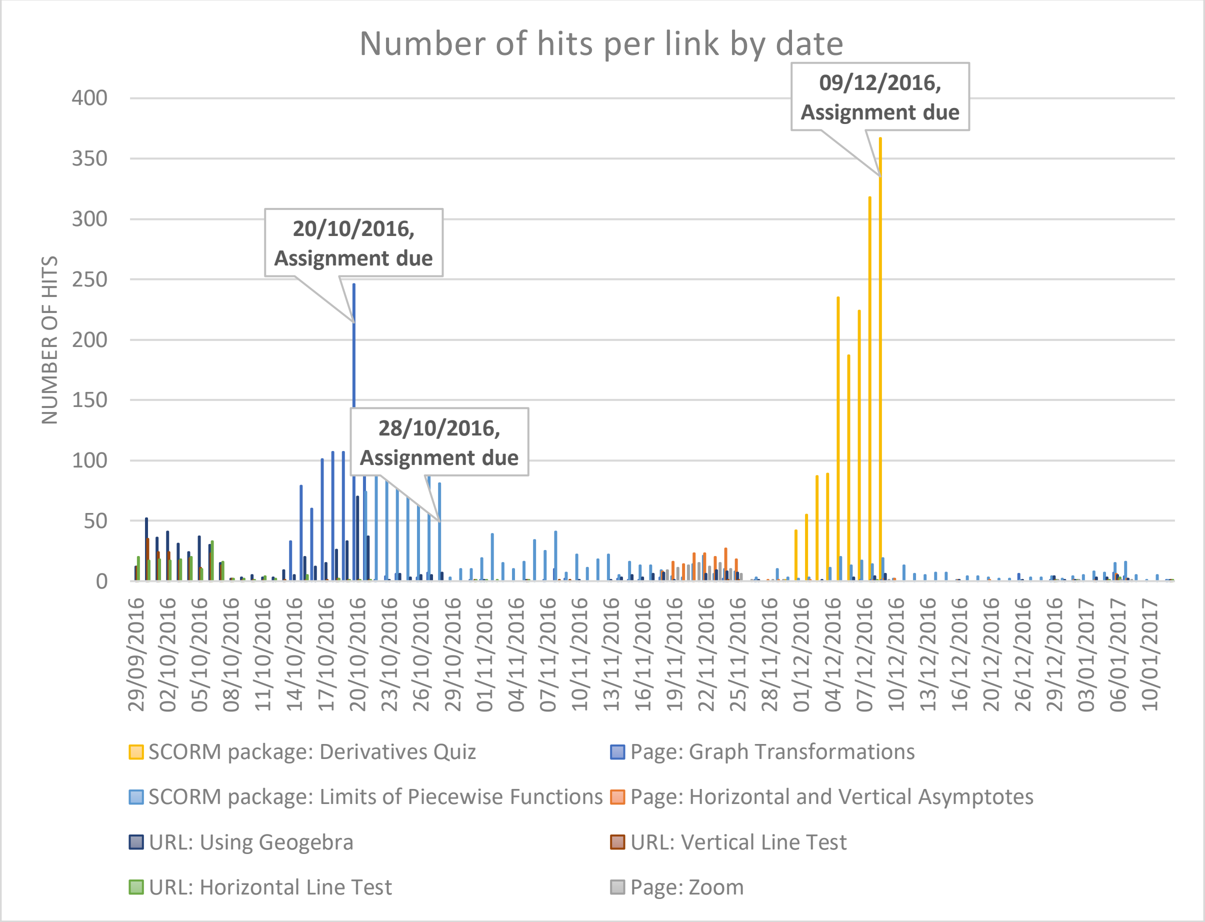
5.3 Student usage of the NF-funded project resources

This section aims to answer the first research question outlined above: RQ5.1: *What usage of the NF-funded project resources was made by students involved in the project?* The use of the GeoGebra tasks and the KA playlists/mastery challenges was electronically recorded through the institutions' VLE. For UniDoodle, lecturer observation and responses to student surveys provided data on usage.

Full details on the specifics of usage for each resource can be found in Appendix H but the more salient points are highlighted here.

In the case of the KA1 and KA2 trials both grade data and usage data were available for students who attended these trials. Analysis of the grade data is contained in Appendix B.

In GeoGebra, for example, in order to determine if there was a pattern of engagement relating to the dates graded assignments were due, the number of hits per day was calculated. . The number of hits per day, by task (or URL link), is displayed as in Figure 5.3.1 for GeoGebra2, where higher access for the assigned tasks coincided with the due dates. In the GeoGebra1 trial there was only one graded assignment, the hits per day for this graded assignment also show that this was the most accessed URL and that access occurred around the assignment due date. This data is illustrated in Appendix H.2.1.



09/12/2016, Assignment due

20/10/2016, Assignment due

28/10/2016, Assignment due

Figure 5.3.1: Number of hits per day in the GeoGebra2 trial

Similarly, 62% of those who accessed the KA3 resources did so in the two weeks prior to the exam, although overall the number of students who accessed the resources was very low (37 out of a total of 335 students).

The students' usage of the various NF-funded project resources is now summarised in Table 5.3.1.

Table 5.3.1: Percentage of students who accessed the NF-resources

Trial	**% students who engaged in any way with the resource**
UniDoodle1 (n=12)	100%
UniDoodle2 (n=165)	83%
KA1 (n=175)	17%
KA2 (n=80)	99%
KA3 (n=335)	10%
GeoGebra1 (n=467) Graded Task	92%
GeoGebra1 (n=467) Non-Graded Task	50%
GeoGebra2 (n=396) Graded Task	87%
GeoGebra2 (n=396) Non-Graded Task	60%

It is clear that there are differences in usage of the various NF-funded project resources. When examined in light of differences between the NF-funded project trials, it is evident that the use of a resource in class, and the association of a grade with its use, impacts on usage.

UniDoodle1 & 2 and KA2 were used in class, and in all three trials usage is higher than in the other trials where students were expected to use the resource in their own time, with the exception of the graded GeoGebra tasks.

In both years, the GeoGebra tasks that were graded were accessed by a greater percentage of students than those that were not graded, and the greatest number of hits occurred around the dates the graded tasks were due. In the KA2 trial, all bar one student engaged with the KA mastery challenges, in contrast to the low level of access in the other two KA trials. Students in the KA2 trial received 10% of their grade for mastery challenge completion..

Therefore, two early emerging factors that encourage usage are identified from this data, the 'use in class', and the 'grade associated with its use'.

5.4 Student opinions of the NF funded project resources - survey

In this section, data related to the second research question outlined at the beginning of this chapter will be presented: RQ5.2: *What are the similarities/differences found in students' opinions of the impact of the various trials of the NF-funded project resources?* The data from the student surveys was used to address this question.

Detailed analysis of the individual trial survey responses is beyond the scope of this study. Instead, the focus is on comparing the outcomes across the different NF-funded project resource trials to determine factors that encourage or discourage engagement. As discussed in Chapter 4, the survey consisted of a maximum of 48 items addressing five dimensions: background, usability, engagement, learning, and confidence. Each of the lecturers involved in the project adjusted the number of survey items used to evaluate their particular NF-funded project resource trial (see Table 5.2.1). Appendix A contains a list of the items asked in each trial.

The analysis is presented as follows: the first subsection examines the items that were common across all the trials; the next three subsections examine the common items asked in the trials of each of the three different resource types: UniDoodle, KA and GeoGebra; and the final subsection contains a discussion of these outcomes.

5.4.1 Common items across the NF-funded project trials

There were three common background questions asked in all the surveys. A total of 637 students responded to these surveys, almost 39% of the total student population involved in the trials, see Table 5.2.1. As the full details of the background data has no bearing on the discussion, it is contained in Appendix I. Apart from background, there were four additional items common to each of the seven trials:

- One Usability item
    - ***Easy to Use*** (For me it was easy to use the resource)
- Two Learning items
    - ***Enhanced Learning*** (Using the resource enhanced my learning of the subject)
    - ***Resource Useful*** (I found the resource useful)
- One Confidence item
    - ***Increased Confidence*** (Using the resource has increased my confidence in my ability to complete 1st year mathematics successfully)

The possible responses to these items were Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D) and Strongly Disagree (SD). The number of respondents who selected SA and A was aggregated for each of these items and an overall percentage of positive responses, per trial, was calculated. See Figure 5.4.1 for a radar of the diagram of the percentage of respondents, per trial, who selected SA or A for each of the four common items asked. Note that the questions are referred to by their short name as in the bold italics above.

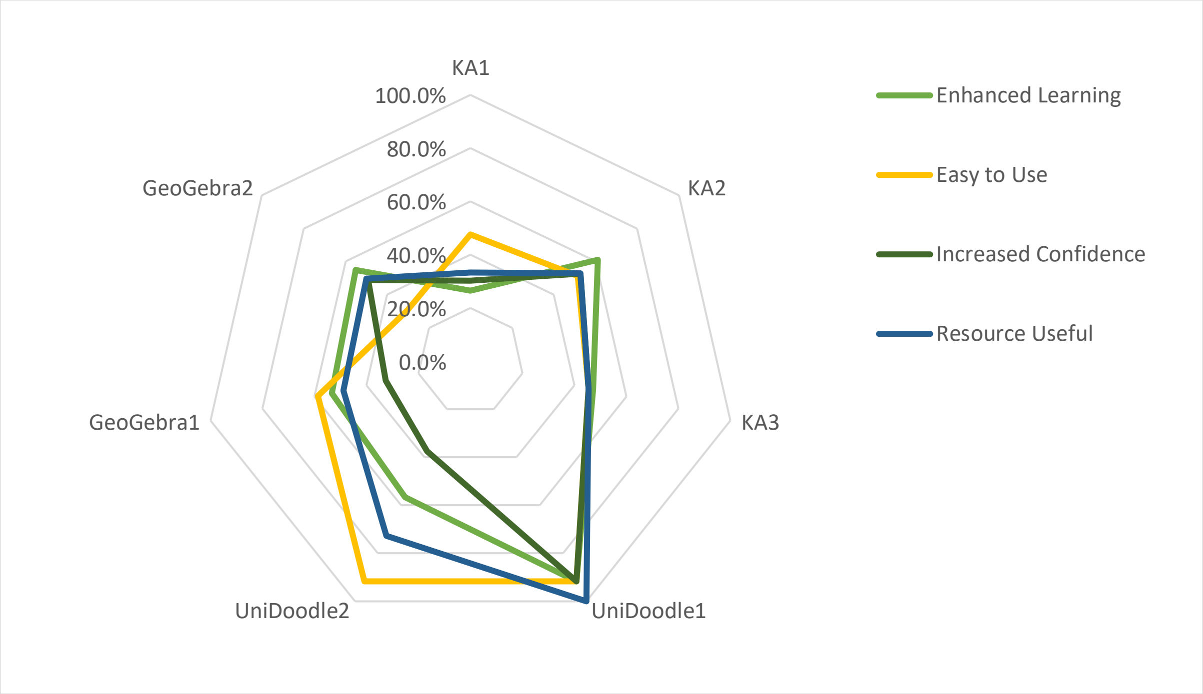


Figure 5.4.1: Positive responses for the four common items in the seven trials

Fisher exact tests were used to compare the distribution of responses (SA, A, N, D and SD) for the different resource types, and between trials of the same resources, and some significant differences were found. The full set of results can be found in Appendix I.2. This data supports the findings illustrated in Figure 5.4.1, in that UniDoodle was the most highly rated resource overall and that, bar the responses to the Easy to Use item, GeoGebra was rated higher than both KA1 and KA3, though not over KA2. Significant differences were also f found between trials of different resource types held within the same university. For example, UniDoodle2 was rated significantly higher than KA3 on the Ease of Use ($p<0.001$) and Resource Useful ($p=0.007$) items. Any differences found between trials of the same resource type will be discussed in the sections on each resource type below.

5.4.1.1 Prior confidence in mathematical ability

There were two further items asked in all trials bar GeoGebra, about students' confidence in their mathematical ability. As discussed in Chapter 3, the students who partook in these trials traditionally have varying mathematical backgrounds and are known to have difficulties with mathematics (Faulkner et al., 2010; Gill & O'Donoghue, 2007a). Thus, these questions were aimed at establishing the students' own views on their confidence in their mathematical ability.

- ***Have Difficulties:*** I regularly have difficulties with mathematics

- ***Handle Difficulties:*** When I have difficulties with mathematics, I know I can handle them

The percentage of respondents who selected either SA or A for these two items is shown in Table 5.4.1.

Table 5.4.1: Percentage of respondents who answered positively to the items on confidence

Trial	**Have Difficulties (% positive)**	**Handle Difficulties (% positive)**
UniDoodle1	25.0%	75.0%
UniDoodle2	31.6%	59.2%
KA1	17.4%	33%
KA2	16.2%	29.7%
KA3	32.4%	55.6%

In general, the students attending the universities (UniDoodle and KA3 trials) have achieved a higher entry level mathematics than those attending the IoT's, (KA1 and KA2 trials) (DES, 2011; O'Sullivan et al., 2015), which could explain why this cohort of students are more confident about their ability to overcome mathematics difficulties.

5.4.2 UniDoodle

5.4.2.1 There were 42 questions asked in both UniDoodle student surveys. In the following analysis, the outcomes of Rasch analysis (completed by Dr. Ann O'Shea) and Pearson Chi Square tests are used to determine any significant differences between the two UniDoodle trials, again with a view to determining factors that encourage or discourage engagement. The Rasch Model investigates the unidimensionality (consideration of a single trait) of Likert scale data; that is that it can be used to validate that a set of questions or items measures a single construct. Responses to a set of related Likert scale items are grouped together and, where the RASCH model fits, can be considered to measure a single latent construct, thus enabling the use of statistical measures to quantify and compare results. Three scales were created from the 42 questions asked in the UniDoodle trials: Ease of Use, Formative Assessment and Increased Confidence. These are discussed below. Ease of use in UniDoodle

There were five survey items in the UniDoodle trials that related to Ease of use: items 25, 26, 28, 29 and 30. While the scale was reliable, no significant differences were found (see Appendix J).

5.4.2.2 Formative Assessment and Learning & Engagement in UniDoodle

Two further scales were created from the 42 items in the UniDoodle trials. Twelve of the 42 items were used to create a Learning & Engagement scale (items 6- 9, 11- 15, 19, 21 and 41) and six to create a Formative Assessment scale (items 17, 18, 20 and 22- 24). Both scales were found to be reliable (Appendix J). Thus, central tendency measures can be computed to determine the students' responses to each of the two scales (see Table 5.4.2).

Table 5.4.2: Summary data for the scales

	Trial	N	Mean	Std. Deviation	Std. Error Mean
Formative Assessment Measure	UniDoodle2	98	-1.8188	1.65113	.16679
	UniDoodle1	12	-3.4325	1.25283	.36166
Learning and Engagement Measure	UniDoodle2	98	-1.1997	1.17566	.11876
	UniDoodle1	12	-2.4067	.80106	.23125

(Note that negative measures correspond to agreement with the statements and vice versa, the further from zero the stronger the agreement).

In Table 5.4.2 we can see that for both scales the mean response show that students more strongly agreed that the UniDoodle2 resource supported both Formative Assessment and Learning and Engagement. The t-test was then applied to compare the results and determine if there was a statistically significant difference response between the two UniDoodle trials in these scales (see Table 5.4.3).

Table 5.4.3: t- test results for UniDoodle1 and UniDoodle2 groups

	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**Lower**	**Upper**
Formative Assessment Measure	3.267	108	.001	1.61372	.49395	.63463	2.59282
Learning and Engagement Measure	3.452	108	.001	1.20697	.34961	.51398	1.89997

The t-tests for equality of means (Table 5.4.3) shows statistically significant differences between the means of the groups on the Formative Assessment and the Learning and Engagement scales. In both cases, the UniDoodle1 students were more positive about the use of UniDoodle. The class size in UniDoodle1 (n= 12) was smaller than in UniDoodle2 (n=165), which is a possible factor that impacts on these results.

5.4.2.3 Increased Confidence in UniDoodle

Item 41 asked the students whether they considered that using UniDoodle had increased their mathematical confidence. A significant difference was found between the UniDoodle1 and UniDoodle2 trial, Pearson chi square test ($r = 12.47$, $\rho= 0.002$). The UniDoodle1 students were more positive, though, as stated, the numbers in the UniDoodle1 trial were low (n=12).

5.4.2.4 Open question in UniDoodle

There were 48 comments added by students in response to the question 'Q.42 Please list the benefits, drawbacks or any other suggested uses of the UniDoodle app. Feel free to add any other constructive comments re the use of the UniDoodle app'. General inductive analysis was used to group these into categories, with some comments appearing in more than one category. See Table 5.4.4 for the number of students per category and sample comments.

Table 5.4.4 Number of segments coded to the categories - UniDoodle trials.

Comment category	**No. of students (n=49)**	**Sample comment**
Improvements	32	'It was difficult writing in the box, could make size of pencil ink even smaller, would be very useful'. UniDoodle1 Student4
Positive	13	'Got an instant answer from lecturer. It was enjoyable and engaging to use'. UniDoodle2 Student46
Negative	10	'Too hard to write, plot and illustrate clearly, very hard to use. Time wasted looking for correct answers. Easily distracted by other apps when could be covering course content'. UniDoodle2 Student 18
Mixed response	6	'Advantages: Fun; different to other lectures. Drawbacks: Wastes time per question asked; can only ask certain question'. UniDoodle2 Student15
Time wasted	5	'It was very time consuming…'. UniDoodle2 Student46

5.4.3 Khan Academy

In the KA trials, along with the four items illustrated in Figure 5.4.1, there were a further three items asked in all three trials. These items were:

- Three Learning items:
    - ***Videos Learning***: The following Khan Academy features helped me to better understand key concepts [Khan academy videos]
    - ***Quizzes Learning:*** The following Khan Academy features helped me to better understand key concepts [Khan academy quizzes]
    - ***Quizzes Test Ability:*** Khan Academy quizzes allowed me to test my mathematical ability

Figure 5.4.2. shows the percentage of respondents who selected SA and A for each of the seven items common to the KA trials.

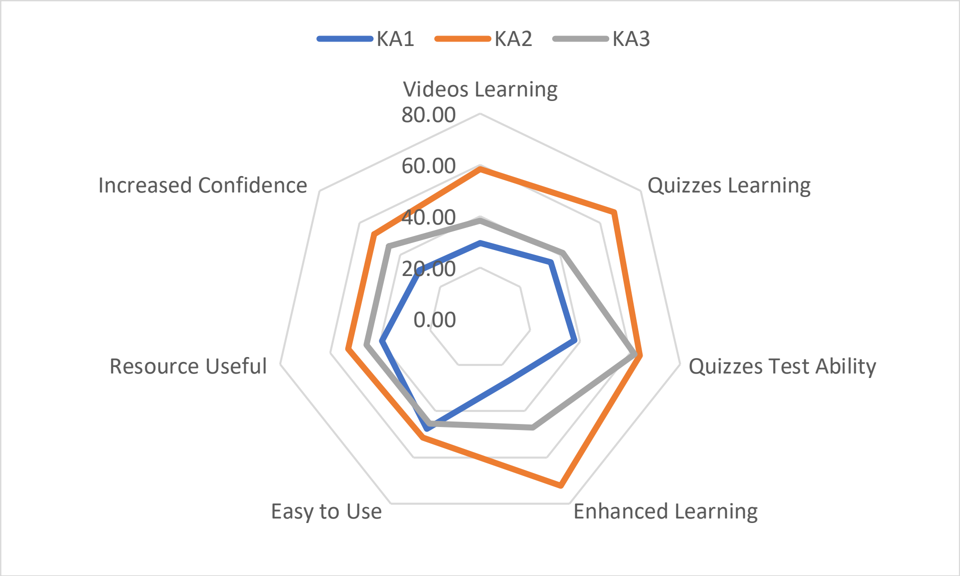


Figure 5.4.2: Positive responses for the 7 common items in the KA trials.

The students in the KA2 trial were generally more positive about their learning from using the resource than in the other two trials. They were also more positive, though less so, about the ease of use and usefulness of KA and the mathematical confidence they gained as a result of using KA.

5.4.3.1 Chi square and Fisher analysis in Khan Academy

In order to determine if there were any significant differences between outcomes in two different institutions, the distribution of responses across all 7 common items in the KA1 and KA2 trials were compared with those in the KA3 trials. Recall, from Chapter 3, that the KA1 and KA2 trials were conducted in the same institution (an IoT), and KA3 in a different one (a university). Table 5.4.5

contains the items and trials where significant differences were found for the comparison of the distribution of responses (SA, A, N, D and SD) between the KA1 and KA3 and the KA2 and KA3 trials. The results columns contain an indication of which trial was more positive (using >) along with the p value of the test.

Table 5.4.5: Fisher exact tests results - KA trials

Item	**KA1 and KA3 results**	**KA2 and KA3 results**
Easy to Use	KA1>KA3, p=0.009	KA2>KA3, p=0.005
Increased Confidence	KA3>KA1, p=0.015	KA2>KA3, p=0.034
Quizzes Learning	KA3>KA1, p=0.006	KA2>KA3, p=0.008
Enhanced Learning	KA3>KA1, p=0.007	KA2>KA3, p=0.000
Resource Useful	KA3>KA1, p=0.044	N/A
Quizzes Test Ability	KA3>KA1, p=0.004	N/A

While students attending the university in the KA3 trial were generally more positive than those students who participated in the KA1 trial, they were less positive than the students who attended the KA2 trial. It is worth recalling that there were differences in the way the KA was integrated in the KA1 and KA2 trials within the same institute. The KA1 trial was like the KA3 trial in that KA use was not tied in with grade, nor was it used in class, unlike in the KA2 trial (Table 5.2.1 & Table 3.7.1).

5.4.3.2 Rasch Analysis in Khan Academy

There were five Learning scale items asked across two of the KA trials, KA2 and KA3. While the RASCH analysis showed a good fit, there was no significant difference found between the trials (See Appendix J).

5.4.3.3 Open responses to Khan Academy

In each of the three trials, the open questions were analysed using general inductive analysis and the themes that emerged were compared across the trials. Segments coded to the categories were aggregated and some segments were coded to two categories. Table 5.4.6 contains a list of the categories and the number of comments coded to each category for the three trials, along with a sample coded segment.

Table 5.4.6: Number of segments coded to the categories - KA trials

Category	**KA1 (n=51)**	**KA2 (n=14)**	**KA3 (n=83)**	**Sample comment**
Negative about use	37	10	64	‘Annoying sometimes if you need to get 5 in a row and you accidentally write your 5th answer wrong and you have to start all over again.’ (KA2 Student30)
Positive about use	5	4	14	‘Its great! Very helpful and easy.’ (KA2 Student15)
Did not need	6	0	35	‘I did not use it, don't feel like need to use it.’ (KA1 Student98)
Was not adequately informed	4	2	14	‘Provide more information about it, we were told to use it but not much about what is on it and the benefits.’ (KA3 Student51)
Relied on other resources	5	1	24	‘I prefer mathstutor.co.uk.’ (KA1 Student78)
Too basic	2	0	3	‘It was very basic, maybe too much at times.’ (KA3 Student78)
Good - formative	0	0	5	‘Clearly explained the basics behind topics which I had difficulties with, making it easier to understand.’ (KA3 Student73)
Easy to Use	0	1	4	‘Easy to use, can be used on phone.’ (KA3 Student85)
Useful	0	2	8	‘Quizzes helped create different unseen questions.’ (KA3 Student81)
Not Useful	1	4	4	‘Time consuming. Preferred Maths Learning Centre.’ (KA3 Student94)

5.4.4 GeoGebra

The same 14 items were used in the two surveys for the GeoGebra trials. Three of these related to background data and have been documented in Appendix I. Chi square and/or Fisher exact tests were used to compare the distribution of the responses to the remaining 11 items. There were significant differences found for two of the items. Students in the GeoGebra1 trial were more positive about Ease of Use (ρ<0.001), and Resource Useful (ρ<0.028) than in the GeoGebra2 trial. It is worth noting that the sample size for the GeoGebra1 survey (9.6 %) was smaller than that for the GeoGebra2 survey (55.8%). This may have been due to the fact that an online out-of-class survey was used in the GeoGebra1 trial, compared to an in-class paper based survey in the GeoGebra2 trial; paper based surveys are known to yield higher response rates (Risquez et al., 2015). It is possible that students who took the time to complete the online survey were more positively disposed to engagement in general.

5.4.4.1 Open question responses

The responses to Q16, the open question '*Please comment below on any aspect of the survey and/or the use of the Interactive tasks in GeoGebra'* were analysed using general inductive analysis. Two of the themes that emerged, in both years, were related to Usability and how difficult students found the use of GeoGebra. In addition, a number of students commented on how helpful they found the tasks. The number of responses along with a sample response related to the Usability theme is shown in Table 5.4.7.

Table 5.4.7: Number of segments coded to the categories – GeoGebra trials

Category	**GeoGebra1 (n=7)**	**GeoGebra2 (n=54)**	**Sample Response**
Hard to Use	3	19	'I found it hard to use which put me off as I was spending more time figuring out how to use it.' GeoGebra2 Student 31
Availability was not made clear	1	8	'Although it was available on moodle, it might have been beneficial for it to be mentioned in class to make people aware of its usefulness.' GeoGebra2 Student36
Needs more instructions	2	9	'Very confusing programme, training how to use in tutorials could be helpful...' GeoGebra2 Student51
Found GeoGebra Helpful	3	15	'…the visual aid helped me to understand functions…' GeoGebra1 Student6
Did Not Use	1	14	'To be honest didn't use it ever. didn't have time and didn't know what it was about or why it was important.' GeoGebra2 Student34

Did Not Need	1	4	'I never used Geogebra it was never useful to me and I never needed it.' GeoGebra2 Student29

5.4.5 Conclusion on students' opinions

The data presented in this section aimed to address RQ5.2: *What are the similarities/differences found in students' opinions of the impact of the various trials of the NF-funded project resources?*

The results outlined in the preceding sections show that there were both differences and similarities in the students' ratings of the survey items. Two factors that encourage student engagement with the NF-funded project resources, 'use in class' and 'grade associated with its use', were previously identified from the usage data. The analysis of the survey results was used to support these factors, and to identify five new factors. These seven factors, along with the particular survey outcomes that support them, are shown in Figure 5.4.3, which is an expanded subset of Figure 5.2.1 shown at the beginning of the chapter. In this diagram the seven factors are numbered and the data that was used to determine the factor is indicated in a colour coded box (yellow for usage, blue for survey data). Within each survey data box the specific data is referred to by either the Section, Figure or Table number as it appears within this section. The genesis of the factors within the research outcomes is discussed in the following paragraphs.

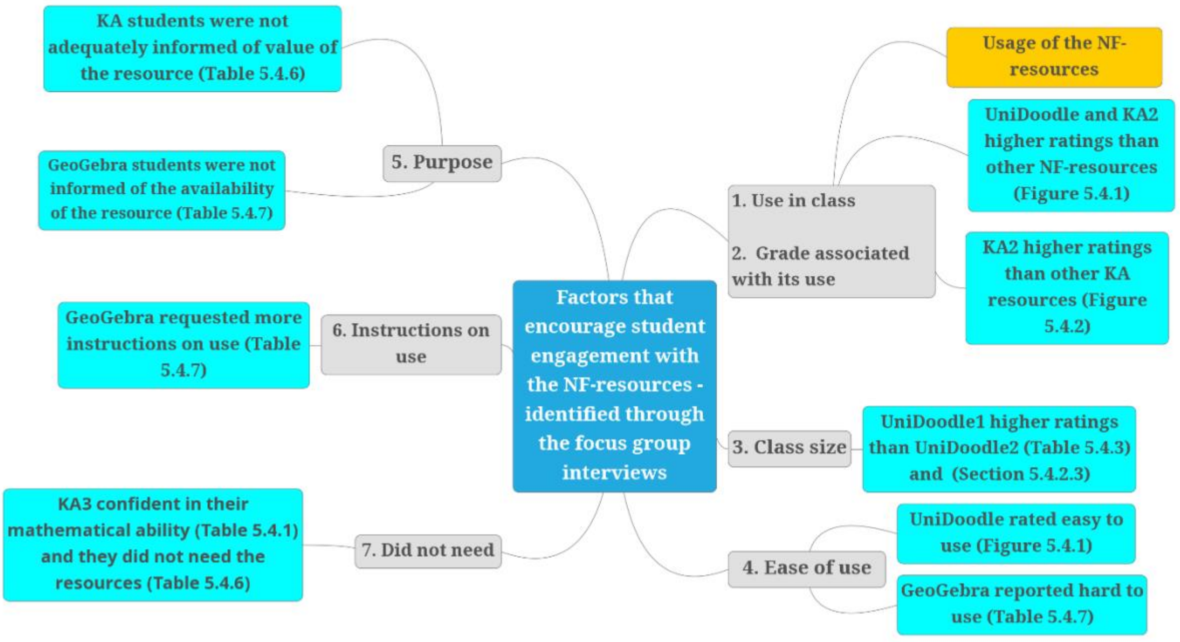


Figure 5.4.3: Survey and usage data outcomes that support the identified factors

Use in class and Grade associated with use

When the survey outcomes are considered in light of the different trials, further evidence to support the factors of 'use in class' and 'grade associated with use' emerge. Figure 5.4.1 shows how the UniDoodle trials and the KA2 trial had higher ratings in the common survey items than the other trials, and some of these differences were statistically significant, as shown in Appendix I.2. In addition, comparison of the three KA student ratings in Figure 5.4.2 show that the students in the KA2 trial rated the use of the resources higher than in the other two trials. The UniDoodle and KA2 resources were the only resources used in class, and there was a grade associated with using the KA in the KA2 trial.

Class size

However, these two factors ('use in class' and 'grade associated with use') do not explain fully the contrast of the opinions of the students in the two UniDoodle trials. The UniDoodle1 students rated Formative Assessment, Learning & Engagement (Table 5.4.4) and Increased Confidence (Section 5.4.2.3) higher than the UniDoodle2 students. One of the differences in these two trials is class size; there were 12 students in the UniDoodle1 trial and 165 in UniDoodle2. Thus 'class size' is put forward as a third probable factor as to why students engage with technology.

Ease of use

The UniDoodle app itself was considered easy to use by students. Students in UniDoodle1 and UniDoodle2 both rated 'ease of use' alike (Figure 5.4.1). In addition, students reported finding GeoGebra hard to use (Table 5.4.7) and usage of GeoGebra was considerably lower than that of UniDoodle (Table 5.3.1). It is known that usability impacts engagement with technology (Galligan et al., 2015; Lavicza, 2010; Oates, 2011) and Bond and Bedenlier (2019) include it as an influencing factor on student technology engagement. Thus 'ease of use' is put forward as a possible factor emerging from the NF-funded project resource evaluations.

Purpose

Other than in the UniDoodle trials and KA2, less than half the students rated the resource useful (Figure 5.4.1, Resource Useful). Even within KA2, where using the resource had a grade associated with its use, only 52.8% were positive about its use. The analysis of the open questions asked in the KA surveys revealed that students had similar opinions on the resources (Table 5.4.6). Within these KA trials, three reasons emerged for why they did not use the KA. One reason was that students indicated that they had found other resources themselves. The second reason was that they considered they did not need it as their mathematics level was sufficient. Finally, the third reason was that they felt that they were not adequately informed about the resources. Similarly, students in the GeoGebra trials reported that the availability of the resource was not made clear to them (Table 5.4.7).

The fact that students self-selected other resources, or considered that they did not need resources, contributes to the idea that they felt they were not fully informed of the value of the resources. Thus a fifth possible factor that impacts on engagement put forward is ‘purpose’ – students require a reason to engage with the technology.

Instructions on use

The idea of a purpose was extended by students in the GeoGebra trials, who commented that they required more instruction on GeoGebra use because they found it hard to use. Twenty-two of the comments (n=61) received through the surveys referred to GeoGebra being hard to use and 11 specifically mentioned the need for more instructions (Table 5.4.7). Typically, students remarked on the fact that they had found GeoGebra hard to use even though they had spent some time on it. As GeoGebra2 Student8 said *‘I downloaded the app. onto my laptop but it was so hard to use!!! … I did spend a good lot of time trying*.’ A sixth possible factor put forward is ‘instructions on use’, which ties in with the notion of instrumental genesis put forward by studies such as Thomas et al. (Thomas et al., 2017)and Jupri et al. (2016).

Did not need

The high proportion of students in KA3 who suggested, in the open question, that they did not use the resources as they did not need them (Table 5.4.6), leads to another factor ‘did not need’. This factor is supported by the fact that these students were reasonably confident that they can handle the mathematical difficulties they have, as evidenced in the 55.6% who had responded positively to that item in the survey (see Table 5.4.1). In addition, 5 of the students in the GeoGebra trials said that they did not need the resource, despite the fact there were grades associated with some of the tasks. Thus, a seventh factor, ‘did not need’, that impacts on student engagement with technology-enhanced resources, is added.

Thus far, seven possible factors have emerged that impact on student engagement with the NF-funded project resources:

- Use in class
- Grade associated with use
- Class size
- Ease of use
- Purpose
- Instructions on use

- Did not need

In the next section, an analysis of the focus group interviews is used to further explore these factors.

5.5 Outcomes of the focus groups in the GeoGebra2 trial

The student focus group interviews were carried out after the GeoGebra2 trial. The interviews were analysed and coded using the general inductive analysis method described in Chapter 4. Only those themes that help address the question RQ5.3: *What evidence emerges from the focus group interviews that contributes to identification of factors that encourage student engagement with technology?* are discussed in this section.

As outlined in Chapter 3, students in the GeoGebra trials were given access to a series of GeoGebra tasks via the institutional VLE, Moodle. In the GeoGebra2 trial, there were 8 tasks: two of which were assignments, and automatically graded within the VLE; one task that students were asked to complete in order to assist them with a paper-based assignment; and five non-graded tasks. In order to refresh students' memory of the individual tasks during the interview, access to the tasks was provided using a laptop. Activity on the laptop was recorded using a freely-available screen recorder, screencast-o-matic, and used to assist with the analysis of the data. A complete list of the tasks and their usage by the students is contained in Appendix H.

The focus group interview transcripts were coded within NVivo using general inductive analysis, as outlined in Chapter 4. Segments of the data were coded into themes that emerged from the transcripts, and where relevant, segments were coded to more than one theme. The themes that emerged were then structured to focus on addressing the research question for this section of the study. Four relevant themes emerged and the relationships between these themes and their subcategories were explored. Two additional themes were created in NVivo: student background and GeoGebra tasks. The first contained the segments of data relating to student background, course and their opinions on their mathematical ability. The second contained the segments of transcripts relating to each individual task. Figure 5.5.1 illustrates the themes identified and their associated categories and subcategories, created in NVivo, along with the number of segments of data coded to each node.

Figure 5.5.1: Themes and associated node categories and subcategories.

Segments were coded to more than one category where relevant.) Note as the themes of Student Background and GeoGebra Tasks were not part of the inductive coding, no breakdown is shown.

In order to explore the relationships between the different node categories, matrix coding was performed on the themes. Matrix coding is a feature of the NVivo application that is used to identify the intersections of the coded data, i.e. where segments of data have been coded to more than one node. In the following sections, the themes and the relationships between them are explored. The section concludes with an examination of how these themes add to the factors already identified and answer RQ5.3.

5.5.1 Background data

There were six students involved in the focus groups, two groups of three. The background data and alias names used to discuss the findings are outlined in Table 5.5.1.

Table 5.5.1: Background data of focus groups students

Date	Student	Discipline and Maths comment	Use of GeoGebra
22nd Feb 2017	Tomás	1st year Chemistry, Biology, Experimental Physics. Likes maths	No. Only for assignment and practice quiz.
	Gráinne	1st year Science Education. Mature student. Used to hate maths but now likes it, thinking about keeping it up for degree.	Tried to for tasks and assignments. Missed one assignment.
	Seán	1st year General Science. Mature student. Maths not always a strong point but would like to get better at it	Tried to for tasks and assignments. Missed one assignment.
28th March 2017	Eilís	1st year Computer Science. Finds graphs and graphing difficult.	Yes, for graph work, using GeoGebra and vertical and horizontal line tests.
	Deirdre	1st year Biotechnology. Was Ok with Maths as did higher level in the Leaving Certificate.	Yes, for assignments
	Conall	1st year Biomedical and Biological Science. Functions is his weak point in Maths.	Yes, once or twice

Note Tomás was the only student who had used GeoGebra prior to attending college. He used it as part of Leaving Certificate mathematics and found it helpful.

5.5.2 Used - Why GeoGebra was used

As indicated by the GeoGebra usage data, in Table 5.3.1, the most accessed tasks were those graded or associated with a grade, in other words considered as "assignments" by the students. This was also evident in the focus group interviews, where 46 segments were coded to the 'Assignment' category within the 'Used- Why GeoGebra was used' theme, henceforth abbreviated to 'Used', shown in purple in Figure 5.5.1. To examine what students said about their use of the tasks for assignments, the relationship between the 'Assignment' category and the 'GeoGebra tasks' theme is illustrated in the matrix code in Table 5.5.2, and the relevant topics are discussed below. Table 5.5.2 contains the number of segments that intersect the 'Assignment' category (within the 'Used' theme) and the theme of GeoGebra tasks. Only three of the non-graded tasks are shown in this table, the other two non-graded tasks did not intersect with the 'Assignment' category.

Table 5.5.2: Intersection of 'GeoGebra tasks' and 'Used-Assignment'

GeoGebra Task	**Used - Assignment (no of segments)**
Transform Task**	21
Numbas quiz limits of piecewise*	15
Derivatives Assignment*	9
Using GeoGebra	3
Asymptote Zoom	1
Vertical and Horizontal line	0

**graded within Moodle.*

*** associated with a grade.*

5.5.2.1 Assignments

Looking at Table 5.5.2, it is evident that students mainly discussed using GeoGebra in relation to the graded tasks (or assignments). Only the students from the second focus group interview accessed the Transform task, which was not graded, but was associated with a continuous assignment question. Eilís used it for the first question on the assignment '… *I'd say I just did it for like the first one so I could get an idea of how the transformations work(s)* …' though Conall reported that he tried and could not follow how to use it. Both Seán and Gráinne, from the first interview, did not use it because they had found GeoGebra hard to use and had learnt how to do transformations previously. Tomás was not sure why he had not used it.

There was a clear indication from the students that they would always try to access the tasks that related to assignments. For example, Deirdre said that she *'…used it* (GeoGebra tasks) *like when we were given assignments … I used it then*'. This was further evidenced by Gráinne who expressed her frustration at having missed an assignment '*I have to get like a 100% in my assignments cos I'd be so afraid that I'll like mess up in the test … but I actually missed one of these … it wouldn't been the case that I just didn't want to do it because I don't like… I would have done it…* '. Gráinne was clearly focussed on completing the assignments. This was echoed by Seán when he said *'if something is not on the test … I just don't have the time, it's not on my priority'*. An exploration of the data coded in the category of 'Graded Assessment', (within the 'Encourage GeoGebra use' theme, orange in Figure 5.5.1) showed that all of the students supported this factor. Conall summed it up by saying *'Honestly like unless it says on the assignment "do this", most people won't…'*, and the two other students in the interview agreed with him.

This evidence supports the premise that 'Grade associated with its use' is a factor in encouraging students' engagement with technology.

5.5.2.2 Useful affordances of the technology

The other predominant category in the 'Used' theme is that the students found the tasks 'Useful', see Figure 5.5.1. In order to determine what they found useful, a matrix code between the 'Useful' category and the 'Affordances of GeoGebra', henceforth 'Affordances', theme was created. Table 5.5.3 shows the number of segments coded at this intersection.

Table 5.5.3: Intersection of Affordances and Used - Useful

Affordances theme sub categories	**Used – Useful (no. of segments)**
Visualisation	23
Sliders and Colours	4
Shows the points	2
Redo until correct	1
Confidence boost	2
Check answers	1

Students found the fact that they could visualise the functions as the most useful feature of the GeoGebra tasks. Referring to how useful the "limits of piecewise functions" task was, Gráinne said *'… I had kinda forgotten about limits and stuff but it straightaway came back when I could see … "a"* (variable) *moving… it is good*'. Eilís also liked the visualisation affordances of GeoGebra, saying, '*when we were asked to plot graphs and like I didn't understand it I just put it into GeoGebra, and it will give me the outputs and everything. So it really helped a lot*'. She used this task, "Using GeoGebra", regularly. This was the first task students were expected to examine and allowed them to input functions in the form of *f(x)*, which GeoGebra then plotted.

In addition, students mentioned how useful the sliders were. In a discussion on the use of the sliders within the "limits of piecewise functions" task, while the task was displayed on the screen during the interview, Eilís started off: *'… the questions says x tends to zero, this one is tending to zero…'* She pointed to the function on the screen while moving the slider and continued saying *'… and that one is tending to zero as well…'*. She then pointed to the other part of the function and said *'… and* *the answer is minus one and zero, so I would guess those are the limits…'*. When asked if this task was helpful, Eilís answered '*It was helpful… Especially with this slider'*.

Thus, it is clear that there are certain features or affordances of the technology that can encourage engagement, which in this case evidenced cognitive engagement in the form of student effort. As a result, the 'affordances' of technology has been identified as a possible additional factor that encourages students' engagement with technology.

5.5.3 Intersection of "Not Used" & "Encourage GeoGebra Use"

A second theme identified was the 'Not Used-Why GeoGebra was not used', henceforth 'Not Used', theme (blue in Figure 5.5.1). The reasons students gave as to why they did not engage with GeoGebra also helps address RQ5.3.

It was evident from listening to the students during the interviews that many of the students did not use the GeoGebra tasks as they found them hard to use, or that they did not know what to do with them. This is apparent from the number of segments coded to these subcategories of the 'Not Used' theme in Figure 5.5.1. Both Seán and Gráinne spoke at length about their difficulty in trying to use the GeoGebra tasks; in fact, they only ended up accessing the graded tasks. Seán indicated that he tried unsuccessfully to use the tasks and went on to say that '*I just went back to my notes… from Peter',* these were notes from attendance at a summer school. Similarly, Gráinne discussed how she had initially tried to use GeoGebra but when she could not figure it out, she accessed other resources, she said *'….I just used go onto like Wolfram Alpha or any of those and type in like that … works to see a graph or like if I ever just wanted to see or compare my own answers.'*. Where they were unable to use the tasks, students tended to use alternatives for obtaining mathematics support.

In order to further investigate what might encourage students to engage with GeoGebra, a matrix code of the intersection of the 'Not Used' and 'Encourage GeoGebra Use' themes was created. The number of segments that intersect these themes are illustrated in Table 5.5.4 and discussed below.

Table 5.5.4: Intersection of ‘Not Used’ and ‘Encourage GeoGebra Use’

Encourage Use / Not Used		Instructions on use	Graded assessment	GeoGebra purpose	Use or demo in lectures	Tutorial on use
Assignment - Missed Assignment			5	4		
Too Hard to use	Hard to use	2				
	Did not know about it - or its purpose	4	1	5		
	Not know how to use it- functionality & confusing	3		4	2	
	No Support - tutors	3				2
	Mature Students					3
Did not need it - understood maths		3				1
Not Useful				2		

5.5.3.1 Instructions on use

As discussed above, one of the dominant themes to emerge from the focus group interviews was that students found the GeoGebra tasks hard to use. In both interviews, students asserted that they needed more guidance on how to use them, and agreed that more instructions on their use would help. While discussing the use of the Transform task, all three students, Deirdre, Eiliís and Conall, said they had looked at it but could not figure out what the sliders were doing. Eilís said ‘*Like when x would change when a would change, it would just change the graph itself but I don’t know just I was still confused*’. Both Seán and Gráinne expressed their difficulty with using the GeoGebra tasks and Seán said, ‘*I tried to use it and I couldn’t get my head around how to actually use it so I just stopped because I felt like I was spending more time trying to learn how to use it than rather the time on doing the maths itself*’. Clearly Seán needed more guidance on how to use the tasks. When asked what might have helped Deirdre said ‘*I think maybe just have more instructions on …*’ and Conall agreed with her ‘*I kinda agree with Deirdre like … But again it wasn’t very clear to me how to use it … but I think if it’s a little bit more clear how to …*’. Gráinne also mentioned the need for instructions ‘*it wasn’t clear enough on the instructions*’.

Thus, the factor of 'instructions on use', suggested from the open question in the GeoGebra survey, is confirmed within the focus group data.

5.5.3.2 GeoGebra Purpose

In addition to 'instructions on use', students who did not know what to do with the tasks suggested that guidance on the purpose was required. Gráinne remarked about the GeoGebra tasks that *'it was kinda there… but I didn't really know what to be doing with it or that so …'*, and Deirdre felt similarly '*I think one thing that no one kinda told the first years…was the actual use of GeoGebra, they were kinda just like oh that it's there for the assignment, you don't need to use it….'*. Deirdre thought that doing the tasks was optional, rather than recommended or required.

Neither Deirdre, Gráinne nor Seán completed the "Limits of Piecewise Functions" task, which was a graded assignment. However, none of the students missed the "Derivatives" quiz task. Deirdre explained why this might have happened: *'See, stuff like this, it said derivatives quiz, I kinda knew, oh I have to do this, where the other one, the limit piecewise* (referring to the "Limits of piecewise functions" task that was graded on Moodle)*, it didn't have like something',* meaning that the word 'quiz' on the name of the task was sufficient to ensure that they recognised the Derivatives quiz as a graded task. The "Limits of Piecewise Functions" had no such identifier. In addition, Eilís said she came upon the "Limits of Piecewise Functions" task by accident while she was browsing Moodle and said *'they didn't say a lot in lectures or anything*'.

Finally, it is worth noting that the only student who did not refer to having difficulties using GeoGebra was Tomás, who had had prior experience of using GeoGebra while at school. However, he had only accessed the two tasks that were graded within Moodle. He said that '*he didn't know where to use it like...'.* After having seen them being used in the interview Tomás said, '…*I should have maybe that would have been more helpful'.*

This analysis illustrates that students reported that they were not always aware of the purpose of the GeoGebra tasks; what they were supposed to do with them and/or whether they were assignments that were graded. They have indicated that if the purpose of the tasks was clear, they would have engaged better with the GeoGebra tasks, particularly those associated with a grade. Thus the 'purpose' factor, identified in the previous section, has been substantiated within the focus group interviews.

5.5.3.3 Demo and Tutorial

The students' suggestions for how they could be supported using the resources included asking for demonstrations in class or having specific tutorials on their use. The students expressed some surprise that neither the tutors in the Maths Learning Centre, nor their mathematics module tutor, showed familiarity with the tasks. Gráinne suggested '*…even to have like a tutorial in a computer room with tutors and that there'.* In the second interview, Deirdre said '*Like in the tutorials or lectures if there like if someone said oh this is what it's for, to use it for this'*. The fact that the NF-funded project resource was used in class in both the UniDoodle trials and the KA2 trial has already been identified as a factor that encourages student engagement. The above suggestions, from the students in the focus group interviews, contribute to the argument that both 'use in class' and 'instructions on use' are factors in encouraging engagement.

5.5.3.4 Ease of Use to User Experience

It is clear from the previous discussions on the outcomes of the focus groups that many of the students expressed a level of confusion over the use of the GeoGebra tasks. Students reported that they did not know what they were for, did not necessarily know where to find them, did not find them useful, found them hard to use, and the functionality within the task was not always clear. These issues are similar to those identified under the umbrella of the terms 'user experience' or 'usability', as discussed in Chapter 2. For example, students did not find the tasks "usable", "valuable", or "desirable", all elements of Morville's honeycomb (Morville, 2016). The factor named 'ease of use', identified previously from the outcomes of the UniDoodle surveys, captures the "usable" component of user experience. Thus, a new factor, 'user experience', is proposed that encompasses 'ease of use'.

5.5.4 Differing needs

When the intersection of the 'Student Background' theme and 'Not Used' theme was investigated, the different needs of students became apparent.

In the first GeoGebra focus group, it was clear that the students themselves rated their mathematical abilities differently. Both Seán and Gráinne had completed foundation mathematics at school and came to university as mature students. They both found mathematics difficult and relied on the notes from the Certificate in Science course that they had completed prior to coming to college, and both reported that they found the GeoGebra tasks hard to use. Indeed, they had used their notes on transformations rather than use the GeoGebra Transform task that was associated with a grade on an assignment. On the other hand, Tomás liked maths, and expressed that he did not need the GeoGebra tasks for support.

In the second interview group, students also expressed that they often knew how to do the assignments without recourse to GeoGebra. Conall said, about the "Vertical and Horizontal line test" tasks '*Yeah, I just knew how to do it, I didn't need to go (in)'.* Deirdre said that the fact that she had completed higher level mathematics at Leaving Certificate level meant she was *'ok'*. Though she added *'… I used it kinda when I was stuck with the assignment rather than other times. I kinda knew what to do I did it myself'.*

This finding highlights the various needs of the students. Similar to the identification of the 'did not need' category in the KA open question responses, there is an element of the students' own views of their specific needs that is reflected in their engagement with the GeoGebra tasks. If a student felt they did not need a resource, then they reported that they were not going to engage. Thus, the focus groups corroborated the 'did not need' factor.

5.5.5 Conclusion on the focus groups

The analysis of the focus group interviews supports all the factors that had been identified thus far, bar 'class size'. In addition, the 'ease of use' factor has been expanded to include the many aspects of 'user experience' and a new factor 'affordances' of the technology has emerged. Figure 5.5.2 illustrates how the focus group analysis has contributed to the existing factors and helped identify new ones.

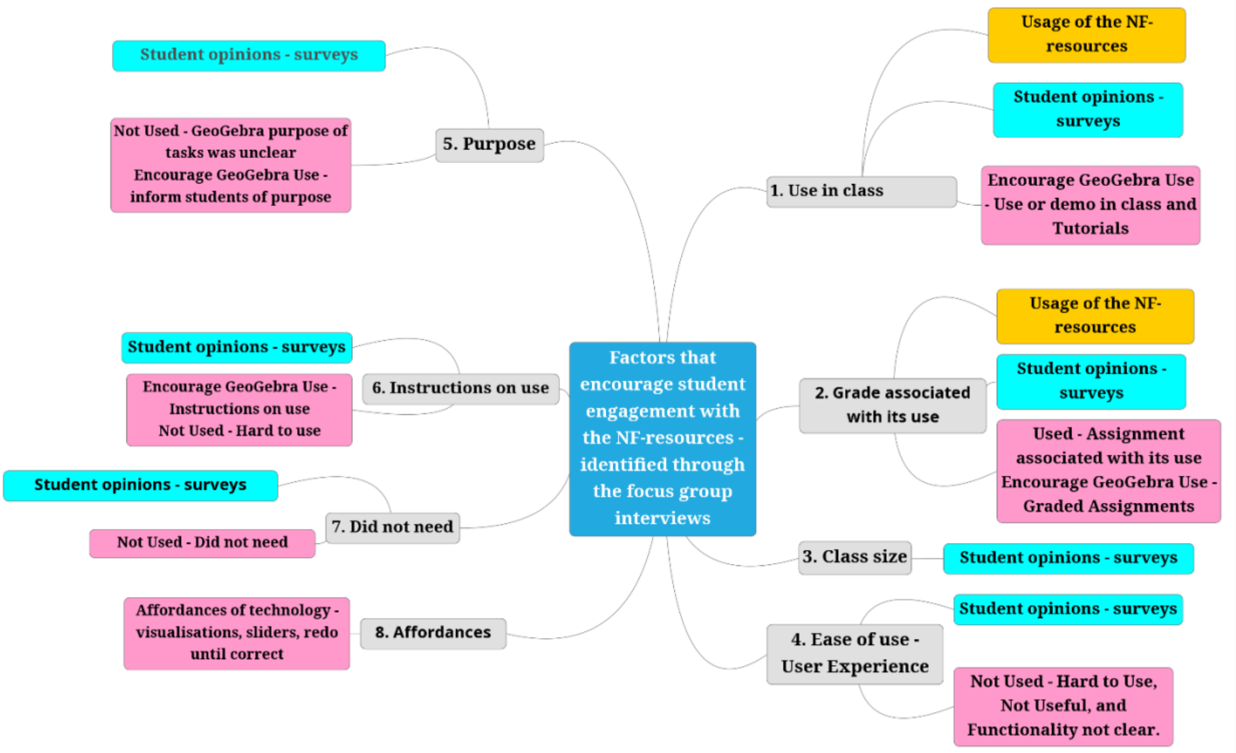


Figure 5.5.2: Focus group outcomes that support the identified factors

Note the Focus Group factors are colour coded pink and contain the name of the themes, node categories and/or subcategories (Figure 5.5.1) that have contributed to the associated factor.

The factors that have emerged so far are:

- use in class
- grade associated with use
- class size
- user experience
- purpose
- instructions on use
- did not need
- affordances

In the next section the comments from the lecturers are considered in light of these factors.

5.6 Lecturer opinions on the use of the NF-funded project resources

In this section of Chapter 5, the narrative analysis of the lecturer comments on the NF-funded resource evaluation reports are considered. This data is used to address RQ5.4: *What are the opinions of the lecturers regarding the use of the NF-funded project resources they developed?*

The lecturers received a report regarding the evaluation of the NF-funded project resource they had implemented. During the compilation of the reports, discussions were held between individual lecturers and this researcher to discuss the outcomes of the trials. These were in the form of unrecorded phone calls, and occasional emails, where this researcher jotted notes after the discussion. Narrative analysis, as discussed in Chapter 2, was used to identify elements of the NF-funded project resource trials as told by the lecturer. The relevant outcomes of this analysis are used to address RQ5.4.

Both lecturers involved with UniDoodle expressed their satisfaction with the use of the UniDoodle app in class. The lecturer in UniDoodle1 used the app every week and was able to give students individual feedback on their responses to questions within the scheduled class time. On the other hand, the UniDoodle2 lecturer used the app less regularly, only four times per term in a 12-week term. While he found using the app useful in terms of behavioural engagement, the volume of responses meant that he could only deal with a limited number of incorrect responses and focussed on the most frequent errors students made. Thus, the level of feedback in this larger class size was not as high as in the smaller class. In addition, due to the time it took for the larger group of students to get out their devices and respond, he regularly waited for just 70 to 80 responses from a class of 150 or more. This evidence supports the notion of 'class size' as a factor of engagement. It also corroborates the fact that students on the UniDoodle1 trial rated the level of formative assessment and learning & engagement higher than the UniDoodle2 students (Table 5.4.4). Thus, the ability of the lecturer to give formative assessment is also a factor of student engagement. Hence, a new factor ‘formative assessment’ is put forward.

Class size was also important to the lecturer in the KA2 trial. This lecturer used the weekly feedback from the KA class application, regarding the students’ levels of mastery challenges achieved, to modify her in-class teaching. She expressed the view that she would not have been able to manage the formative assessment elements with a bigger class (n=80). This evidence corroborates that ‘class size’ is a factor in engagement, and a factor that impacts on ‘formative assessment’.

While the lecturer involved in the KA2 trial was pleased with the level of engagement with the KA mastery challenges, neither lecturer involved in the other two KA trials expressed surprise at the low level of KA playlist usage. They commented that these particular student groups are generally unaware of the low level of skill they have and therefore rarely access the supports that are provided. This corroborates the ‘did not need’ theme identified both in the KA open question survey and the focus groups on the GeoGebra tasks. All the lecturers involved in the project mentioned that they regularly find that these cohorts of students, attending non-specialist mathematics modules, are not engaged in increasing their mathematical understanding and are focussed on getting a pass grade in the module. This ties in with the finding that students are focussed on the grade, as indicated both by usage and the focus group interviews. In Section 5.5.4, the different needs of students, as they expressed them, were considered and the factor of ‘did not need’ identified. However, from the discussion with the lecturers, it is evident that it is not necessarily that students do not need support resources, but that they are unaware of their lack of mathematical skills, and/or disinterested in mathematics. These traits are often, though not always, found in this particular group of students, those attending first-year undergraduate non-specialist mathematics modules. Thus, rather than ‘did not need’ as a factor, ‘student cohort’ is used.

5.6.1.1 Conclusion on lecturer comments

The opinions of the lecturers supported some of the already identified factors and have suggested some new ones. ‘Class size’, as a factor that impacts student engagement with technology, was corroborated by the lecturers and ‘formative assessment’ was identified as a new factor. In addition, the lecturers referred to their students as having particular traits with regard to their views and actions with studying mathematics and the previously identified factor of ‘did not need’ was incorporated into the new factor of ‘student cohort’.

5.7 Factors from the literature

The factors identified and discussed in the previous section include those that refer to the NF-funded project lecturers' pedagogical practices, such as the provision of formative assessment, or the inclusion of a grade associated with the use of the technology. They also include factors pertaining to the educational setting, such as class size and student cohort. A focussed analysis of the literature was conducted to determine if other features of technology integration have been identified that are known to impact student engagement and success in mathematics education. *RQ5.5: What are the factors, if any, found in the literature that need to be considered in addition to those identified through the resource evaluations?* is answered in this section.

While some of the features discussed in the literature were also identified as factors during the NF-funded project resources evaluations, such as teacher privileging ('use in class') and linking tool use to assessment ('grade associated with its use'), others were not as apparent from the evaluations. Table 5.7.1 lists the pedagogical features that impact student engagement and success with technology that emerged from the focussed analysis of the relevant literature discussed in Chapter 2, along with a similar factor, if any, identified from the NF-funded project resource evaluations.

Table 5.7.1: Pedagogical features from the literature

Feature	**Study**	**Similar factor identified in the NF evaluations**
Privileging of tools by the teachers	Drijvers (2015); Thomas et al. (2017)	'use in class'
Use of the digital tools explicitly linked to the continuous assessment of the modules	Kanwal (2020); Thomas et al. (2017)	'grade associated with its use'
Technology affordances	Buteau et al. (2010); Handal et al. (2012); Takači et al. (2015); Thomas et al. (2017)	'affordances'
Technological communication between teachers and students	FaSMEd (2020a); Thomas et al. (2017)	'formative assessment'
Didactical contracts (such as flipped classrooms)	Gueudet and Pepin (2018); Pierce and Stacey (2010); Steen-Utheim and Foldnes (2018)	'purpose' & 'use in class' & 'grade associated with its use'

Formative assessment	Geiger et al. (2016); J. Lee (2014); Trenholm et al. (2015)	‘formative assessment’
Instrumental Orchestration	Jupri et al. (2016); Pierce and Stacey (2010); Thomas et al. (2017)	‘instructions on use’
Educational Background	Drijvers (2015); Geiger et al. (2016)	‘student cohort’
Sustained use of the technology throughout the module	Thomas et al. (2017)	‘use in class’
Design of technology and relevant digital tasks	Drijvers (2015); Pierce and Stacey (2010); Thomas et al. (2017)	Not found
Technology Types	FaSMEd (2020a); Galligan et al. (2015); Hoyles and Noss (2003)	Not found
Student self-select tools	Anastasakis et al., 2016; Thomas et al., 2017; S. Trenholm et al., 2019 Anastasakis et al. (2016); Thomas et al. (2017); Trenholm et al. (2019)	‘purpose’
Collaborative or peer learning	Takači et al. (2015)	Not found

The factors that emerged from the NF-funded project’s resource evaluations have been discussed in previous sections of this chapter. Therefore, only those features that were not previously identified as factors in their own right, will be considered below.

The didactical contract between students and teachers is an important pedagogical feature of education that can be impacted upon when integrating technology (Gueudet & Pepin, 2016). This concept is similar to the pedagogical responsibilities referred to by Attard and Holmes (2020) in their engagement framework, FEM. Pierce and Stacey (2010) view this contract in terms of the classroom dynamics, how and when the tool is used in the classroom. Drijvers (2015) refers to this as part of the educational context of the technology implementation. Factors such as whether the tool is used outside of the classroom, if assessment is associated with its use, and the motivation of the students, are all considered part of the educational context referred to by Drijvers (2015). In undergraduate education, Thomas et al. (2017) refer to need for sustained use of technologies, which can be considered as part of the didactical contract and aligns with ‘use in class’ factor identified in this study. Developments in educational theories suggest that enabling students to self-regulate their learning positively impacts on their eventual success (Conley & French, 2013; Wehner, 2019; Zimmerman, 1990). Allowing students to self-select the technology tools they could use, a feature in the Thomas et al. (2017) study, was a key component of its success. These factors, when and where the tool is used, how it impacts on the relationship between students and the teacher, and student motivations, are important features to consider when integrating technology. For the purposes of this discussion, these will be referred to as the two factors of ‘didactical contract’ and ‘educational background’, where the latter refers to student cohort and student motivation.

The theory of instrumental genesis and orchestration has been under consideration since it was first mooted by Artigue (2002) in her investigation of the use of CAS technologies in secondary mathematics education. Since then a number of educators, in undergraduate mathematics, have used this theoretical framework to investigate students’ cognitive engagement with technologies that afford significant task redesign (Jupri et al., 2016; Oates et al., 2014; Stewart et al., 2005; Thomas et al., 2017). Such literature refers to the need for teachers to develop instrumental schema that can be used to best support students effectively (Jupri et al., 2016; Thomas et al., 2017). Within the context of the NF-funded project, this requirement is considered in terms of the need for practitioners to provide effective instruction on how to use the technology.

Task design when using technology emerged from the literature as a pedagogical feature that impacts students’ success (Drijvers, 2015; Pierce & Stacey, 2010; Thomas et al., 2017). Tasks created by teachers are part of the mathematical practices that Drijvers (2015) and Pierce and Stacey (2010) refer to, and the pedagogical repertoires discussed by Attard and Holmes (2020). Designing mathematical tasks for learning is an important pedagogical feature of engaging students cognitively (Breen et al., 2019; Breen & O’Shea, 2012), whether technology is in use or not. Thus, from a technology integration perspective, the important factor is how the technology is constructed to support the task (Drijvers, 2015; O’Shea, Breen, & Jaworski, 2016; Thomas et al., 2017). Handal et al. (2012) referred to the fact that different technologies afford different levels of task complexity, and hence the selection of the type of technology is important when matching it to the task. Thus, task design, technology affordance and technology type are all pedagogical features of technology integrations that impact on student engagement.

Facilitating effective communication and collaboration between students has also been recognised by educational theorists as a means to encourage learning (Milkwood, 2014). The literature on mathematics educational technology also revealed that enabling peer communication, generally in the format of formative assessment, impacts student engagement with technology and success in learning (Takači et al., 2015; Thomas et al., 2017; Trenholm et al., 2019).

The pedagogical factors that emerged from the literature are listed below with a reference to the similar factor, where relevant, identified in the NF resource evaluations:

- Didactical contract (purpose, use in class, grade towards assessment)
- Educational background (student cohort)
- Instrumental Orchestration (instructions on use)
- Technology affordances (affordances)
- Technological communication (formative assessment)
- Technology type
- Task design
- Collaboration with peers

5.8 Discussion and Conclusion

Stage 3 of the research was aimed at evaluating the NF-funded project resources with a view to contributing to the following two research questions:

> **RQ1:** What are the key factors of technology-enhanced resources and their implementations that influence students' engagement with these resources?
>
> **RQ2:** What are the key pedagogical features of technology-enhanced resource implementations that impact on student engagement with these resources?

When considering the list of final factors that were identified through this research, precedent was given to those identified through the research rather than the literature. For example, rather than state ‘didactical contract’ as a factor, the three factors of ‘use in class’, ‘grade associated with its use’ and ‘purpose’ are identified separately. In the context of this study, the resources are provided by the lecturer for the students, hence there is no option to ‘self-select’ resources and this factor is not considered. Thus, the final set of factors that have been identified through these evaluations and from a review of the literature provide the answer to these two questions. These factors are:

- use in class
- grade associated with its use
- class size
- user experience

- purpose
- instructions on use
- student cohort
- affordances
- formative assessment
- technology type
- task design
- collaboration with peers

These research outputs were presented in Figure 5.2.1 at the beginning of the chapter. This diagram is reproduced below, in Figure 5.8.1, to aid in the discussion and conclusions on student engagement.

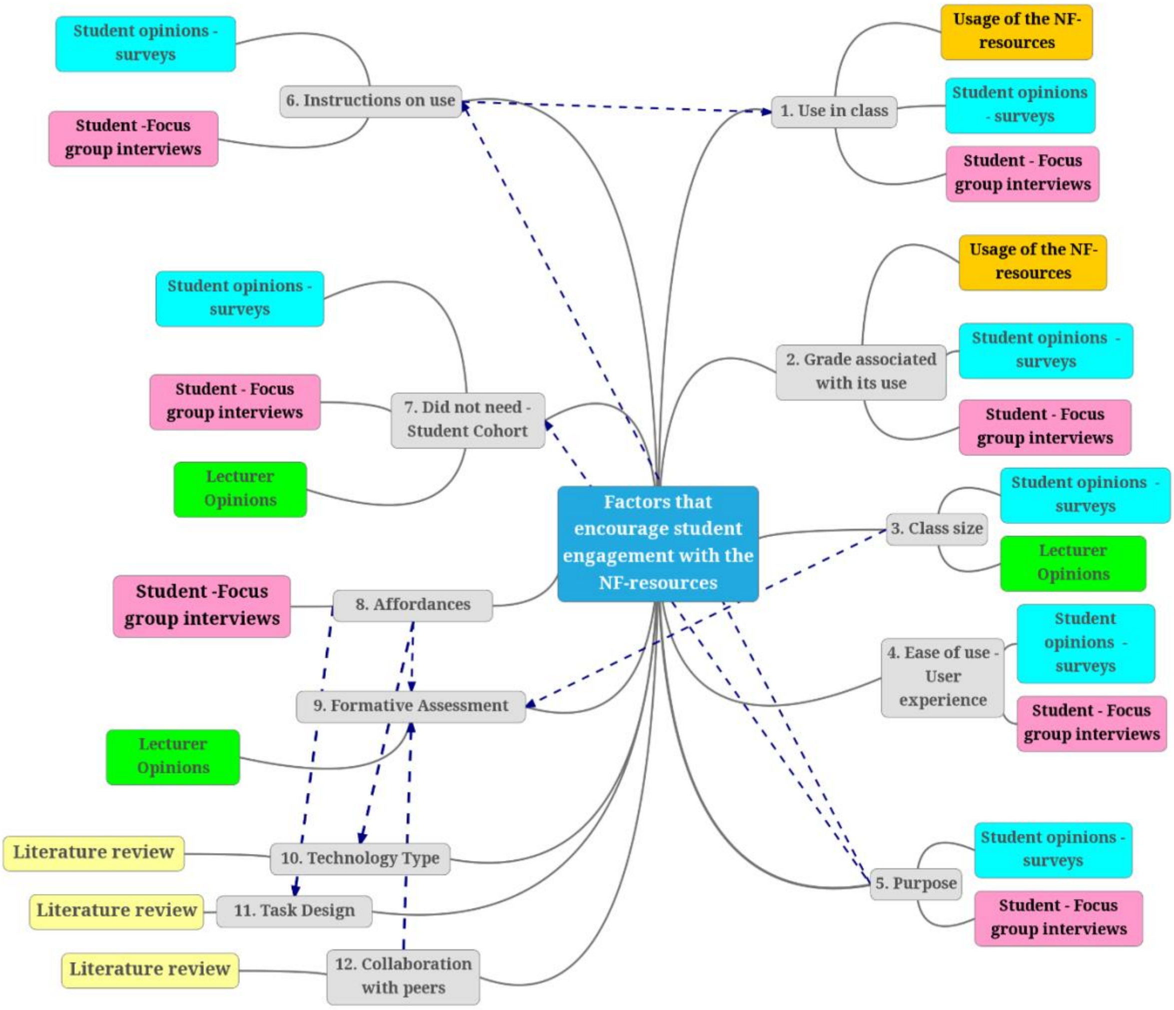


Figure 5.8.1: Final research instruments that contributed to the identification of the factors

Grey – Factors that impact student engagement; Orange – resource usage; Blue – Student Surveys; Pink – Student focus group interviews; Green – Lecturer opinions; Yellow – Literature review;

Continuous black line – connect factor to identifying research instrument; Dashed navy lines - connect factor that impacts on another factor.

In the next section, the measures used to determine the factors will be examined in terms of student engagement. This is followed by a discussion of the factors in relation to existing studies in the area.

5.8.1 Student engagement

As one of the aims of this research is to explore student engagement with technology-enhanced resources, it is important to reflect on how the measures used in the evaluations indicate student engagement.

Indicators of engagement are observable and/or measurable entities that signify actions or reactions that can be classified as one of behavioural, affective or cognitive engagement (M. Bond & Bedenlier, 2019). In Chapter 4, the operational definition of student engagement with technology, as used in this thesis, was outlined as follows:

- Behavioural - concerned with students' actions in relation to using technology, such as: use/non-use; duration they used it; or effort in trying to use it.
- Affective - concerned with students' emotions prior to or as a result of using the technology, such as: satisfaction; annoyance; confusion; or frustration.
- Cognitive - concerned with students' learning from using the technology, such as: developing understanding; or achieving competence in methods.

In the analysis of the NF-funded project resources trial evaluations, the measures used signified both positive and negative engagement actions and reactions of the students. For example, the students in the GeoGebra focus groups indicated their desire to do well in the assignments. Desire to do well has been recognised as an indicator of positive affective engagement (M. Bond & Bedenlier, 2019). On the other hand, attendance, operationalised as technology usage, had a negative impact on behavioural engagement in the GeoGebra tasks. Figure 5.8.2 demonstrates how the measures and observations, used in the NF-funded resource trial evaluations can be considered as indicators of the three dimensions of engagement. In this diagram, engagement indicators recognised in the literature (M. Bond & Bedenlier, 2019; Fredricks et al., 2004) have been observed in the study. Note some of the measures indicate a negative engagement impact, such as Self-Regulation, where KA3 students did not cognitively engage with the resources.

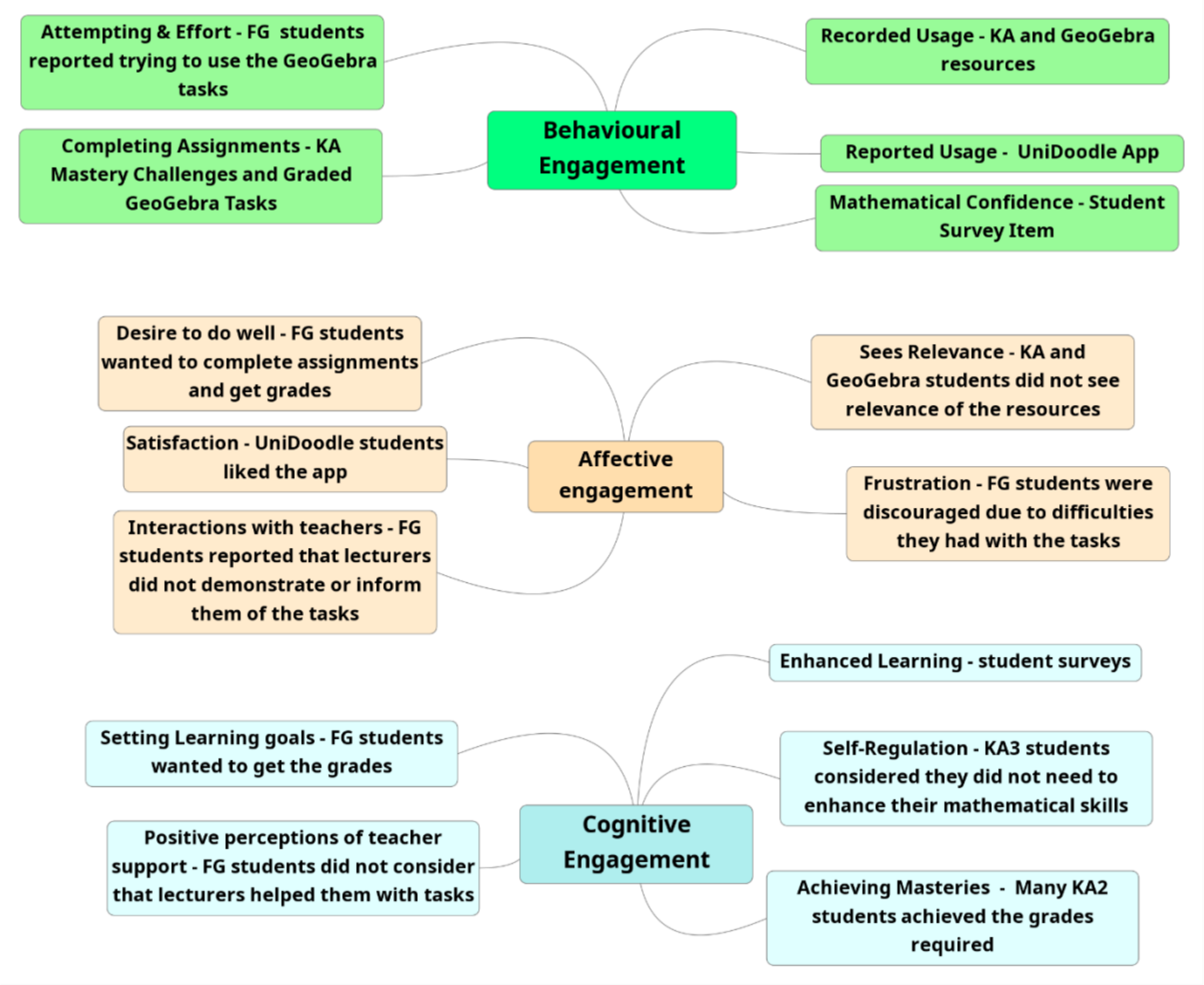


Figure 5.8.2: Indicators of engagement that were observed or measured

The three dimensions of behavioural, affective and cognitive are colour coded. Note: FG stands for "focus group".

These indicators of student engagement were used to differentiate between the various trials of the NF-funded project resources which led to the identification of factors that impact on student engagement with technology. These factors will be considered in light of existing studies of student engagement with technology.

5.8.2 Factors that encouraged or discouraged engagement

Student engagement is a multidimensional construct that is influenced by many different factors (M. Bond & Bedenlier, 2019; Kahu & Nelson, 2018). While Bond and Bedenlier (2019, p. 3) do not list recorded usage of technology as an indicator to measure engagement, they suggested similar indicators such as attendance, homework completion and time on task. Students' usage varied across the different resource types and implementations. Using these indicators, assessment, or 'grade associated with its use' was identified as a key factor that encouraged or discouraged behavioural engagement. Students used the KA2 resource, for which 10% of the grade was associated with its use. The number of students who accessed the graded GeoGebra tasks was significantly higher than for the non-graded tasks (McNemer test ρ=0.00). While using assessment to encourage engagement has been recognised in the literature (Schindler et al., 2017, pp. 21–22; Krause, 2005, as cited in Trowler, 2010, p. 46), the effect of integrating assessment with the use of technology has not been fully investigated in mathematics education. The Thomas et al. (2017) study suggested that assessment should be key to the integration of technology, which is in line with the finding in this study. Hence 'grade associated with its use' can be considered as a key pedagogical factor that impacts on students' engagement with technology.

Using the resources in class also impacted on students' usage of the resources. A large proportion of the students in the UniDoodle trials used the resources and all bar one student registered for, and used, the KA class application in the KA2 trial. On the other hand, usage in the two other KA trials and the GeoGebra trials, where the resources were not used in class, was a lot lower. In studies within K-12 education (USA), it has been suggested that students learn best if the technologies are brought into the classroom (Christenson et al., 2012). This is also in line with the findings from Thomas et al. (2017); using technologies in class has been shown to encourage use of the technology. Studies have also shown that using technology in class can increase students' engagement in learning (Galligan et al., 2015). Thus, 'use in class' is identified as a factor that has been found to encourage students' behavourial engagement with the resource.

While class size did not necessarily impact on students' usage of the NF-funded project resources, it did impact on the student and lecturer views of formative assessment. In the smaller UniDoodle class, students were significantly more satisfied with formative assessment than in the larger class. In addition, the lecturer in the KA2 study commented that implementing formative assessment strategies in a class of greater than 80 would not have been manageable. '*Positive perceptions of teacher support'* is an indicator of cognitive engagement, which can be implied from the student survey responses in both these trials (M. Bond & Bedenlier, 2019, p. 3). In addition, satisfaction, as expressed by the students in the UniDoodle1 trial, is known to be indicative of affective engagement (M. Bond & Bedenlier, 2019, p. 3). Thus, 'class size' is a factor that impacts on student engagement.

The usefulness of formative assessment was rated highly by students in a number of the trials. Students reported positively on the ability to retake quiz questions in the graded GeoGebra tasks and the KA online quizzes. Formative assessment has long being valued in education (Wiliam & Thompson, 2008) and it has been suggested that the use of technology can facilitate online formative assessment (Gikandi et al., 2011). The immediate feedback made available to students as a result of online quizzes, or the affordance of the technology to support feedback in terms of visual representations, has been shown to support learning (Geiger et al., 2016; J. S. Lee, 2014; Wong & Yang, 2017; Yang et al., 2018). Trenholm et al. (2015) investigated feedback practices in fully online undergraduate mathematics modules and suggested that, in addition to the provision of high quality feedback, it is important that students use this feedback. The fact that students using the NF-funded project resources remarked on the value of the online quiz feedback is an indication of their engagement with this feedback. This persistence to complete the quizzes is also one of the indicators of behavioural engagement outlined by Bond and Bedenlier (2019, p. 3). Thus, the provision of 'formative assessment' is a further factor that encourages students to engage with technology. Along with formative assessment between the lecturer and student, the peer-to-peer communication that technology can afford has also been shown to support formative assessment and hence engagement (FaSMEd, 2020a; Thomas et al., 2017). Collaboration with peers through the use of technology has been shown to support student cognitive and behavioural engagement (M. Bond & Bedenlier, 2019), and is identified as a factor.

Particular features or affordances of the GeoGebra tasks appealed to students. The ability to adjust variables using a slider, or to input a function and hence visualise the output, were considered valuable by students in contributing to their mathematical understanding. Artigue (2002) discusses the epistemic affordances of using technology in mathematics education, in that it can be used to enhance mathematical understanding. The affordances of CAS resources, such as GeoGebra, have been well recognised in the literature on mathematics education (Ball et al., 2018; Pierce & Stacey, 2010; Thomas et al., 2017). In this study, students have indicated how the use of such technologies can support their mathematical understanding. The identification by students that their understanding is improved is an indicator of students' cognitive engagement (M. Bond & Bedenlier, 2019, p. 3). Hence another factor emerges, which is the exploitation of the 'affordances' of technology to encourage students' mathematical understanding.

Tied into the affordances of the technology is the type of technology; different technology types provide various affordances and hence can be used to design different types of mathematical tasks. In mathematics education, the technology type and its impact on the successful integration of technology has been reported on in the literature (FaSMEd, 2020a; Galligan et al., 2015; Hoyles & Noss, 2003). Task design has been identified as a factor in students' engagement in technology-enhanced mathematical resources (Drijvers, 2015; Geiger et al., 2016; Pierce & Stacey, 2010) and the complexity of the task design will depend on the affordance of the particular type of technology. Hence the two factors of 'task design' and 'technology type' have been identified.

Seeing the relevance of the material students cover is considered an indicator of affective engagement (M. Bond & Bedenlier, 2019, p. 3). It has also been highlighted in studies on online education (Martin et al., 2019) and on students' engagement with mathematics (Steen-Utheim & Foldnes, 2018). While studies on student engagement and on mathematics education have identified the desirability of making the relevance of content explicit (M. Bond & Bedenlier, 2019; Gueudet & Pepin, 2018), there has been no finding that suggests the purpose of the technology use needs to be made explicit. In this study, both students in the KA and GeoGebra trials expressed that the purpose of the technology supports were not evident to them. In fact, students in the focus group interviews stated that, had they known the purpose, they would have used them. The next factor that impacts on engagement found from this study is the need for the relevance or 'purpose' to be made explicit to students.

In addition to purpose, students clearly indicated that they needed instructions on how to use GeoGebra. This need for instruction is widely reported in literature on the use of technology in mathematics education, with some educators calling for teachers to orchestrate the use of technology through the development of schema for its use (Jupri et al., 2016; Kieran & Drijvers, 2016; Thomas et al., 2017). The fact that the lecturers in the GeoGebra trial did not use the technology in class was referred to in a negative way by students, further supporting the idea of the need for teachers to 'privilege the use of technology' (Jupri et al., 2016; Kieran & Drijvers, 2016; Thomas et al., 2017). This indicates a further factor that impacts students' engagement with technology, the need for 'instruction on use'.

A number of usability issues were identified, such as the lack of clear labels in GeoGebra and the use of colour in UniDoodle. These issues have not been to the fore in the evaluation of technology in education (Zaharias & Poylymenakou, 2009), though they are of increasing concern (JISC, 2015; Morville, 2016). In their micro-level model of the influences of the learning environment and technology on student engagement, Bond and Bedenlier (2019, fig. 3) include usability as a factor. Thus, the factor of 'user experience' has been identified in this study.

It is known that students' mathematical confidence and affective disposition impact on their motivation to engage with mathematics (Alves et al., 2016; Matthews et al., 2013; Tariq & Jackson, 2008). In this study, it was found that for this particular cohort of students, first-year undergraduates attending non-specialist mathematics, motivations and confidence impacted on their engagement with the NF-funded project resources. Educational background has also been identified in the literature as impacting on student engagement with technology (Drijvers, 2015; Geiger et al., 2016) and in both Kahu and Nelsons' (2018) and Bond and Bedenliers' (2019) frameworks of engagement. Thus 'student cohort' is identified as the final factor.

Now that these factors have been identified, how can they be used? Drijvers (2015) suggested that one of the issues with technology integration is a lack of knowledge of the factors that influence successful implementations. In addition, many authors (Conole & Alevizou, 2010; Dimitriadis & Goodyear, 2013; M. King et al., 2014) have identified the need for frameworks of evaluation that can be used to measure the success of technology integration. In the next chapter, the factors that have been identified here will be used to develop a framework that can classify technology integration both prior to and after the implementation of the technology in a module.

Chapter 6 Development of the TeRMEd Framework

6.1 Introduction

So far, this research study has identified 12 factors that impact on student engagement with technology-enhanced resources, in part answer to RQ1 and RQ2. These factors, along with the results of the literature review, were used to develop the TeRMEd classification framework. Practitioners, those who are involved in the teaching of first-year undergraduate mathematics, can use this TeRMEd framework to plan and evaluate technology-enhanced resource implementations intended as supports for their students. The need for such frameworks has been widely recognised (Drijvers, 2015; M. King et al., 2014; Lopes & Costa, 2019; Mishra & Koehler, 2006) and prompted RQ3: *How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?*

This chapter aims to address RQ3 and explains the rationale for the development of the TeRMEd framework.The first section of the chapter contains an overview of the TeRMEd framework. Subsequent sections contain detailed discussions of the genesis of the categories and subcategories of each of the four sections of the TeRMEd framework. The TeRMEd framework is then used to classify the NF-funded project resources, followed by an evaluation of this classification by the lecturers involved in the project. In the final section, the value of the framework is discussed.

6.2 TeRMEd framework – an overview

As discussed in Section 3.5, as a member of the NF-funded project team, I held initial discussions with the project lead, Dr. Ann O'Shea, and my two supervisors, on the possibility of developing classifications of the NF-funded project resources. Subsequently, I worked on classifications that incorporated the characteristics of the NF resources, the outcomes of the NF resource evaluations and existing relevant frameworks and models, to create the TeRMEd classification framework, consulting with my supervisors when and where necessary.

There are four sections defined in the TeRMEd framework: Implementation; Technology; Learning; and Formative Assessment. . The decision to include these four sections, and the associated categories and subcategories, was based on how best to incorporate all of the characteristics of the NF-funded resources, the factors identified in Chapter 5, and relevant parts of existing models or frameworks, into a single framework. This was an iterative process completed throughout the development of the TeRMEd framework, whereby the classifications were repeatedly examined to ensure all inputs were included in a manner that enabled clear distinction between the different sections, categories and subcategories. The Implementation section characterises the educational setting, the didactical functions of the technology and the user experience. The technology type, and the level of cognition and user task control afforded by the technology are defined in the Technology section. The characteristics of the types of expected mathematical proficiency are covered in the section on Learning. Finally, the different aspects of formative assessment supported by the resource are characterised in the Formative Assessment section. Figure 6.2.1 illustrates the four sections and the categories within each section.

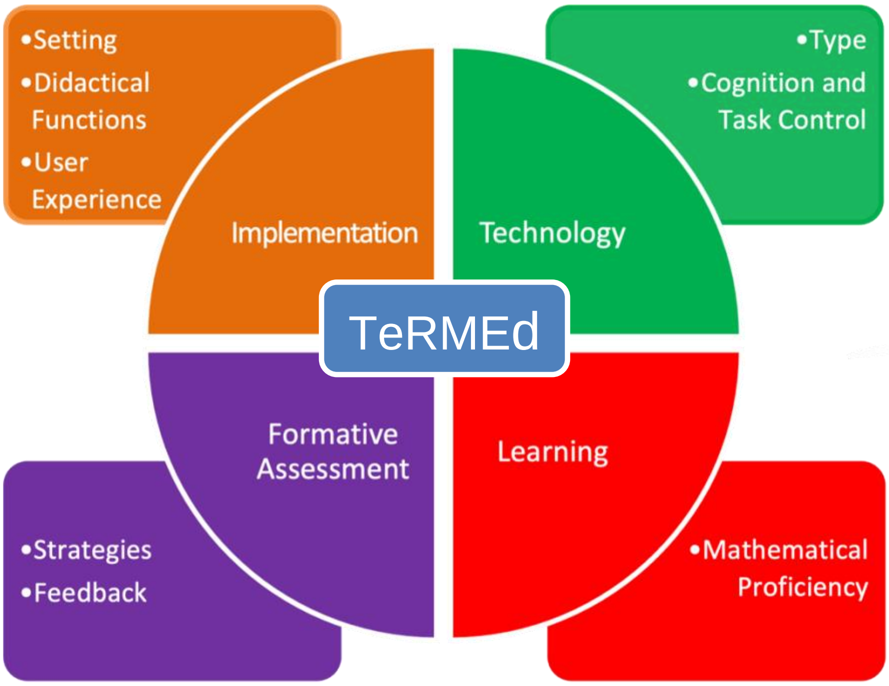


Figure 6.2.1: The TeRMEd classification framework

The development of the TeRMEd framework was an iterative process, described in detail in Chapter 4. In the first instance, the NF-funded project resources were characterised in conjunction with the lecturers (Appendix D). Details of the NF-funded project's resource trials were then gathered (Table 3.7.1) and characterised in Table 5.2.1. These characterisations, along with the analysis of the NF-funded project's resource trials, were used to identify factors that impacted on students' engagement with the resources (Chapter 5). The next step was to examine existing frameworks of evaluation to determine how they might be used to contribute to the development of an evaluation framework. This analysis is described below.

6.2.1 Existing evaluation frameworks and models

In Chapter 2, a number of models and frameworks that are used to describe and characterise the use of technology in education were reviewed. A subset of these frameworks was selected for further examination. The selection was based on their relevance to mathematics education, and on their widespread use as reported in the literature. In addition, frameworks that focussed exclusively on teacher-student interactions were excluded, as they are not of primary concern within the NF-funded project's resource classifications. Each of the selected frameworks was reviewed with both the characterisation of the NF-funded project resource trials (Table 5.2.1) and the 12 factors identified in Chapter 5 in mind. Table 6.2.1 contains a list of the frameworks considered and a brief rationale behind the inclusion or exclusion of their elements within the TeRMEd framework. Details of the elements that were included will be discussed in the context of the discussion of the TeRMEd framework development in subsequent sections of this chapter.

Table 6.2.1: Models and Frameworks used to classify technology use

Model/Framework	**Purpose**	**Included**	**Rationale to include/exclude**
FaSMEd (2016)	Characterises aspects of secondary-level classroom use of formative assessment technology tools	Partially	Focus on technologies used within classroom, at secondary level. Insufficient categorisations to include all factors identified for NF-funded project resources.
SAMR (Puentedura, 2006)	Characterises how technology tools adopted into existing education environment	No	Focus on tasks technology supports. Technologies used by NF-funded project resources can support more than one task, and more than one of SAMR levels.
Bray and Tangney (2017)	Technology Classification System (general characteristics of technology-enhanced interventions in mathematics education)	No	Learning theory and intervention aim characterisations outside scope of TeRMEd framework. Technology classifications relevant but did not adequately describe all technology types evident in NF-funded project resources.
Mobile App categorisation	Categorises use of mobile apps for schools based on instructional roles and	Yes	Allows categorisation of pedagogical affordances that

(Handal et al., 2011)	media richness as: productive, explorative, and instructive		different technology types can support.
Categories of digital tools. (Hoyles & Noss, 2009)	Four categories of tools: (1) dynamic and graphical tools (2) tools that outsource processing power (3) new representational infrastructures (4) connectivity that supports mathematics activity	No	Categorisations useful in consideration of technology section but did not encompass all inherent and pedagogical affordances of technologies used in NF-funded project trials.
Experimental mathematician (Borwein, 2005)	Provides a list of eight ways that experimental mathematicians use computers	No	Solely concerns specific affordances of technology.
Pedagogical opportunities (Pierce & Stacey, 2010)	Map of ten pedagogical opportunities, grouped into three levels: (1) Task that has been set, (2) Classroom interaction, (3) Mathematical topic	No	Concepts behind map fruitful in developing educational context (classroom and didactics); map itself focusses on MAS technology. NF-funded trials implemented other technology types in addition to MAS.
Didactic Functionalities (Drijvers, 2015)	Three didactical functions supported by technology: (1) Do (2) Learn – Practice Skills (3) Learn-concepts	Yes	Suitable as classification of different task types used in NF-funded project resources.
Instrumental Orchestration (Artigue, 2002; Kieran & Drijvers,	Converts digital tools into artefacts, connects technical skills and	No	Complex set of elements to describe how students develop mathematical understanding.

2016; Lopes & Costa, 2019; Thomas et al., 2017)	conceptual understanding required		Used by researchers – not a focus for practitioners.
Didactic Tetrahedron (Trgalová et al., 2018)	Examines digital tool use as interactions between (1) tools and knowledge, (2) tools, knowledge and the learner, and (3) integration of tools in curriculum or classroom	No	Tool to understand how students interact with technology to achieve mathematical understanding. Used by researchers – not a focus for practitioners.
User Experience Honeycomb (Morville, 2016)	Attributes of technology deemed desirable to enhance student experience of using technology	Partially	Seven attributes considered in line with questionnaire items used in NF-funded survey evaluations.
TAM (Buchanan et al., 2013; Nikou & Economides, 2017; Zogheib et al., 2015)	Theorises usage behaviour of technology - Perceived usefulness and Perceived ease-of-use	Partially	Concept of two scales - considered and reflected in user experience section of TeRMEd framework.

None of these frameworks contained all of the 12 factors that impact on student engagement that were identified in Chapter 5. Therefore, in the construction of the TeRMEd framework, elements identified in the table above, Table 6.2.1, were incorporated where appropriate and new characteristics were created to fill any voids. Figure 6.2.2 illustrates where the TeRMEd classifications are original, modified, or previously existing. The origin and development of each of these is discussed in greater detail in the following sections.

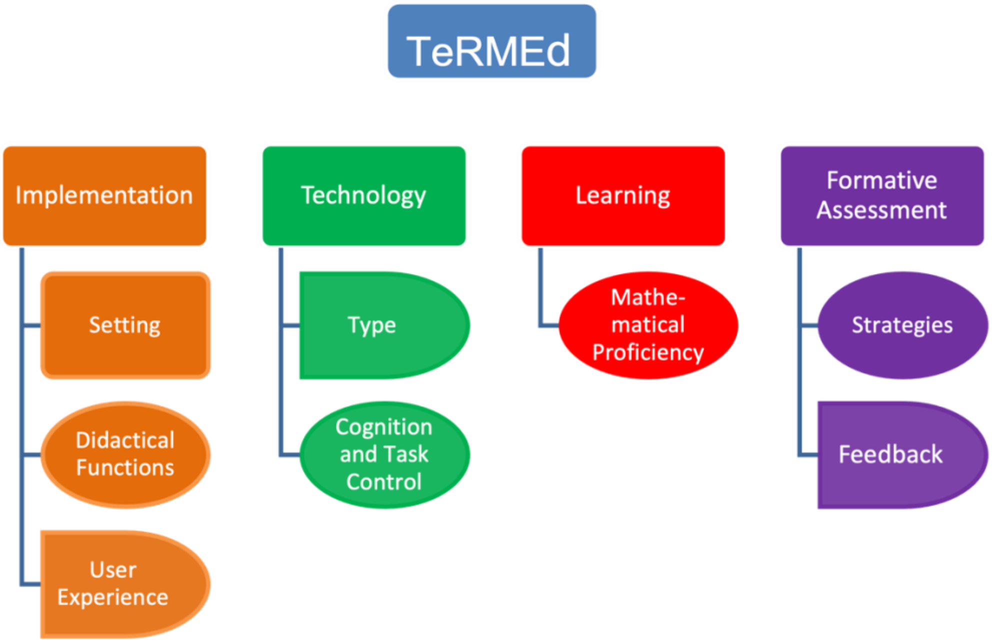


Figure 6.2.2: Contribution to knowledge made by the TeRMEd framework

Description: Rectangles represent original content; ovals represent content developed by others; half/half represent content developed by others but modified by this researcher, or some original subcategories and some developed by others.

6.3 Implementation Section

The necessity of including 'implementation' in our framework stems from Drijvers' (2015) suggestion that the 'educational context' of a technology resource implementation is essential in determining its effectiveness. This section has three categories: Setting; Didactical Functions; and User Experience, each with a number of subcategories, as shown in Table 6.3.1.

Table 6.3.1: TeRMEd framework - Implementation Section

Section	Category	Subcategory	Options
	Setting	Class Size	Small < 30
			30 ≤ Medium < 100
			Large ≥ 100
		Use in Class	Lecture only
			Study time only
			Both lecture & study time

Implementation		Summative Assessment	Yes
			No
		Student Cohort	Non-specialist
			Specialist
	Didactical Functions	Do	
		Learn - practise skills	
		Learn – concepts	
		Lecturer Instructions	Instructions
			Purpose
			Instructions & Purpose
			None
	User Experience	Navigation	Likert scale
		Usable	Likert Scale
		Learnability	Likert Scale
		Accessibility	Dynamic or Static
		Consistency	Dynamic or Static
		Visual Design	Dynamic or Static
		Technologically ready	Dynamic or Static
		Useful	Likert Scale
		Usage	Recorded by technology/ lecturer

The three categories of the Implementation section of the TeRMEd framework are discussed below.

6.3.1 Implementation - Setting

The sub-categories and options that stem from Setting were determined as a result of four of the factors identified during the evaluations of the NF-funded project resources in consultation with the literature. These four factors are:

- class size
- use in class
- grade associated with use
- student cohort

The factor ‘class size’ determined the first subcategory, Class Size. In the literature on the impact of class size on student learning in higher education, there is little consensus as to the number of students that constitute a ‘large class' (Dean & Wright, 2017). Fischer and Grant (1983, as cited in Cuseo, 2007, p. 7) defined small classes as 15 or fewer, medium as 16 – 45 and large classes as 46 or more. Alternatively, large classes were defined as ones where student learning is negatively affected (Hornsby & Osman, 2014) or where interactions with and by students is constrained (Dean & Wright, 2017). Thus, I set the Class Size sub-categories to Small <30, 30 ≤ Medium < 100, and Large ≥ 100, based on the observations from the use of the NF-funded resources and how some of the technologies impacted within different class sizes. As discussed in Section 5.6 the lecturers in the UniDoodle1 & 2 and the KA2 trials commented on the fact that class size impacted on their teaching. These three trials had 12, 165 and 80 students respectively. Subsequent discussions with the NF-funded lecturers identified the limits of 30, 100 and greater than 100 as the approximate number of students that would impact in such a way.

The Use in Class subcategory was identified as a result of the ‘use in class’ factor: the effect on student engagement of using the NF-funded project resources in prescribed class time versus in students’ own time. This subcategory also aligns with the theoretical underpinnings of instrumental orchestration, where use of the technology in class by lecturers and teachers is encouraged to ensure instrumental genesis, i.e. to enable students to be able to use educational technology effectively (Thomas et al., 2017).

The Summative Assessment subcategory was created as a result of the ‘grade associated with its use’ factor, and evidence that suggests that students are more likely to engage in learning assessments that contribute towards their grade (Gibbs, 2010). Note the term Summative Assessment was used as practitioners are likely to be familiar with this term from the literature, where assessment is often delineated as either summative or formative (Gibbs, 2010; Gikandi et al., 2011; Nicol & Macfarlane-Dick, 2007).

The final Setting subcategory, Student Cohort, takes into account the ability and attitude of the particular student group, and their assessment of their own need for such resources. It has been shown that students taking non-specialist mathematics modules often do not have the required mathematics level (Faulkner et al., 2010; Gill & O’Donoghue, 2007a), and the analysis of the data in

Chapter 5 revealed that this group of students are more invested in achieving a grade rather than developing mathematical understanding.

6.3.2 Implementation - Didactical Functions

The second category, Didactical Functions, captures the need to take into account how the teacher puts the digital tool into effect. This has been identified as being important for effective technology implementations in the classroom (Drijvers, 2015). Therefore, it is necessary to characterise the pedagogical functionality that is enabled by teachers' implementation of the technology. The Drijvers' (2015) model of Didactical Functionality, as outlined in Chapter 2, was used to describe how the pedagogical functions of the resources can be enacted by the lecturers. This model is suitable as it maps to the initial intention of the NF-funded project: to address the concepts and procedures with which students have most difficulty. The resources were developed with these in mind; hence, the tasks selected by the lecturers were readily categorised within this model. There are three main didactical functions supported by the technology: (1) Do: the functionality related to doing mathematics, where work that could be done by hand is done by the technology; (2) Learn – practice skills: the functionality provided to practice skills; and (3) Learn – concepts: the functionality that supports the development of conceptual understanding (Drijvers, 2015, p. 136). The inclusion of didactical functionality also takes into account the need for 'task design', one of the factors that was identified, in Chapter 5, through the literature review as having an impact on student engagement.

In addition, two factors identified in the outcomes of the evaluations were the need for clarity of 'purpose' and 'instructions on use' of the resource. Therefore, an additional didactical function, Lecturer Instructions, was added. This refers to the didactical practices of the lecturer, specifically provision of purpose and instructions, when implementing the technology. The need to consider these didactical practices has also been discussed within the instrumental orchestration theoretical framework (Jupri et al., 2016; Kieran & Drijvers, 2016; Thomas et al., 2017) and the didactical tetrahedron (Trgalová et al., 2018). The options for this sub-category are: Instructions, Purpose, Instructions & Purpose, None.

6.3.3 Implementation – User Experience

The third category in the Implementation section is the User Experience. This category stems from the 'user experience' factor identified in the NF-funded project evaluations and a review of the relevant literature. User experience has long been a concern of the education community with respect to the selection of educational software for use by teachers (JISC, 2015; Squires & Preece, 1999). The addition of this category in the framework supports the belief that the user interface impacts on student engagement, and hence learning from using the resource (M. Bond & Bedenlier, 2019). As discussed in Chapter 2, there are many different usability and user experience factors that have been investigated in the development and use of technology in education. In the construction of the subcategories for the TeRMEd framework, the items used in the survey, and described in Chapter 4 from Zaharias and Poylymenakou's (2009) usability evaluation method, were first examined. In addition, the seven usability attributes from Morville's User Experience Honeycomb and the two scales of the TAM were considered (Buchanan et al., 2013; Morville, 2016). The resultant User Experience category contains nine subcategories. Four of the subcategories stem directly from four survey items asked in the student surveys of the NF-funded resource evaluations: Navigation; Usable; Learnability and Useful and are populated from the results of the survey. For example, the percentage of students who were positive about how easy to use they found a resource will be the value for the Usable subcategory (recall the survey item was - For me it was easy to use the resource). The Usage subcategory is the percentage of students who used the technology as recorded electronically or by the lecturer involved in the study. The remaining options for these subcategories are set by a static/dynamic value, which indicates whether the feature is controlled by the product designer (static) or the lecturer (dynamic). For example, the accessible subcategory will be static when the technology used has not been modified by the lecturer and dynamic if it has. These subcategories are described below:

- Navigation: Learners can navigate their way around resource without seeking help
- Usable: Learner's perception of how easy-to-use they find resource
- Learnability: Learner's perception of how their learning has been enhanced using resource
- Accessibility: Resource is accessible and follows UDL principles
- Consistency: Consistency of terminology, design and functionality within resource
- Visual Design: Screen is easy to read, and information is placed in optimal places to attract learners' attention
- Technologically ready: Resource is free from technical problems
- Useful: Learners' perception of how useful they find resource within the context
- Usage: Percentage of learners who used resource

6.4 Technology Section

The second section of the TeRMEd framework, 'Technology', was included in response to Drijvers' suggestion for a focus in educational studies on the particular technology used (Drijvers, 2015). The classifications in this section were focussed on 'affordances' of the different 'technology types' as a result of the identification of these factors in the analysis reported on in Chapter 5. This section has two categories: Type; and Cognition and Task Control, see Table 6.4.1. Type is used to consider the inherent affordances of the different types of technology in use, and Cognition and Task Control characterises the pedagogical affordances provided by the associated mathematical tasks. In addition, the Cognition and Task Control category takes into account elements of 'task design'; one of the factors that the literature review helped identify as having an impact on student engagement (Drijvers, 2015; Pierce & Stacey, 2010; Thomas et al., 2017).

Table 6.4.1: TeRMEd framework – Technology Section

Section	Category	Subcategory
Technology	Type	Communication Tool
		MAS
		CAA
		Instructional Material
	Cognition and Task Control	Productive
		Explorative
		Instructive

6.4.1 Technology -Type

The technology type is used to characterise the different functionalities that the technology supports, and supports the 'technology type' factor identified in the literature. In the FaSMEd project, two technology types were defined: Connected Classroom Technologies (CCT), which are used to support interactive teaching and learning in classroom situations via interconnected devices; and Computer-Aided-Assessment (CAA), defined by Bull and McKenna (2004, p. xiv) as '*the use of computers in the assessment of student learning*', and extended by FaSMEd to include all types of assessment and tablets and handheld devices (FaSMEd, 2020b). These technology types do not encompass all possibilities, for example Mathematical Analysis Software (MAS). MAS is increasingly being used to help students explore the relationships between multiple representations of mathematical objects (Breda & Dos Santos, 2016) and encompasses mathematical tools such as dynamic geometry, computer algebra systems, computation and mathematical modelling (Pierce & Stacey, 2010). A fourth type of resource is online instructional videos which are used in e-lecture contexts (Howard et al., 2018; Trenholm et al., 2019). This generated four technology types: CCT, CCA, MAS and online instructional videos. However, some technologies provide a means of communication between students and their lecturer without interconnecting devices within classrooms, so it was decided to name these Communication Tools, of which CCT is a subset. In addition to online instructional videos; podcasts, screencasts and text-based documents may be used as instructional material. Hence, the four sub-categories in the Type category are: Communication Tool; MAS; CAA; and Instructional Material. Based on an extensive literature review, these four types of technology-enhanced resources encompass the majority of such resources in use in mathematics education today.

6.4.2 Technology – Cognition and Task Control

Inherent in the technology and its functionality are the complexity of the tasks that can be performed. While both Hoyles and Noss (2003) and Borwein (2005) considered the categories and functionalities of technology mediated learning, they did not adequately and simply capture how the NF-funded project resources were used. In order to characterise this, a category called Cognition and Task Control, based on the work of Handal et al. (2011), was created. The Handal et al. (2011) classifications are a modified form of the Goodwin pedagogical classification of tablet apps (Goodwin, 2012). Handal et al. (2011) added the concept of media richness to describe the ability of the app to provide a '*high level of problem solving and low prescription*'. In the context of the TeRMEd framework, the three subcategories are defined as follows:

- The Productive subcategory is used to define those tasks that engage students in the highest level of cognition and over which they have most control; students are required to construct mathematical representations such as graphs.
- The next level of cognition required is in the Explorative subcategory; these tasks are used for simulations and guided discovery.
- The lowest level of cognition and task control are afforded by Instructive subcategory tasks which are generally focussed on drill and practice.

6.5 Learning Section

One of the aims of the NF-funded project was to design and trial technology-enhanced resources in order to help students develop mathematical proficiency. The term 'mathematical understanding' is not well-defined in the literature and there is no single definition. Many authors have attempted to describe it in different ways. Skemp (1976, p. 2) divided understanding into two types: instrumental, knowing what to do without reason; and relational, knowing both 'what to do and why'. On the other hand, Pirie and Kieren (1994) proposed a more complicated model of understanding that featured eight levels, starting from 'primitive knowing' through 'formalising' to 'inventising'. As discussed in Chapter 3, the project team wanted to use mathematical tasks that supported students' ability to both 'understand' and 'do' the types of mathematical problems they encountered (Ní Shé et al., 2017a). Therefore, the team chose to work with the concept of 'mathematical proficiency', as defined by the NRC (2001, pp. 115–145). The NRC uses the term to bring together five strands that are considered necessary for anyone to learn mathematics successfully. Thus, the category called Mathematical Proficiency was created to characterise whether the resources supported the development of understanding under these five strands, see Table 6.5.1. The use of these subcategories also supports the practitioner in the consideration of 'task design', a factor identified in Chapter 5.

Table 6.5.1: TeRMEd framework - Learning Section

Section	**Category**	**Subcategory**
Learning	Mathematical Proficiency	Conceptual Understanding
		Procedural Fluency
		Strategic Competence
		Adaptive Reasoning
		Productive Disposition

6.6 Formative Assessment Section

One of the aims of the development of the NF-funded project resources was to support mathematics learning using technology-supported formative assessment techniques, see Chapter 3. Thus, a Formative Assessment section was created with two categories: Formative Assessment Strategies, and Feedback. The categories, subcategories and options for the Formative Assessment section are illustrated in Table 6.6.1 and discussed in more detail in the subsections below.

Table 6.6.1: TeRMEd framework - Formative Assessment Section

Section	**Category**	**Subcategory**	**Options**
		Clarifying and sharing learning intentions	Yes/No
		Engineering effective classroom discussion	Yes/No
		Providing immediate feedback	Yes/No

Formative Assessment	Formative Assessment Strategies	Activating students as instructional resources for one another	Yes/No
		Activating students as owners of own learning	Yes/No
	Feedback	Feedback Type	Feedback about task (FT)
			Feedback about process (FP)
			Feedback about self-regulation (FR)
			Feedback about self (FS)
		Feedback Direction	Lecturer to student
			Technology to student
			Student to student

6.6.1 Formative Assessment – Strategies

The FaSMEd framework (FaSMEd, 2020a) encompassed Wiliam and Thompson's (2008, p. 64) five key strategies to characterise aspects of the use of technology to support formative assessment in the classroom. This framework is also appropriate for the NF-funded project, as Wiliam and Thompson's work (2008) was used to guide the provision of formative assessment within the NF-funded resources, see Chapter 3. Thus, the five subcategories were created as illustrated in Table 6.6.1 above. These strategies encompass a number of the factors that have been identified. In the first place, they provide strategies for 'formative assessment'. In addition, 'Activating students as instructional resources for one another' supports the factor of 'collaboration with peers' and 'Clarifying and sharing learning intentions' serves to support the 'purpose' factor.

6.6.2 Formative Assessment - Feedback

The identification of the 'formative assessment' factor, reported on in Chapter 5, was a result of both student and lecturer opinions on the value of, and the ability to, provide feedback. While the value of using technology for feedback has been acknowledged in the literature (Gikandi et al., 2011; J. Lee, 2014; Moreno & Pineda, 2020; Trenholm et al., 2015; Wong & Yang, 2017; Yorke, 2003), it is important that feedback is both used by students, and targeted at developing mathematical understanding, rather than simply providing praise (or otherwise) (Moreno & Pineda, 2020; Trenholm et al., 2015). In a meta-analysis of the literature on feedback interventions Kluger and DeNisi (1996) found that while feedback interventions can improve performance, in over one third of studies performance was reduced. They found that the nature of the feedback impacted on its success. For example, simple praise is sometimes detrimental, whereas 'computerised feedback that is likely to focus attention on the task' can enhance student performance (Kluger & DeNisi, 1996, p. 275). A 'Feedback' category was thus created to take into account the importance of how feedback is provided within technology integration.

The outcomes of the NF-funded trials indicated that students rated feedback from lecturers higher than that from technology, and that lecturers valued the feedback provided by students. Students, lecturers and technology are considered as the agents in the feedback process (FaSMEd, 2020a; Hattie & Timperley, 2007), thus a 'Feedback direction' subcategory was created which delineates feedback as being from: lecturer to student; technology to student; and from student to student. The latter option, student to student feedback takes into account the factor of 'collaboration with peers' as identified in Chapter 5.

In addition, a Feedback Type subcategory was created to characterise feedback according to the four recommended types identified by Hattie and Timperley (2007). They drew from the work of Kluger and DeNisi (1996), that identified feedback that works or does not, when developing their feedback model (Hattie & Timperley, 2007, p. 85). Feedback about the task (FT) relates to the correctness of a response and the need to acquire new or different knowledge. This type may appear as a grade, or as an opportunity to retake a question in a quiz. Feedback about the process (FP) is aimed at the learning process and may provide cues to students about task strategies. Feedback about self-regulation (FR) is aimed at developing students' self-assessment skills and is known to be very powerful in enabling students to identify the gap in their knowledge and encouraging them back to the task with more commitment. The fourth level of feedback identified by Hattie and Timperley (2007) is Feedback about the Self (FS) and is related to self-efficacy. This element of the classification supports the need for feedback to be carefully crafted in order to encourage the desired elements of student engagement and learning (Moreno & Pineda, 2020; Trenholm et al., 2015). These feedback types are used within the TeRMEd framework to enable practitioners to take into consideration how they intend their students to use the feedback.

6.7 Conclusion on the TeRMEd framework development

The TeRMEd framework discussed in the previous section is based on a theoretical foundation taken from the reviewed literature, and the outcomes of a research study. Drijvers (2015) pointed to the need to focus attention on the educational setting, the didactical practices and the design of the technology use, in order to ensure success in technology integration. The TeRMEd framework contains all three of these. The educational context, which is also considered to be an important factor in determining successful engagement with technology (M. Bond & Bedenlier, 2019; Drijvers, 2015; Kahu & Nelson, 2018; Trowler, 2010), has been captured in the Setting category of the TeRMEd framework. The pedagogical classifications contained in the TeRMEd framework document the didactical practices that are used within the technology integration. Finally, the design of the technology use is considered throughout the TeRMEd framework. The resultant classifications can be used to highlight the pedagogical similarities and differences of technology integrations. In addition, the variation in usage and student opinion of the technology in use are captured, in order to evaluate the technology integration. The latter parameters are important as indicators of student engagement which can be used to respond to the question posed by Drijvers (2018, p. 173) as to the need to identify the '*decisive factors that determine the eventual benefits in specific cases'* as to what works.

The first part of RQ3 has been addressed: a framework of evaluation, the TeRMEd framework, has been developed using the outcomes of RQ1 and RQ2. However, RQ3 also asks that the framework be used by practitioners to evaluate the effectiveness of technology-enhanced resource integrations. This issue is addressed in the next two sections of this chapter.

6.8 Classifying the NF-funded project resources

Thus far in this chapter, the outcomes of RQ1 and RQ2, and the review of the literature, have been used to develop a framework, the TeRMEd classification framework. The aim of the framework is to enable the effective planning and evaluation of technology-enhanced resources that are used in first-year non-specialist undergraduate mathematics modules. In a first step to determine if the framework is fit for purpose, the NF-funded project resources are classified according to the framework.

The values used within the framework were drawn from the descriptions and characterisation of the NF-funded project resources as described in Chapter 3 (and subsequently confirmed with the lecturers involved in the trials) and the evaluation data gathered as part of the trials, reported on in Chapter 5. The classifications, along with the relevant rationale, are presented in the subsections below.

6.8.1 Implementation Section - NF resource classification

Table 6.8.1 contains the Implementation Section classification for all seven NF-funded project resource trials.

Table 6.8.1: Implementation section - Classification of the NF-resources

Category	**Subcategory**	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**
Setting	Class Size	Small	Large	Large	Medium	Large	Large	Large
	Use in Class	Lecture only	Lecture only	Study time only	Both lecture & study time	Study time only	Study time only	Study time only
	Summative Assessment	No	No	No	Yes	No	Yes	Yes
	Student Cohort	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist
Didactical Functions	Do							
	Learn – practise skills			✓	✓	✓		
	Learn – concepts	✓	✓				✓	✓
	Lecturer Instructions	Instructions & Purpose	Instructions & Purpose	Purpose	Instructions & Purpose	Purpose	Instructions & Purpose	Instructions & Purpose
User Experience	Navigation	91.67%	84.38%	17.31%	N/A	36.36%	N/A	N/A
	Usable	91.67%	91.67%	47.62%	51.35%	45.45%	58.70%	30.45%
	Learnability	91.67%	56.70%	26.61%	61.11%	47.06%	53.33%	55.09%
	Accessibility	Static	Static	Static	Static	Static	Dynamic	Dynamic
	Consistency	Static	Static	Static	Static	Static	Dynamic	Dynamic
	Visual Design	Static	Static	Static	Static	Static	Dynamic	Dynamic
	Technologically ready	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic
	Useful	100.0%	72.8%	33.3%	52.8%	45.5%	48.9%	49.8%
	Usage	100.0%	83%	17%	99%	10%	92% & 50%	87% & 60%

N/A – indicates that data was not available in the surveys in response to this item.

The data for the Setting category was taken directly from the characterisation of the NF-funded project resources and subsequently confirmed by the lectures.

A similar approach was taken for determining the values in the Didactical Functions category. In the case of UniDoodle, the availability of free-form input by students allowed the audience response system to be used to support conceptual understanding. The pedagogical functionality supported by UniDoodle therefore was Learn - concepts. The lecturers explained the purpose of using the app and provided instruction on its use, at the beginning of class. The KA was used to support the pedagogical functionality of Learn – practise skill in all three KA trials. In the case of the KA1 trial, the students were informed of the purpose of the KA, after they got their first diagnostic test (DT1) result, but they were not guided in the use of KA. In the KA2 trial, the lecturer guided the students through the KA mastery challenges and provided both purpose and instructions. Finally, in the case of KA3, the resources were uploaded on the VLE and an explanation of their purpose was given in the associated lecture. GeoGebra was used to support the pedagogical functionality of Learn – concepts, the aim was to develop students understanding of functions. In this instance, the students were informed about the purpose of the tasks during a face-to-face lecture and, in that class, the lecturer demonstrated how to access and use them. In addition, the first GeoGebra task students were asked to access contained some tips on how to enter functions in GeoGebra.

The data for the User Experience subcategories was obtained from the surveys, the usage, and in consultation with the lecturers. Values for the four subcategories of Navigation, Usable, Learnability and Useful are the percentages of respondents that selected either SA or A to the relevant item in the questionnaire, as reported in Chapter 5. The Usage measures are also taken from the evaluation data, as reported in Table 5.3.1. The remainder of the subcategory values, either static or dynamic, were based on the implementation of the technology type and discussed with the lecturers involved in the project.

6.8.2 Technology Section - NF resource classification

The technology section was completed from the descriptions of the resources outlined in Chapter 3 that had been agreed with the lecturers involved in the NF-funded project, see Table 6.8.2 below.

Table 6.8.2: Technology section – classification of the NF-resources

Category	**Subcategory**	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**
Type	Communication Tool	✓	✓		✓			
	MAS						✓	✓

	CAA			✓	✓	✓	✓	✓
	Instructional Material			✓	✓	✓		
Cognition and Task	Productive							
	Explorative	✓	✓				✓	✓
	Instructive			✓	✓	✓		

The UniDoodle app was used by lecturers to communicate questions to students and by students to communicate their responses; hence, it was classified as a Communication Tool. The tasks involved students exploring concepts, guided by their lecturer, so it was classified as Explorative.

All three trials of the KA involved the use of online quizzes (CAA) and instructional videos. In addition, the KA2 resource allowed communication between the lecturer and student in the form of monitoring of student progress and setting of KA masteries. These resources provide practice and drills and relatively low level of cognition; thus, they are classified as Instructive under the cognition and task control subcategory.

GeoGebra is a MAS and was used to allow students explore relationships in a manner guided by the GeoGebra software (Explorative). In addition, some of the GeoGebra tasks involved an online quiz element (CAA).

6.8.3 Learning Section – NF resource classification

The selections for the Learning section were based on the original aim of the NF-funded project, the provision of support on the concepts and procedures that students had difficulty with, and agreed with the project team. These are shown in Table 6.8.3.

Table 6.8.3: Learning section – classification of the NF-resources

Cate-gory	**Subcategory**	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**
Mathematical Proficiency	Conceptual Understanding	✓	✓				✓	✓
	Procedural Fluency			✓	✓	✓		
	Strategic Competence							
	Adaptive Reasoning							

	Productive Disposition							

All the trials are classified as either conceptual understanding or procedural fluency, as this was the aim of the NF-funded project (Ní Shé et al., 2015). The lecturers involved in the UniDoodle and GeoGebra trials had identified particular areas of conceptual understanding that their students were lacking in, thus they designed mathematical tasks that supported students in developing such understanding. In the case of the KA trials, the lecturers were more concerned with the lack of their students' ability to carry out mathematical procedures, hence they selected tasks, from the KA application, that that can be used to support procedural fluency.

6.8.4 Formative Assessment Section – NF resource classification

The values entered for the Formative Assessment section were decided on in conjunction with the lecturers involved in the development of the resources. Table 6.8.4 contains the classifications for the Strategies and Feedback categories of this section which are discussed below.

Table 6.8.4: Formative Assessment section- classification of the NF-resources

Category	**Subcategory**	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**
Strategies	Clarifying and sharing learning intentions	✓	✓	✓	✓	✓	✓	✓
	Engineering effective classroom discussion	✓	✓		✓			
	Providing immediate feedback	✓	✓	✓	✓	✓	✓	✓
	Activating students as instructional resources for one another	✓	✓					
	Activating students as owners of			✓		✓	✓	✓

	own learning							
Feedback	Feedback Type	FT	FT	FT	FT	FT	FT	FT
		FP	FP		FP			
				FR	FR	FR		FR
		FS	FS	FS	FS	FS	FS	FS
	Feedback Direction	Lecturer to student	Lecturer to student		Lecturer to student			
		Student to lecturer	Student to lecturer					
				Tech. to student	Tech. to student	Tech. to student	Tech. to student	Tech. to student

With respect to formative assessment strategies, a number of them were supported by the different NF-funded project resources, as illustrated in Table 6.8.4. As this cohort of students (those attending first-year undergraduate non-specialist mathematics modules) are often unaware of the mathematical skills that are required (Faulkner et al., 2010; Gill & O'Donoghue, 2007a), one of the initial aims of the NF-funded project was that the resources developed would provide clarification to students on the learning intentions of the mathematics modules (within which the resources were used). A second aim, used to address this student cohort's lack of ability (Faulkner et al., 2010; Gill & O'Donoghue, 2007a), was that the resources should provide immediate feedback to students on their progress. In the UniDoodle trials, this feedback was provided by the lecturer in class, while in the KA trials, it was provided by the grade and feedback they received on the KA online quizzes. The GeoGebra tasks provided feedback in the form of visual representations of graphs when students used sliders to adjust the variables of a function. Thus, all seven trials satisfy both the "Clarifying and sharing learning intentions" and the "Providing immediate feedback" sub-categories.

The use of the UniDoodle app in class "engineered effective classroom discussion". The lecturer was able to pinpoint incorrect responses, display them to the class and discuss the errors. Subsequent questions were then created based on those errors and students responded once more with UniDoodle. The use of students' responses as the focus of class discussion also supported the idea of "activating students as instructional resources for one another". Class discussion was also facilitated in the KA2 trial. Students' progress in the KA class application mastery challenges was monitored by the lecturer and used by them in class to discuss problematic areas with the students.

Finally, the formative assessment strategy, “activating students as owners of their own learning” was used in the KA1 and KA3 trials, where use of the KA was optional. Similarly, the majority of the GeoGebra tasks were optional and students were encouraged to manage their own learning.

Feedback type and direction also varied across the trials, Table 6.8.4, and as they are inextricably linked, they are discussed together. In the UniDoodle trials, feedback direction was, in the first instance, from students to the lecturer, as students sent in their responses to the problems posed. Subsequently the lecturer sent three feedback types to the students. First, students received feedback on the correctness of their response (FT). Secondly, for incorrect responses, the lecturer gave feedback to the class, in the form of further instruction and explanation of concepts, and strategies that can be used to solve similar problems (FP). Finally, the lecturer gave verbal feedback for correct responses in the form of praise (FS).

In all three KA trials, feedback was given by the technology to the student. FT and FS were given to students for the KA quizzes, in the form of technology computed calculations of correctness and grades. In the KA2 trial, the lecturer provided feedback on the process (FP) to the students during class time in the form of strategies on how to approach solving the problems. The fact that students using online quizzes in KA had the opportunity to redo them when their answers were incorrect, meant the feedback from the technology helped them identify gaps in their knowledge which they could use to self-regulate their learning (FR).

In the GeoGebra graded tasks, students received feedback from the technology in the form of correctness and praise (FT and FS). In addition, the fact that students could repeat the questions in the online quiz in the GeoGebra2 trial meant that they obtained feedback from the technology that helped identify gaps in their knowledge which they could use to self-regulate their learning (FR).

6.8.5 Conclusion on TeRMEd classifications

The classifications of the NF-funded project resources are illustrated in each of the four tables, Tables 6.8.1 – 6.8.4. The data used to populate the tables was generated from two sources: the first was the results of the evaluations of the NF-funded project resources, and the second was the outcomes of conversations and consultations with the lecturers involved in the NF-funded project. The similarities and differences between the NF-funded resource trials are apparent in the classifications, and demonstrate the variation in educational setting, pedagogical practices and resultant student engagement for these resources. Three examples are given to demonstrate this conclusion. As a first example, the use of the resource in class, and whether it was graded, varied across the resources; this impacted on the students’ usage of the resources (Table 6.8.1). A second example is found in the contribution that feedback from the lecturer, and in particular feedback about the process (FP) (Table 6.8.4), gave to the generally higher ratings in the User Experience subcategories of Usable and Learnability (Table 6.8.1) for the UniDoodle and KA2. The final example considers the difference in the type of learning envisaged (Table 6.8.3) for the use of UniDoodle (conceptual understating) versus KA (procedural fluency). The tasks in UniDoodle were used to support Learn – Concepts whereas KA was used for Learn – Practice Skills (Table 6.8.1), and this is reflected in the affordances that the different technology types support: explorative versus instructive (Table 6.8.2).

This framework is aimed at practitioners; therefore, it is necessary to obtain feedback on the usefulness of the framework from the practitioner perspective. The results of a detailed survey with the lecturers involved in the NF-funded project are discussed in the next section.

6.9 The TeRMEd framework– practitioner view

In the previous section, the TeRMEd framework classifications of the NF-funded project resources were used to illustrate how pedagogical practices influence student engagement with technology-enhanced resources. The intention in developing the TeRMEd framework is that practitioners could use it to consider the planning and subsequent effectiveness of their technology-enhanced resource integrations. In order to determine practitioner opinions of the TeRMEd framework, six of the lecturers involved in the NF-funded project were asked to complete an online survey. The survey and analysis methodology were described in Chapter 4.

The two main objectives for the survey, both of which contribute to addressing RQ3, were:

1. To determine if the TeRMEd framework categories and subcategories are relevant to the lecturers' practice.
2. To establish if the practitioners found the TeRMEd beneficial when evaluating the integration of the resources they trialled as part of the project, and in considering future technology integrations.

These two objectives will be used to focus the outcomes of the survey. Note that one of the lecturers who responded to the survey was involved in the pilot (see Chapter 4 for details), and the subsequent pilot data from his students was not included as part of the student evaluations. Hence the pilot lecturer did not respond to the survey section asking for lecturers' reaction to the User Experience values calculated within the TeRMEd classifications (Table 6.8.1). Thus, there are six responses considered in Section 6.9.1 and five in Section 6.9.2.

6.9.1 Relevance of TeRMEd framework – practitioner view

The first objective of the survey was to determine if the lecturers found the categories of the framework relevant to their practice. Lecturers were asked if they had taken each of the categories and subcategories into account prior to the development of the trial of their particular NF-funded project resource, selecting Yes/No/Unsure on a range of items. The items were grouped according to the TeRMEd framework sections, and at the end of each section they were asked to comment on their selections where relevant. The outcomes of this analysis are considered in the four sections below. As mentioned in Chapter 4, the same lecturer ran both the KA1 and KA2 trials, and only one of the lecturers from the GeoGebra trials responded. In the figures below, only selected data points are labelled with the relevant trial name, so as not to overcrowd the diagram, and a discussion of the most relevant lecturer comments follows each figure.

6.9.1.1 Implementation Section – practitioner view

The lecturer responses to whether or not they had taken each of the items on the Implementation section into account are shown in Figure 6.9.1. Note the lecturer in the KA3 trial did not answer the item on Learnability.

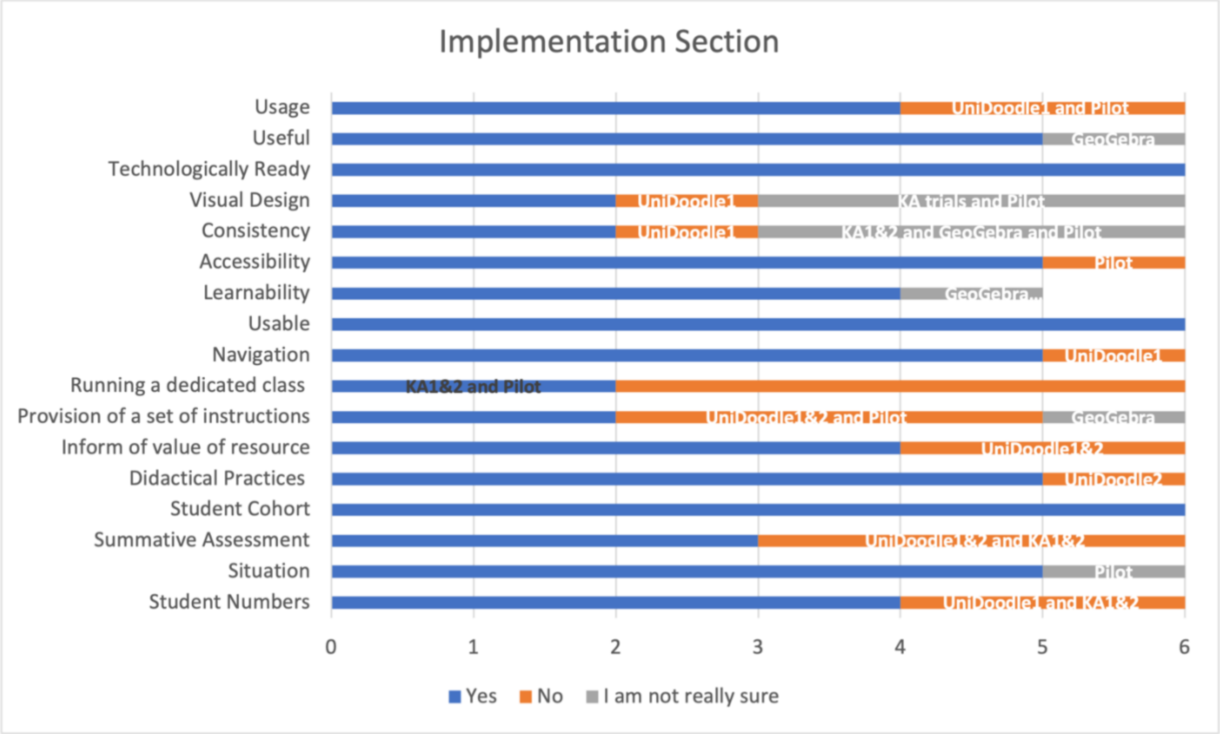


Figure 6.9.1: Implementation section responses

The main points of interest are where the lecturers selected that they had not taken a particular category into consideration, or were unsure. In their comments, the lecturers did not always specifically refer to why they selected ‘No’ for a particular item. For example, in both UniDoodle trials, the provision of instructions was not considered. Neither lecturer commented on this particular selection; rather the UniDoodle2 lecturer commented on the general implementation of UniDoodle within the module. It may be, that since the UniDoodle app was going to be used in class, and was designed to be easy to use (as the lecturers commented later in the survey), that the lecturers considered that a separate set of instructions was not required.

The GeoGebra lecturer was unsure about whether they had considered how Useful or Learnable the GeoGebra tasks might be to the students. She said that *‘we probably thought about how the learning might be enhanced or how useful the resource might be rather than the learner's perception of these things’.* This remark illustrates how the lecturers focussed on the effective teaching of the mathematics over and above how the students might perceive the resources, although student perception is likely to impact upon their engagement with the resource.

Also of note is that, while the lecturer in the UniDoodle2 trial may not have been familiar enough with the Didactical Practices, as outlined by Drijvers (2015), to select that he had considered them, his remarks illustrated that he had, in fact, done so:

‘*Specifically, what concepts would benefit most from being addressed in this graphical manner, and how to best phrase questions to ensure that students would use their visual understanding of the mathematical concept*’ (UniDoodle2 Lecturer).

Clearly from these comments, the UniDoodle2 lecturer designed tasks that supported the didactical practice of Learn-concepts, despite having selected “No” for this.

A number of the lecturers selected ‘No’ or ‘Unsure’ about visual design and consistency. But, as remarked by the lecturer in the KA1&2 trials about this selection, ‘(they*) were considered - I had no control over these elements*’. Using technology-enhanced resources that are embedded within an externally available product will mean that there are certain elements over which a practitioner will have no control.

Finally, another point to note is that the lecturers involved in the trials in the IoTs (KA1&2 and pilot) were the only lecturers who considered running a dedicated class on the use of the technology. As mentioned in Chapter 3, students attending the IoTs generally have achieved lower grades in their Leaving Certificate than those attending universities. It is possible that the lecturers in the IoTs may have taken this into account, by providing a dedicated class as a form of support for their students, whereas those working in universities did not.

6.9.1.2 Technology Section – practitioner view

Figure 6.9.2 contains the lecturer responses to the items on the Technology section of the framework.

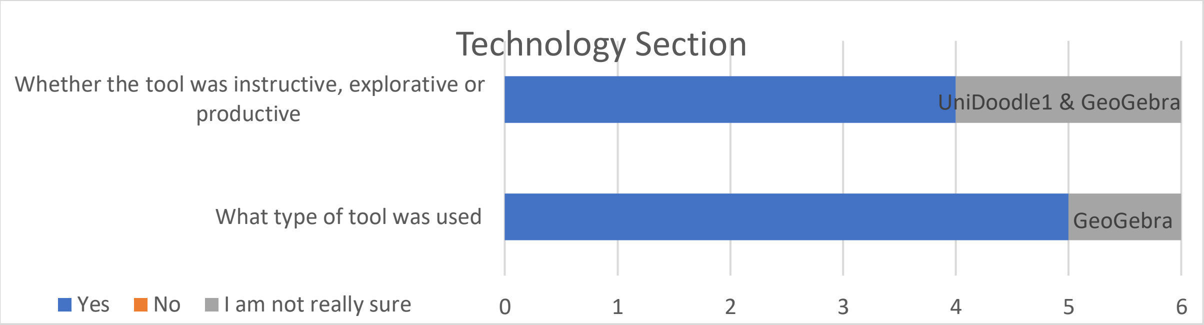


Figure 6.9.2: Technology section responses

All but two of the lecturers took the instructive, explorative and productive nature of the tool into account, even though they were unlikely to have been familiar with the categorisation of apps by Handal et al. (2011). This demonstrates how the TeRMEd framework has captured what these practitioners do when implementing technologies, and justifies its inclusion in the framework.

The lecturer in the KA1&2 trials qualified her selection of the types of quizzes she used with KA by saying '*…the nature of the quiz associated video was considered - whether instructive or explorative*'. While the KA integrations were classified in the TeRMEd framework as Instructive, it is interesting to note that the lecturer also considered how the mathematics learning they supported could be explorative.

With respect to the type of tool, the lecturer in the GeoGebra trial said '*I think we knew we wanted to use GeoGebra because of previous experience with it, rather than searching for a tool that would enable us to address our objectives'.* This provides us with some insight into how familiarity with a particular tool can influence the choice of technology employed in the classroom.

6.9.1.3 Learning Section – practitioner view

The lecturer responses to the items on the Learning section of the framework are shown in Figure 6.9.3.

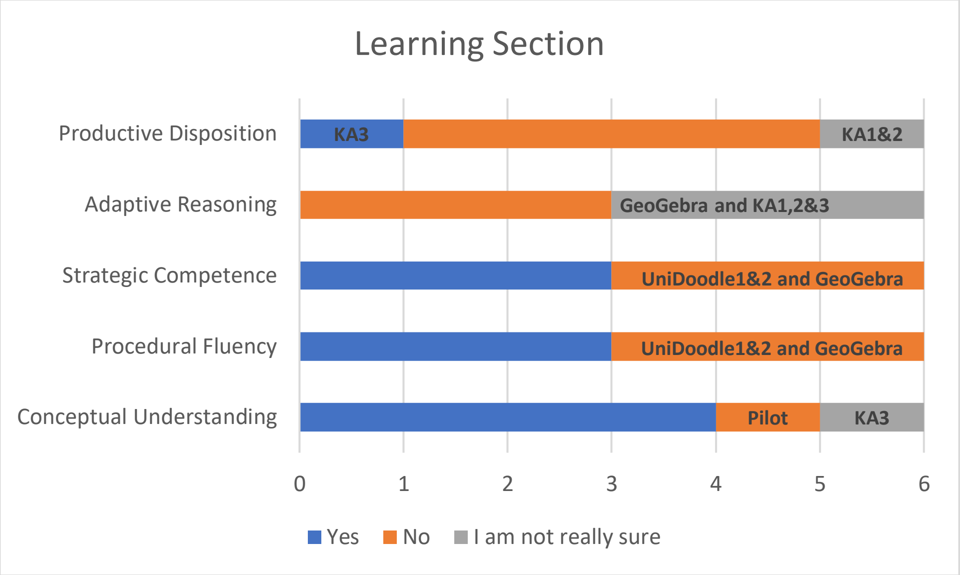


Figure 6.9.3: Learning section responses

Based on the original focus of the NF-funded project, the NF-funded resources were all classified as supporting either Conceptual Understanding or Procedural Fluency (see Table 6.8.3). The lecturer responses in Figure 6.9.3 show a slightly different picture, in that there was also some consideration of other strands of the NRC's model of mathematical proficiency (National Research Coucil, 2001). When asked to qualify their choices, the lecturers in the KA trials all said that the other strands did not play as big a role as procedural fluency. As put by the lecturer in the KA1&2 trials, '*The main focus in using KA was on procedural fluency but in embedding this within a module setting, other aspects such as strategic competence were considered.'* The lecturer in the GeoGebra trial said she was unsure of adaptive reasoning, but that they had wanted students to '*recognise a pattern, reflect on it and be able to justify (informally) any conjectures they mad*e'. The nature of the NRC model is that the strands are intertwined (National Research Coucil, 2001), and this association was evident from the lecturer responses.

6.9.1.4 Formative Assessment Section – practitioner view

Figure 6.9.4 contains the lecturer responses to the Formative Assessment items in the lecturer survey.

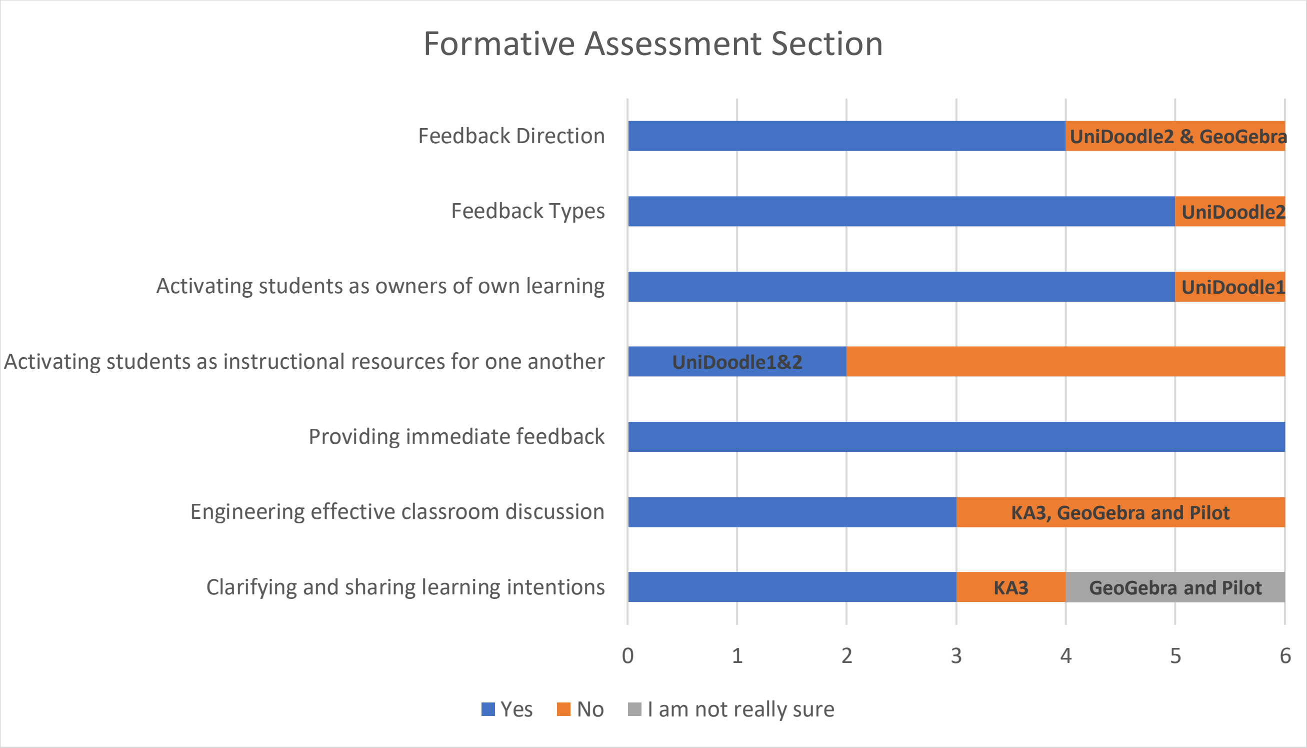


Figure 6.9.4: Formative Assessment section responses

Similar to the responses on the Learning section of the framework, it is clear that there are some differences between the lecturer responses in this figure and the Formative Assessment section classifications contained in Table 6.8.4. For example, the lecturer in the KA3 trial selected that he did not take “Clarifying and sharing learning intentions” into consideration, contrary to the classification in Table 6.8.4. This was a first-year mathematics module for business students. It may have been that this lecturer’s focus in providing the KA playlists was to support students in achieving the prerequisite mathematical skills required for their mathematics module, rather than on supporting them achieve the learning objectives of the module itself. Similarly, for the GeoGebra tasks, the lecturer had said that the focus was on developing understanding of functions within a broader Calculus module.

The relevance of this section of the framework is found in the remark made by the lecturer involved in the UniDoodle2 trial when commenting on the Formative Assessment section: ‘*The tool was great for all of the above. It forced students to challenge their understanding, based on visual information. This learning intention was made clear with them. Feedback was instantaneous and it facilitated a lot of peer to peer learning*.’ This comment shows that the subsections of the Formative Assessment section were appropriate for the use of this tool in the classroom.

6.9.2 Benefits of the TeRMEd framework – practitioner view

The second objective of the lecturer survey was to determine if the lecturers found the classification of their NF-funded trial beneficial when considering the success, or otherwise, of their technology integration, and if they would use the TeRMEd framework when planning future technology integrations. In order to address this objective, the lecturers were asked whether the classifications within the TeRMEd framework were as they expected, if there was anything new or that came as a surprise to them, and whether they might change their practice in the future based on these outcomes. These are discussed in two sections below. The first section considers the lecturers' reflections on the values within the User Experience classifications, which were based on the student survey and usage data. The second section considers the broader value of the TeRMEd framework for the lecturers. As noted above, the lecturer in the pilot did not complete this section of the survey, hence there are five responses.

6.9.2.1 Lecturer reflections on students' opinions

When asked whether they would have predicted the outcomes of the survey contained in the User Experience categories of student opinions and usage, the lecturers, with a few exceptions, agreed that they would. Figure 6.9.5 illustrates the lecturer responses and is followed by a discussion of the pertinent comments made by the lecturers on their responses, though they did not all always comment on each selection.

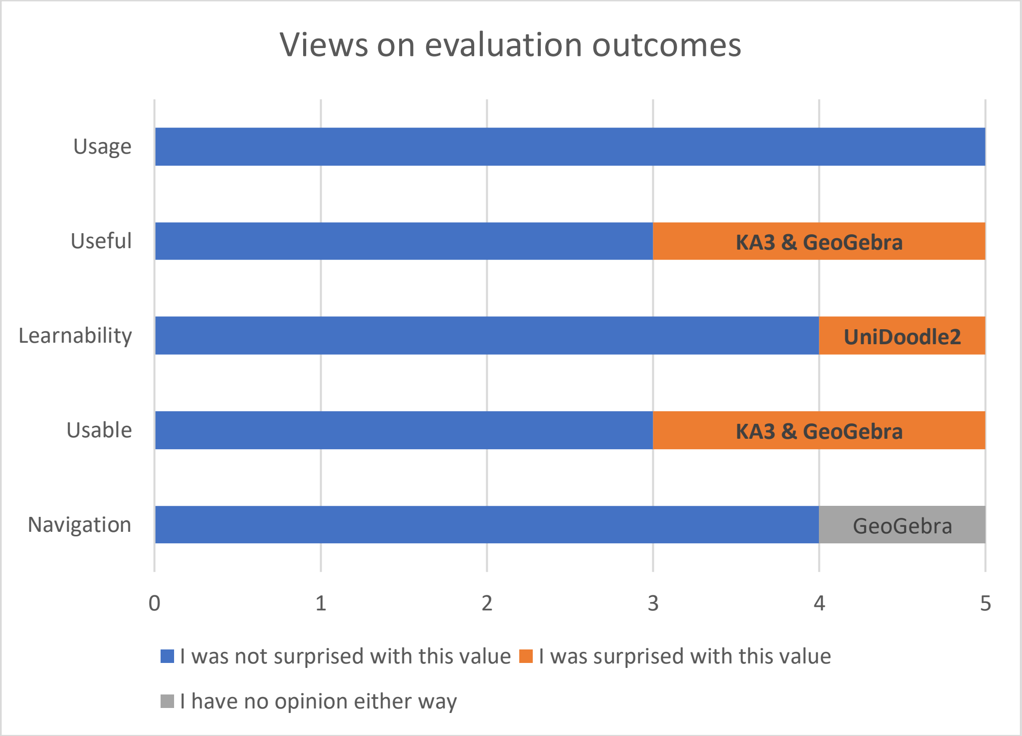


Figure 6.9.5: Lecturers' surprise or otherwise on students' opinions

UniDoodle

Both lecturers said that the Usage, Usability and Navigation of the UniDoodle was as expected, because it was used in class and designed with ease of use in mind. '*My students are pretty technologically competent and the app was well designed so I am not surprised that most found navigation easy (and ease of use*)' (UniDoodle2 lecturer). The UniDoodle1 lecturer was not surprised by the Learnability outcome as it helped *'their learning of the various concepts involved (through visually seeing their mistakes)*'. However, in the UniDoodle2 trial, the lecturer expressed concern that more students rated Useful (72.8%) highly than Learnability (56.70%), see Table 6.8.1. He remarked that students may not have liked to be forced into engaging graphically and visually with mathematics, *' but (I) am a little surprised that more students did not see the value of it'*. Despite having given considerable time to the development of tasks, the lecturer goes on to say that '*Perhaps this is my fault for not reinforcing the concepts well enough during the exercises'*. The use of the evaluations within the TeRMEd classifications has prompted this lecturer to reflect on his teaching.

KA resources

Even though he considered that KA is in fact easy to navigate, the lecturer involved in the KA3 trial was not surprised that the students stated they found it hard to navigate. *'…While students tend to need some instruction in navigating new platforms, they seem to be able to do so when there is a strong incentive, e.g. because CA marks are at stake'* (KA3 lecturer). However, he was surprised that students did not rate it easy to use: '*I had expected that those who used the resource would have found it more usable'* (KA3 lecturer). He was also unsurprised at the value for Learnability, and once more suggested that this was related to grades: *'… some students felt that as the KA material was not immediately focussed on their exam, …(it) did not help them learn in the sense of 'prepare for the exam'.* Interestingly, he was not surprised at the low values for Usage; rather he expressed disappointment: '*I think I'd describe the result as disappointing rather than surprising, so I would have hoped rather than expected a more positive result.'* It would appear that the lecturer involved in the KA3 trial was well aware of the typical engagement patterns of this student cohort with mathematics (first-year undergraduate business students) and though he provided additional supports, he had not really expected them to use them.

The sentiments regarding students' technical ability and CA were echoed by the lecturer involved in the KA1&2 trials. While she was not surprised with the figures for Usable and Navigation, as she had obtained this feedback in class, she was surprised by their lack of skill in this regard, *'… particularly IT students… and their inability to overcome minor difficulties in (their) use of the* *resources'* (KA1&2 lecturer). With respect to the high values for Learnability, she equated this with the fact that CA was attached. '*Students are very CA-driven and their learning is often focused on that which allows them achieve better grades - where KA was built into the Continuous assessment on a module students felt they were learning what was relevant'* (KA1&2 lecturer). In addition, she said that she was surprised by the students' '*unwillingness to revisit tasks required to achieve mastery*' and reckoned that students' dislike of this aspect of the resource *'may have impacted their view of its usability*'. Similarly, for Useful, she noted that students disliked having to repeat skills that they considered they had already completed. However, she added '...*that many returned to the resource in the lead up to semester examinations*'. This lecturer has emphasised the importance, in her experience, of embedding the use of resources with grades.

GeoGebra

The lecturer who completed this survey on GeoGebra was involved in the development of the resources but did not partake in the trials. She said she had no knowledge of this student cohort and therefore based her response on her theoretical expectations. However, she would have expected a greater percentage of students to rate the use of the GeoGebra tasks higher than they did. She said, '*I expected students to find GeoGebra resources more useful'*.

6.9.2.2 Using the framework to consider factors that impact student engagement

All of the lecturers agreed that the use of the TeRMEd framework helped them identify factors that they should have taken, or would in the future take, into consideration to improve student engagement. The lecturers discussed that the values within the User Experience classification, generated from the student survey data, would drive future technology integrations. '*In future implementations I would re-examine the classifications and consider whether anything could be done to improve on the values in some subcategories where values were low or missing'* (GeoGebra lecturer). When expressing his concern at the low value of Learnability in the UniDoodle2 trial, the lecturer wondered it if was his fault for not having reinforced the concepts. He went on to say that while he had put work into designing the technology use *'I still feel that my usage of it (and the students' appreciation of it as a learning tool) can be improved*'. The use of the framework of part of the evaluations has prompted these lecturers to reconsider future iterations of their resource integration.

Examples where lecturers referred to specific factors of the TeRMEd framework include summative assessment and usability. The lecturer in the KA3 trial had been unsurprised with the values in the User Experience categories and suggested that his student cohort are CA driven. In his final remark, he suggested he may use CA in the future, *'Having a summative assessment element attached to* *the KA playlists would have increased the take-up, and perhaps increased the overall usefulness of the resource for the students'* (KA3 lecturer). Indeed, there was a large difference between the Usage values for the KA1 trial (17%) and the KA2 trial (99%), both managed by the same lecturer. The results of the evaluation of the KA1 trial may have influenced the lecturer to embed CA in the KA2 trial. With respect to usability, the lecturer involved in the GeoGebra trials was surprised at the difference in values between the two trials (Table 6.8.1) and said that she would be *'focussing more on usability & learnability'* in future iterations in order to encourage greater student engagement with the GeoGebra tasks.

The lecturers also highlighted that there were factors that they had not considered before. These included Didactical functions, User Experience subcategories and aspects of both the Learning and Formative assessment sections. The lecturer in the UniDoodle1 trial had not considered all the strands of Mathematical Proficiency and expressed his desire to consider them in the future, '*I would like to see if I can use the UniDoodle resource to capture more than just the 'conceptual understanding*'. Similarly, the KA1&2 lecturer indicated that the use of the TeRMEd framework helped her identify some strands of Mathematical Proficiency and the Feedback Types classifications as factors in technology integrations. The lecturer in GeoGebra trials said she had not considered how Feedback Direction might impact on student engagement and that '*activat(ing) students as instructional resources for each other...could propagate the learning taking place or enable peer teaching (learning)'.* Specifically, the framework had made them think about these aspects '*because I wasn't familiar (or hadn't really thought about) the various sub-aspects within these sections'* (UniDoodle1 lecturer).

The lecturers found the TeRMEd framework useful in a number of ways. First of all, they felt it was comprehensive: '*The framework is very comprehensive and allows one to compare various tools on many different aspects/using many different criteria'* (GeoGebra lecturer). Secondly, they liked that it can be used as a design tool: *'It provides a useful design tool that I would take into consideration for future use of KA or other resources*' (KA3 lecturer). Thirdly, the UniDoodle2 lecturer considered it useful for '*Sharing of experience between practitioners to ensure best practice*.' Finally, it would facilitate the lecturer in focussing on the factors that impact engagement '… *if I have the document in front of me with the detailed breakdown of categories, it would focus my mind on a range of aspects to consider in the use of any new resource I would consider using*' (UniDoodle1 lecturer).

6.9.3 Conclusion on practitioners' views

The aim of the lecturer survey was to determine if the TeRMEd framework can be used by practitioners in both the planning and evaluation of technology integrations. The outcomes of the survey, which contribute to answering RQ3, have illustrated that the lecturers can use the TeRMEd framework in this way.

In response to the first objective of the survey, to determine if the TeRMEd framework categories and subcategories are relevant to the lecturers' practice, it is clear that the TeRMEd framework was relevant to the practitioners. This is evidenced from the data in Figures 6.9.1-5 and the associated lecturer comments. While not every option was taken into account in every trial, every category had been considered by at least one lecturer. Furthermore, lecturer comments on categories that they had not necessarily taken into account showed their relevance. One example is where the KA1&2 lecturer commented on how she had not had control over some of the user experience categories, though she had considered them. This response validates the choice to provide a 'static' and 'dynamic' option to these subcategories within the framework (see Table 6.3.1). A second example is where the UniDoodle2 lecturer described how he had designed the tasks for use with the app, and in doing so, had unknowingly used the Learn-concepts category of the Didactical Practices. A third and final example is where the lecturers from IoTs considered running a dedicated class on using the resources, whereas the university lecturers had not. As stated, students attending IoTs would generally have achieved lower entry grades than those at university, hence the lecturers are addressing the needs of their student cohort, validating the inclusion of this in the framework. Relevance of the TeRMEd framework is also demonstrated by the fact that lecturers expressed the desire to investigate subcategories for future consideration. Even though the NF-funded project resources were aimed at supporting conceptual understanding and procedural skills, other strands of mathematical proficiency were considered by the lecturers and a number of lecturers expressed their interest in investigating these for future technology integrations (Section 6.9.1.3). These outcomes demonstrate the validity of the categories and subcategories selected for the framework. Not only are they rooted in the literature, but they also reflect the practice of lecturers who are engaged in the development and investigation of the successful integration of technology in first-year undergraduate mathematics education.

The second objective of the survey was to determine if the lecturers found the TeRMEd framework useful for evaluating and planning their technology integrations. When the lecturers reflected on the User Experience values and considered them in the context of the TeRMEd classifications, they put forward suggestions for how they might modify their future technology integrations. While the lecturers in the UniDoodle trials were largely unsurprised with the values, the UniDoodle2 lecturer was concerned with Learnability and suggested he would need to reconsider the teaching of concepts within his practice. Similarly, the KA lecturers were largely unsurprised with the values but suggested that the Navigability and Usable values *'reflect the idea that students' technical skills* *as digital natives do not extend to a platform such as KA'* (KA3 lecturer). The two KA lecturers concurred that CA drives their cohort of students and appears to explain why usage was low in both the KA1 and KA3 trials, but high in the KA2 trial. This analysis of the User Experience classifications within the TeRMEd framework prompted the KA3 lecturer to state that he would use summative assessment in future iterations. In the GeoGebra trials, the lecturer had discussed how she was surprised with some of the results and that in future iterations she '*would re-examine the classifications and consider whether anything could be done to improve on the values in some subcategories where values were low or missing'.* In addition, the lecturers identified other factors from the TeRMEd framework that they had not previously considered and suggested they might use them in the future. For example, the GeoGebra lecturer had not considered the value of collaboration and peer learning for student engagement and said she would use the Formative Assessment strategy 'activating students as instructional resources for each other' in future iterations. This use of the TeRMEd framework has prompted the lecturers to consider changes in practice, thus validating the TeRMEd framework and the associated short student survey as a means for lecturers to evaluate the effectiveness of their technology-enhanced resource integrations.

Interestingly, there were differences between some of the classifications of the NF-funded project resources presented in Section 6.8 (which had been agreed with the lecturers), and the responses by the lecturers to the respective survey items in Section 6.9.1. This is not unexpected: the lecturer survey items specifically asked the lecturers had they taken aspects into account before integrating the technology resource. Thus, the classifications refer to how the technology integrations occurred, whereas the lecturer survey responses are what they might have considered in the planning stage. It is also possible that, given the time to reflect on their technology integration with the framework in front of them, the lecturers considered more deeply the pedagogical outcomes associated with the choices they made in implementing the resources. For example, the KA is classified as Instructive (Table 6.8.1), though the lecturer in the KA1&2 trials did consider the nature of the quizzes in terms of their explorative or instructive nature. The latter shows the value of including such aspects of task design and technology affordances within the TeRMEd framework.

Another area of discrepancy concerned the instructions given by the lecturers to students with respect to how to use the resource, and its value within the module. As can be seen in Table 6.8.1, Instructions & Purpose were provided for all trials, except for the KA1 and KA3 trials (where only Purpose was included). The lecturers in UniDoodle had used the resource in class where they had explained and demonstrated its use. However, they had not considered a formal set of instructions or purpose (Figure 6.9.1). Tied in with the fact that UniDoodle2 was a large class (Table 6.8.1), this may go some way towards explaining why students in the smaller UniDoodle1 class rated Learnability higher than those in UniDoodle2 (Table 6.8.1). Perhaps the provision of a set of instructions outlining the value of using the resource to enhance their learning would have achieved better student engagement with respect to Learnability.

Another valuable aspect of the framework is where lecturers can consider the affordances of the technology for their didactical purpose. The UniDoodle2 lecturer was clear that the UniDoodle app supported the learning he wished his students to achieve. On the other hand, the GeoGebra lecturer said they used GeoGebra as a tool simply because of familiarity, and as such perhaps the inclusion of other options within the Technology Type category will prompt practitioners to consider other tools.

Finally, one obstacle in the integration of technology was highlighted by the UniDoodle2 lecturer, and that was time. He said that using the '*Android sketch app required quite a bit of planning in terms of what questions to ask'* and that it '*requires a lot of thought to make sure that it is being integrated effectively and complementing what is happening elsewhere*'. Therefore, successful integration needs more time and '*room to breathe*'. Having a tool such as the TeRMEd framework to guide practitioners in technology integration is one way to help overcome this issue of time.

There is no doubt that these lecturers found the TeRMEd framework valuable and would use it when integrating technology going forward. Lecturers commented that it was '*comprehensive*' (GeoGebra lecturer), would help with '*planning'* (KA1&2 Lecturer), provided a '*useful design tool'* (KA3 Lecturer) and it would *'focus my mind'* on a range of useful aspects of technology integration (UniDoodle1 Lecturer).

6.10 The TeRMEd framework - conclusion

The aim of this chapter is to respond to RQ3: *How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?*

Researchers have identified a need for frameworks of evaluation to facilitate the gathering of evidence with respect to the success of the implementation of educational technology (Drijvers, 2015; M. King et al., 2014; Lopes & Costa, 2019; Mishra & Koehler, 2006). The aim of developing the TeRMEd framework was to allow for the classification of technology-enhanced formative assessment resources used in undergraduate mathematics, a classification that facilitates the planning and subsequent evaluation of different resources. Other models and frameworks have been used to classify how technology can be integrated into education (Bray & Tangney, 2017;

Drijvers, 2015; FaSMEd, 2020a; Handal et al., 2011; Hoyles & Noss, 2009; Pierce & Stacey, 2010; Puentedura, 2012), and how to investigate student learning and engagement (Artigue, 2002; Attard & Holmes, 2020; Buchanan et al., 2013; JISC, 2015; Morville, 2016; Trgalová et al., 2018). However, these proved insufficient to encompass the factors that impact student engagement, as identified in Chapter 5. Neither do any one of them allow the gathering of the evidence required to address the three issues outlined by Drijvers (2015): the design of the technology integration and the associated tasks; the role of the teacher in orchestrating the use of the technology; and the educational context, which includes the mathematical practices relevant to the level of study. In addition, many of the frameworks mentioned above deal with innovations at primary or secondary school level and not at university level where issues such as large class size become significant. Given this context, the TeRMEd framework had to address implementation, technology, mathematical learning, and formative assessment. As a result of the literature review reported on in Chapter 2, it is evident that these four dimensions have not all previously been included in one framework, and each one is a crucial element of a full resource classification.

The combination of these four sections (Implementation, Technology, Mathematical Learning, Formative Assessment) not only allows the classification of the individual NF-funded resource trials but also the comparison of the outcomes of the various trials of different technologies. For example, lecturers' use of technology affordances and didactical practices were used to support different learning types. The KA lecturers' adoption of Learn-practice skills, using the Instructive affordances of the KA, supported student development of mathematical proficiency, whereas the UniDoodle lecturers' use of Learn-concepts supported conceptual understanding. Within the TeRMEd classifications, it is evident that the same resource can be used or implemented in very different ways and that the details of the implementation can affect the outcomes of the innovation. For example, the KA resource trials demonstrate how comparison of the Summative Assessment and Use in Class sub-categories can be used to explain variations in Usage of the KA resources. This latter comparison demonstrates how the TeRMEd framework can be used to pinpoint the 'decisive factors' that Drijvers (2018, 2015) discusses.

Due to the nature of the pragmatic paradigm of this researcher, it was also important to ensure that the framework could be put to use by practitioners; thus, the NF-funded project lecturers were consulted. In the first instance, the evidence supplied by the lecturers justifies the selection of the categories and subcategories and their respective options. Not only was every category or subcategory taken into account in at least one trial, lecturers demonstrated how their practices were embedded in the framework. For example, the lecturers were aware of the constraints of the technology choice on the User Experience categories, like Visual design and Consistency, justifying the ‘static’ and dynamic’ options. They understood the importance of the technology affordances even though it is unlikely they had come across the Handal et al. (2013) classifications. They also demonstrated the value of including Student Cohort when discussing how Usable the resource had been rated by their students. These outcomes demonstrate how the TeRMEd framework has captured the characteristics of best practice in this area, a view supported by the UniDoodle lecturer when he commented on its value for sharing best practice.

Interestingly, the KA1&2 lecturer was the only one who considered running a dedicated class on the resource, and the UniDoodle lecturers stated they had not considered provision of Instructions or Purpose when planning their technology integrations. From the examination of the student opinions in Chapter 5, it is evident that many students would have liked more instruction on the use and value of the resources. Indeed, the UniDoodle2 lecturer was concerned at his students’ low rating of the Learnability of the resource, which may be related to their lack of understanding of the purpose of using the resource. There is clearly value in including the subcategory of ‘Instructions & Purpose’ in the TeRMEd framework.

Secondly, the lecturers planned to use the outcomes of the evaluations for future iterations. One of the KA lecturers said he would use Summative Assessment to ensure behavioural engagement and the UniDoodle2 lecturer said he would re-design his tasks so that students would better value the enhanced learning to be achieved using the app. When planning her next iteration of the resource, the GeoGebra lecturer plans to examine each of the classifications in light of the User Experience values. The comments from the lecturers involved in the NF-funded project support the assertion that the TeRMEd framework can be used to evaluate technology-enhanced resource integrations.

Finally, the comments the lecturers made on the value of the TeRMEd framework, in terms of its comprehensiveness, support in the design of technology integration, and ability to efficiently guide practitioners towards best practice, have demonstrated the value of the TeRMEd framework in planning effective technology integrations. Using the TeRMEd framework enabled the lecturers to reflect on their practice and focus on the decisive factors that encourage student engagement with technology-enhanced resources.

While the value of planning in advance was supported by the lecturers’ comments from the survey reported on in Section 6.9, these resources all formed part of the NF-funded project. In order to further validate this work, it is important to investigate the use of the TeRMEd framework in an authentic setting. Thus, the TeRMEd framework was used in planning the integration of Matlab in a first-year undergraduate engineering mathematics module. The outcomes of this research are reported on in Chapter 7.

Chapter 7 Using and evaluating the TeRMEd framework

7.1 Introduction

The development of the TeRMEd framework resulted from evaluations of NF-funded project resources. Subsequent analysis of the views of the NF-funded project lecturers indicated their satisfaction with this framework as a tool to support the planning and evaluation of their resources. It was then important to investigate if the TeRMEd framework could be used outside the context of the NF-funded project, to ascertain its wider applicability and contribution to the field, and so that it could be made generally available to lecturers in the future. Stage 5 of the PhD research addresses this issue. During this research stage, the TeRMEd framework was used to classify a planned technology-enhanced resource integration of Matlab, in a first-year engineering mathematics module at DCU. Afterwards, the students were asked about their experiences in a variety of ways. The research presented in this chapter aims to further confirm the validity of the TeRMEd framework and to provide further evidence to answer RQ3: *How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?*

7.1.1 Research Questions addressed in this chapter

The following research questions were formulated in order to focus the research on answering RQ3:

- RQ7.1: What does the TeRMEd classification of the planned use of Matlab predict about student engagement with Matlab?
- RQ7.2: How does the information obtained from the student survey, when considered within the TeRMEd classification, help evaluate students' engagement with Matlab?
- RQ7.3: How do the outcomes of focus group interviews with students corroborate the responses to RQ7.1 & RQ7.2?
- RQ7.4: Does additional evidence about student engagement with Matlab emerge from the focus groups? If so, what is this?

7.1.2 Research Context

EM114, numerical problem-solving for engineers, is a module taken by all first-year engineers in DCU. This is a 100% continuous assessment module. The use of Matlab, a MathWorks product (https://www.mathworks.com/products/matlab.html), is a compulsory component of the module. Marks are allocated to solutions of prescribed numerical problems that are solved by the students using Matlab code, during lab sessions. The module consists of a weekly two-hour lecture and a two-hour lab, during the 12 weeks of the semester. In the academic year 2017/2018, the first-year engineering students were divided into two groups of approximately 75 students. Each group attended a Matlab lab session every second week. There were two or three postgraduate lab assistants, supported by the lecturer, to facilitate the students. Students also had access to Matlab outside of the class and sample problems were made available to them prior to each lab. During the lab session, students were given a number of mathematical problems (example in Appendix K) and sample Matlab code as a reference to solve the problems. Students were allowed to write their own code, or use Matlab functions, to solve the problems. Students were encouraged to go beyond simple manipulation of the code and to explore how changing the variables impacted on their solutions. At the end of the lab, students submitted their solutions electronically for grading.

Prior to the module's implementation, this researcher, in consultation with the lecturer, classified the planned integration of Matlab using the TeRMEd classification framework. Following the end of the Matlab module, students were asked to complete a short evaluation survey, containing the items required to populate the User Experience subcategories of the TeRMEd framework. In addition, volunteers were sought to partake in focus groups interviews. There were three parts to this research:

1. The classification of Matlab within the TeRMEd framework prior to its use within the first-year engineering mathematics module.
2. The collection and analysis of the User Experience values for the TeRMEd framework, taken as part of the evaluation of the module
3. The conducting of focus group interviews to further explore the students' opinions on the use of Matlab within the module

In the following sections, the data gathered during this stage of the research is presented to address research questions RQ7.1-7.4. For ease of reference, this part of the PhD research study will be referred to as the "Matlab trial", from here on in. In the first section, the classification of the Matlab trial in EM114 within the TeRMEd framework is presented. In the following sections, the outcomes of the survey and the focus group interviews with respect to Matlab are reported. The final section discusses students' engagement with Matlab and the contribution of the TeRMEd framework to the lecturer's evaluations within this trial.

7.2 TeRMEd classification of Matlab

Prior to the commencement of the module, details gathered from the lecturer about the specific use of Matlab within the EM114 module were used, by this researcher in conjunction with the lecturer, to classify Matlab within the TeRMEd framework. The classifications were agreed according to the same parameters outlined for the classification of the other trials (described in Section 6.8). The classification is shown in Table 7.2.1, where categories with blank spaces indicate options where the functionality was not included as part of the Matlab trial and those marked '*pending*' will be completed in the post-implementation analysis (Section 7.3). The use of the TeRMEd framework in this way served to focus the lecturer on the planning of the integration of Matlab within the EM114 module.

Table 7.2.1: TeRMEd classification of Matlab

Section	**Category**	**Subcategory**	**Matlab_Trial**
Implementation	**Setting**	Class Size	Medium
		Use in Class	Lecture & study time
		Summative Assessment	Yes
		Student Cohort	Non-specialist
	Didactical Functions	Do	✓
		Learn - practise skills	
		Learn – concepts	
		Lecturer Instructions	Instructions & Purpose
	User Experience	Navigation	*Pending*
		Usable	*Pending*
		Learnability	*Pending*
		Accessibility	Static
		Consistency	Static
		Visual Design	Static
		Technologically ready	Dynamic
		Useful	*Pending*
		Usage	*Pending*
Technology	**Type**	Communication Tool	
		MAS (Mathematical Analysis Software)	✓
		CAA (Computer Added Assessment)	
		Instructional Material	
	Cognition and	Productive	✓

Section	**Category**	**Subcategory**	**Matlab_Trial**
🟩		Explorative	✓
		Instructive	
Learning	Mathematical Proficiency	Conceptual Understanding	✓
		Procedural Fluency	✓
		Strategic Competence	✓
		Adaptive Reasoning	
		Productive Disposition	
Formative Assessment	Formative Assessment Strategies	Clarifying and sharing learning intentions	✓
		Engineering effective classroom discussion	
		Providing immediate feedback	✓
		Activating students as instructional resources for one another	
		Activating students as owners of own learning	
	Feedback	Feedback Type	FT (Feedback about the Task)
			FP (Feedback about the Process)
			FS (Feedback about the Self)
		Feedback Direction	Lecturer to student
			Technology to student

In order to address RQ 7.1: *What does TeRMEd classification of the planned use of Matlab predict about student engagement with Matlab?,* the relevant decisive factors that encourage student engagement, as identified in Chapter 5, are considered in light of the Matlab trial classifications. The decisive factors and the associated rationale, as discussed in Chapter 5, along with the expected prediction for student use of Matlab, are given in the four tables below, one per TeRMEd framework section.

Table 7.2.2: Expected student engagement - Implementation factors

Decisive Factor: (TeRMEd subcategory for Matlab)	**Rationale (based on analysis in Chapter 5)**	**Expected engagement outcome for Matlab**
Use in class: (Use in Class – Lecture and study time)	Usage of resources higher in implementations where resource used as part of class	Students expected to use Matlab
Grade associated with use: (Summative Assessment -Yes)	Grade found to encourage student usage of resources	Students expected to complete assignments and hence use Matlab
Class size: (Class Size -Medium)	Lab with small/medium size class allows lecturer and/or assistants to give individual feedback	Students expected to use Matlab and to receive in-class verbal feedback and instruction on its use
Student Cohort: (Student Cohort- Non-specialist)	Mathematics not their main focus and priority is generally to pass module	Students expected to focus on getting grades for assignments, over and above learning mathematics
Task Design (Didactical Practices – Do)	Tasks must be designed to support the didactical practices required in the specific context	Students expected to do mathematics and solve mathematical problems
Purpose: (Lecturer Instructions – Instructions & Purpose)	Students require specific details on how use of resource fits in with their required mathematics learning	Students expected to understand value of engaging with Matlab within the EM114 module
Instructions on use: (Lecturer Instructions – Instructions & Purpose)	Students require specific instructions on use of MAS tools as they find them difficult to use	Instructions provided expected to help students overcome difficulties they may have in using Matlab

The Implementation section classifications within the TeRMEd framework suggest that students should use Matlab to solve mathematical problems and complete the associated assignment. They also suggest that the instructions and availability of teaching staff in the labs should ensure that students should receive sufficient instruction to help them overcome any challenges of using Matlab. Finally, students should understand the value of using Matlab.

Table 7.2.3: Expected student engagement - Technology factors

Decisive Factor: (TeRMEd subcategory for Matlab)	**Rationale (based on analysis in Chapter 5)**	**Expected engagement outcome for Matlab**
Technology Type (Type – MAS)	Students find non-MAS tools easier to use than others	Students expected to find Matlab difficult to use
Affordances: (Cognition and Task control – Explorative & Productive)	High and medium levels of cognition and control over tasks engages students in deep learning	Students expected to be required to put in sustained cognitive effort to use Matlab and to solve the numerical problems
Task Design: (Cognition and Task control – Explorative & Productive)	Effective task design is required to take advantage of technology affordances	Matlab tasks expected to support students in engaging in exploring and producing mathematics

The Type classification of Matlab, as a MAS, suggests that students should find the tool hard to use. The Cognition and Task Control classifications suggest that students should be required to put in sustained cognitive engagement in order to both explore and produce solutions to the mathematical problems they are required to resolve.

Table 7.2.4: Expected student engagement - Learning factors

Decisive Factor: (TeRMEd subcategory for Matlab)	**Rationale (based on analysis in Chapter 5)**	**Expected engagement outcome for Matlab**
Task Design: (Conceptual Understanding & Procedural Fluency & Strategic Competence)	Tasks must be designed to specifically support the types of learning required	Matlab tasks expected to support students in achieving the learning outcomes of the EM114 module

The Learning section classifications of Matlab suggest that students should be presented with mathematical tasks that are relevant in supporting them to achieve the three strands of Mathematical Proficiency that the lecturer identified as appropriate for the learning outcomes of the EM114 mathematics module.

Table 7.2.5: Expected engagement - Formative Assessment factors

Decisive Factor: (TeRMEd subcategory for Matlab)	Rationale (based on analysis in Chapter 5)	Expected engagement outcome for Matlab
Formative Assessment: (Strategies –Clarifying Learning Intentions)	Informing students of required learning for module keeps them focussed and engaged in tasks	Students expected to be aware of mathematical understanding and skills required to achieve learning outcomes of EM114
Formative Assessment: (Strategies –Providing Immediate Feedback)	Ability to give and receive feedback encourages cognitive engagement	Students expected to be provided with immediate feedback which should support them in further cognitive engagement
Formative Assessment: (Feedback Direction – Lecturer to Student)	Students find that lecturer feedback is more beneficial than technology feedback	Lab assistants and lecturer expected to provide feedback that should benefit students' learning of mathematics
Formative Assessment: (Feedback Type, FT, FP & FS)	Type of feedback impacts in various ways on student engagement. Selecting correct type of feedback essential to ensure its effectiveness	Students expected to seek new information (FT), be informed of new strategies to solve problems (FP) and when praised encouraged to continue (FS)

Finally, the formative assessment categories suggest that the feedback provided by the lecturer and the technology should support students in identifying knowledge they are lacking and provide them with strategies to complete the tasks so that they should be encouraged to retry the problem when they fail. In essence, encouraging them to engage cognitively with the required mathematics.

7.2.1 Response to RQ7.1

In this section, the TeRMEd classification was used to predict how students should engage with Matlab in order to address RQ7.1*: What does the TeRMEd classification of the planned use of Matlab predict about student engagement with Matlab?* In response to RQ7.1, it is expected that students should use Matlab and complete the associated assignments. In addition, students should be supported in gaining the necessary skills to become proficient in the use of Matlab and hence engage cognitively with the associated mathematics. Finally, the lecturer expects that the students should have achieved the relevant learning outcomes of the module through the use of the carefully designed tasks that take advantage of the affordances of the technology and appropriate feedback.

In the next section, the post-use student survey will be used to evaluate if and how student engagement occurred with the use of Matlab.

7.3 Survey and Usage as measures of student engagement

In this section, I address the second research question, RQ7.2: *How does the information obtained from the student survey, when considered within the TeRMEd classification, help evaluate students' engagement with Matlab?* As stated in Chapter 6, Likert scale questions are used to gather student evaluation data and populate the following four User Experience subcategories in the TeRMEd framework: Navigation, Usable, Learnability and Useful. A fifth User Experience subcategory, Usage, is populated using the recorded usage of the resource. These subcategories were originally labelled '*Pending*' in Table 7.2.1.

The evaluation data for the Matlab trial was gathered as part of a post-module survey. There were 99 respondents who completed the survey in full. In addition to the four items required to populate the TeRMEd framework, students were asked three further Likert scale items relating to their experiences of using Matlab, three questions regarding their background, and an option to comment on the use of Matlab (See Appendix F). The percentages of students who responded positively to each of the seven Likert scale items were calculated by aggregating the percentage of respondents who selected Strongly Agree (SA) and Agree (A). Table 7.3.1 contains this percentage of respondents (n=99) who selected either SA or A in response to the survey items after the EM114 module was completed.

Table 7.3.1: Survey item responses after the EM114 module

Likert Scale Item	**User Experience Subcategory or (abbreviated item)**	**Percentage SA & A added (n=99)**
I used the Matlab application regularly, even when it was not assigned as part of the EM114 module	(Self-reported Usage – outside class)	7%
* For me it was easy to use Matlab	Usable	23%
* Using Matlab enhanced my learning of the mathematics required in EM114	Learnability	46%
* I was easily able to navigate the content in Matlab	Navigation	24%
* I found that Matlab is a useful resource for solving mathematics problems	Useful	70%

It was clear to me what I needed to accomplish when using Matlab within the EM114 module	(Understand accomplishment)	31%
Using Matlab increased my confidence in my ability to complete 1st year mathematics successfully	(Confidence)	22%

The four items required to populate the User Experience subcategories of the TeRMEd are preceded by an astericks.

From this data, it is evident that, while a majority of students (70%) found Matlab useful, and some (45%) said it enhanced their learning, students were less positive about other aspects of Matlab and did not tend to use it outside of the assigned activities.

In order to answer RQ7.2, this data, along with students' actual usage, were inputted into the Implementation section of the TeRMEd framework (see "*pending*" in Table 7.2.1). Table 7.3.2 shows the User Experience subsection of the TeRMEd framework Matlab classification containing these values (shaded). Note that as Matlab use was compulsory, usage is 100%.

Table 7.3.2: TeRMEd classification of Matlab - User Experience

Implementation Section		**Matlab**
User Experience	Navigation	24%
	Usable	23%
	Learnability	46%
	Accessibility	Static
	Consistency	Static
	Visual Design	Static
	Technologically ready	Dynamic
	Useful	70%
	Usage	100%

In Section 7.2, the classification of Matlab within the TeRMEd framework was used to predict that students would use Matlab and complete the associated assignments (Table 7.2.2). As seen in Table 7.3.2, students did use Matlab (100% Usage) and found it Useful (70%) for solving the mathematics problems. It was also predicted that students would find Matlab difficult to use, as it is a MAS tool (Table 7.2.3). However, it was expected that the provision of Instructions would help students overcome these difficulties (Table 7.2.2). Despite these Instructions, and the availability of tutors in the labs, the values for Usable and Navigation (23% and 24%) indicate that students found Matlab hard to use. In addition, it was expected that the explorative and productive nature of the activities and the immediate feedback they provided, along with the use of tasks designed to support the relevant mathematical proficiencies (Table 7.2.3-5), would encourage cognitive engagement with the Matlab tasks and associated mathematics. This type of engagement would be expected to result in enhanced learning of mathematics. While 46% of respondents considered their learning was enhanced, the majority (54%) did not.

In addition to the values included in the TeRMEd classifications, the responses to the other two survey items (Table 7.3.1) indicate that students felt that they were not clear on what they needed to accomplish using Matlab (31%) and did not feel their confidence in their mathematics ability (22%) had increased (Table 7.3.1). Only 7% reported using Matlab when it was not assigned. Clearly the students had not become comfortable with Matlab, and did not value it as a technology-enhanced resource that supported their learning of mathematics.

In order to probe this further, the 34 responses to the open question in this survey were also analysed for indicators of engagement. Inductive analysis, as described in Chapter 4, was used to generate themes that arose. The NVivo tool was used to create nodes and sub-nodes relating to the themes and sub-themes identified. Two main themes initially emerged from students' responses: comments where students were positive about the use of Matlab and comments where they were negative. A total of 28 students (n=28) commented negatively on the use of Matlab and eight positively, with two students who had both negative and positive things to say about Matlab. The comments were coded to a Negative and a Positive node within NVivo. The comments coded to these two nodes were further coded into sub- nodes that relate to themes of the survey items on Navigation, Usable, Learnability, and Useful, which are the evaluation items used to populate the User experience subcategories in the TeRMEd framework (Table 7.3.2). In addition, the theme of Lecturer Instructions emerged from the negative comments. Some comments were coded into more than one sub-node. A sub-node called General was used for any comments that did not fit into one of these categories. The number of comments coded (x) at each sub-node are listed in Table 7.3.3. Note no students referred to Navigation of Matlab, therefore no comments were coded to this sub-node. The coding scheme, which lists the NVivo nodes, a description of the code and an example, is contained in the Appendix F.

Table 7.3.3: Number of comments coded - survey open question

Negative (n=28)	**No. of comments coded at each sub-node (x)**	**Positive (n=8)**	**No. of comments coded at each sub-node (x)**
Useful	4	Useful	6
General	3	General	2
Usable	9		
Learnability	3		
Lecturer instructions	17		

Students who wrote positively (n=8) about their Matlab experience stated how they found Matlab useful to help solve complicated problems and to check their answers for correctness. For example, one student said '*I found Matlab to be very useful in solving more complicated problems that would be strenuous with pen and paper*' (Matlab Student2). Several students (n=3) expressed the opinion that the value of Matlab went beyond the scope of the module. One student said '*Matlab is a very resourceful software and the use of it in EM114 ignited a keen interest in exploring of it beyond the scope of EM114 …*' (Matlab Student35), and another '*Used it in other modules to confirm my maths answers*' (Matlab Student78).

However, there was a strong sense of negativity reported by students about the use of Matlab within EM114 (n=28). Students considered that they had an inadequate level of instruction on the use of Matlab. One student who had said Matlab was a useful resource added, '*...but it was not taught in the proper way*' (Matlab Student4). A suggestion of how they should have been taught Matlab was put forward '*…We should have been taught the basics what each line/function did*' (Matlab Student82). Another student went further and suggested they had no instruction '*I feel like we were told we had to use Matlab but never shown how to use Matlab*'(Matlab Student5). As a result of a perception of receiving inadequate instruction, another student referred to having taught themselves Matlab, '*Lecturers did not explain how to use Matlab correctly. I had to teach myself through YouTube*' (Matlab Student62).

Some (n=5) of the negative comments refer to students' specific difficulties in using Matlab. For example, one student who reported that they found it very difficult to complete the assignments, due to a lack of understanding of Matlab, said they '*did not understand the basic commands…*' (Matlab Student1). Another student referred to problems understanding the Matlab code '*... And more just given a code without properly understanding it*' (Matlab Student85), which was echoed by Matlab Student82 '*It was not explained well at all. I did not like how we just copied and pasted codes…*'. The code used in Matlab proved difficult for these students.

Finally, Matlab Student89 found that the disparity between the homeworks and the assignment completed in the lab mitigated against understanding Matlab, '*the questions for homework were very different to the tests*... '.

7.3.1 Response to RQ7.2

This section of Chapter 7 is aimed at addressing RQ7.2: *How does the information obtained from the student survey, when considered within the TeRMEd classification, help evaluate students' engagement with Matlab?* To summarise the findings, the post-use survey data indicates that, while students generally considered Matlab a useful tool for solving the mathematical problems, they reported that they did not find it easy to use and that the instructions provided were insufficient to support them. They were also divided on how much it enhanced their learning of mathematics for the EM114 module. Thus in response to RQ7.2, the information from the student survey serves as a means to determine how successful the integration of Matlab was from the perspectives of the students. This facility enables the lecturer to reflect back on the planned or expected outcomes of the use of Matlab (as classified within the TeRMEd framework) and evaluate what changes, if any, should be made for future iterations of the resource.

In the next section, outcomes of the focus group interview data that relate to the post-use survey are examined.

7.4 Focus group and survey comparison

The third research question addressed in this chapter, RQ 7.3: *How do the outcomes of focus group interviews with students corroborate the responses to RQ7.1 & RQ7.2?*, was answered by analysing the focus group data for themes relating to the User Experience TeRMEd classifications. In the first instance, the data was analysed using inductive analysis, as outlined in Chapter 4. A number of themes emerged from this process, and those relating to RQ7.3 and RQ7.4 were coded to a parent node labelled Matlab. This node contains all the segments of focus group data that referred to Matlab. Recall that segments are uninterrupted phrases, sentences or paragraphs spoken by the student in the focus group. In order to provide a comparison between the survey open-question responses and the focus group responses, the focus group data within the Matlab parent node was coded to the same named nodes and sub-nodes that were used for the open responses (see Table 7.3.3). This comparison facilitated the triangulation of the data, which contributes to the validity of a study as discussed in Chapter 4. The same coding scheme was used as for the survey, documented in Appendix F. The number of segments (x) coded to the Matlab negative and positive nodes and sub-nodes from the focus group interview is tabulated in Table 7.4.1. Note there were no segments coded at the General and the Navigation sub-nodes. In the subsequent discussion, the five students who partook in the focus groups are referred to with the pseudonyms of Gearóid, Barra, Donal, Niall and Ronan.

Table 7.4.1: Number of segments coded to nodes - focus groups

Negative	**Number of segments (x)**	**Positive**	**Number of segments (x)**
Easy to Use	22	Easy to Use	6
Learnability	6	Learnability	11
Lecturer instructions	9	Lecturer instructions	2
Useful	8	Useful	22

As a result of the analysis, there were four significant findings, which are discussed in the following four sections. This is followed by a section on the response to RQ7.3.

7.4.1 Easy to Use

All, bar one, of the students in the focus groups concluded that they found Matlab hard to use. The one student, Donal, who felt he had managed to master Matlab commented, throughout the interview, on the amount of time and effort he put in himself in order to be able to use Matlab. For example, he said *'… that involved a massive amount of additional ... hours ... massive…loads...I put in ...'*. One of the other four students, Niall, found Matlab difficult to use right from the start, *'I felt it like it got very difficult very quickly… I got kinda a little bit lost.'*.

Segments coded as Positive-Easy to Use (x=6) were mainly where three of the students who found Matlab easy to use in the early labs were unable to follow the code in later labs. Gearóid said: *'I find Matlab very easy in the beginning but then as it went on I just didn't understand what they were doing'* and Niall said *'…first off I was a little confused …. but once I got into it, it was seemed pretty ok until we got to where it was graphing and stuff like that and then I felt it like it got very difficult very quickly'*.

Segments coded Negative-Easy to use (x=22) included the following remark from Ronan *'if we weren't given that base code I think it would have been impossible for us to do'*. Gearóid referred to how difficult it was to follow some of that code they were given *'I wasn't really able to understand cos the code for integration is like two pages long and so it's just complicated.* Barra found the graded questions harder than the practice ones they had completed before the lab '*… before every lab we were given a sample to do and we did the sample and the sample was in no way related to the actual lab as we found out later*'.

7.4.2 Learnability

There was a mixed response to this: some segments indicated students being positive about learning mathematics using Matlab (x=11); other segments were negative (x=6). Being able to see how variables changed the output helped students understand the mathematics better. For example, Niall discussed the value of Matlab for visualising a graph: *'I think we plotted like sine graphs or something like that … and yeah it was good to be able to see like the graphs after it was done'*. Ronan found that Matlab enhanced his mathematical learning when he was able to manipulate the code to get more accuracy:

'*…when you are given the intro code, it tells you a little bit about what is going on …in really complex maths terms that are kinda go over your head sometimes and ah then you can sort of like go through it and see what everything sort of does and maybe mess around with this part or that part and then see like ok its changed that figure by more decimals or being more accurate or something …*'.

However, most of the students, four of them, also referred to how hard they found it to understand exactly what the code was doing. For example, Gearóid said *'this is what the code does and you're like ok, this is what it does and you put it in and you think it does it but then you don't understand the concept behind it'*. Barra expressed a similar sentiment when he said '*…I couldn't focus on what I was learning mathematically, I just had to manipulate the code to get my answers*'.

7.4.3 Useful

Despite the difficulties indicated by students, there were many positive remarks (x=22) about how useful Matlab is, or could be in future years of their engineering programme. Students referred to the ability to be able to do calculations using Matlab; for example, Donal said, *'…I used it for the homework…because for example speaking of matrices…they are not that complicated, they are simple enough but the amount of calculations you have to do if you are working with a three by three matrix for example multiplying all those numbers.'*. Similarly, Barra referred to using Matlab for checking his answers to homework *'… you had to do a question … you would do it out as a homework and …then you could use Matlab to actually …check your answer*'.

Segments that were negative about the usefulness of Matlab (x=8) referred to the fact that it was so hard to use, that for some of the assignments all they were doing was manipulating the code, and that in any event they did not always have to use Matlab to answer the assignments. Niall said *'… the last two labs…were very difficult. And I found that I didn't use it as much … we could do out the questions without using matlab ... I found that doing them without the matlab code was a lot easier*'. In the same vein, Gearóid used his own methods *'cos the code was so hard … I just decided I am going to solve these things on paper if I can and for like the homeworks I only did code for like one of the questions and like the rest I was able to do it on paper.*'.

7.4.4 Lecturer Instructions.

All of the students were negative about the instructions they received. For example, Barra said: '*we are not given… like a basics lecture in Matlab so we don't really know how to start'*. Ronan expressed his frustration with the lack of instructions:

'... I think the … thing about it was we were thrown … into the deep end straight off. It's …so you are in this, you are going to be using Matlab and like… and you are like ok what's Matlab? And then they are … there is this code here… it was slightly frustrating in a way because we were told just to … do something that …we had no inclination of how to do'.

Donal expressed his opinion in a more straightforward way: '*Well they are not really teaching you how to use the Matlab*' and went on to learn how to use Matlab himself which was a '*massive*' amount of work.

7.4.5 Response to RQ7.3

It is clear that there are similarities between the outcomes illustrated in Table 7.4.1, from the focus groups, and what emerged from the user experience survey outlined in Table 7.3.2. The evidence from the focus groups demonstrates how difficult students found Matlab to use. The only student who reported that they had managed to use Matlab effectively had spent a considerable amount of time learning Matlab himself. Similar findings were reported on from the survey data, where only 23% rated Matlab easy to use (Table 7.3.2). The students in the focus groups described how they used Matlab to enhance their learning of mathematics, for example when plotting graphs. However, they also pointed out how they could not learn from it due to the difficulty with manipulating the code. Similarly divided in the survey, 46% agreed that it enhanced their learning. With respect to usefulness, 70% of those surveyed found it useful, despite it being hard to use. Similarly, there were 22 segments of the focus group data coded as being positive about usefulness, where students recognised the value of Matlab in helping with calculations and checking answers to homework. Finally, the students in the focus groups echoed the sentiments of the comments in the survey, where students perceived that the instructions they received on using Matlab were inadequate in enabling them to successfully engage with Matlab. There were 17 comments in the survey (Table 7.3.3) that were negative about lecturer instructions and all of the students in the focus group had something negative to say about the level of instruction they received. To illustrate this similarity, two comments are quoted, one from the focus group and one from the survey. Niall (focus group) said, '*… I felt like it got very difficult very quickly without much explanation on how to do it …*' and Matlab Student60 (response to open question) said, '*Matlab was really hard to use, very little explanation on how to use it…*'.

In this section, in response to RQ7.3: *How do the outcomes of focus group interviews with students corroborate the responses to RQ7.1 & RQ7.2*, it has been shown how the focus group interview data corroborates the outcomes of the survey. In addition, the analysis also shows that, contrary to the predictions from the TeRMEd classification of Matlab (Table 7.2.1), the level of instruction on Matlab was considered by the students to be inadequate in enabling them to effectively engage with Matlab. In the next section, analysis of the focus group data is used to further explore student engagement in Matlab.

7.5 Further exploration of engagement

In Section 7.4, it emerged from the analysis of the data that students found Matlab difficult to use and that they perceived that the instructions they received were inadequate. In this section, the outcomes of an inductive analysis of the focus group data, with respect to engagement with Matlab, is discussed with a view to answering RQ7.4, *Does additional evidence about student engagement with Matlab emerge from the focus groups? If so, what is this?* The Matlab parent node was further analysed and a number of themes and sub-themes emerged. Segments of data relating to the themes were coded into NVivo nodes and sub-nodes in a hierarchical structure. Sub-nodes that represent the themes that emerged from this inductive analysis are shown in Table 7.5.1, along with a description of the theme and the number of segments coded at the sub-node. Indented sub-nodes are sub-themes relating to a theme. Full details of the coding scheme can be found in Appendix F.

Table 7.5.1: Number of segments coded to nodes and sub-nodes

Name of Node and sub-node	**Description of theme** **Students refer to:**	**No. of segments (x)**
Coding in Matlab	Code in Matlab having a bearing on their work	20

Cognitive Engagement		22
Learn by self	Trying to learn to use Matlab and code without lecturer/lab assistant help	18
Not Learn by self	Not trying to learn Matlab by themselves	4
Last two labs	Last two labs/assessments in EM114	20
Ease of Use		45
Difficult to use	Difficulties they had with Matlab / considered themselves lost / did not follow code	22
Easy to use	Being able to use Matlab to own satisfaction	6
Not enough guidance throughout the module	Needing more help to enable them use Matlab	17
Usefulness		30
Matlab use outside of EM114	Using/not using Matlab outside of EM114	7
Purpose and future use of Matlab	Able to identify purpose of Matlab within EM114 or how it might be used in future	20

The themes Ease of Use and Usefulness have already been identified and discussed in Section 7.4, therefore only new analysis from these themes are discussed below.

A further theme under Ease of Use emerged, 'Not enough guidance throughout the module'. The students identified that more guidance on the use of Matlab (x=17) would help them to be able to use Matlab effectively. For example, Barra thought more guidance on the basic codes might help, *'I find GeoGebra relatively easier than Matlab... like a basics lecture in Matlab ... up to that certain point where we can generate all kinds of graphs that we want to'* (Barra). Gearóid echoed this when he suggested they have tutorials on Matlab*, '… if there was more tutorials on how to do it in college more so than like just giving the lab … If it was actually scheduled times … show you how to use it.'*

With respect to the Usefulness of Matlab, the theme of 'Purpose and future use of Matlab' emerged (x=20). Students demonstrated their awareness of the purpose of becoming proficient with Matlab. In the first instance, as discussed above, students explained how it helped them solve numerical problems. Ronan explained its purpose in calculating, '*for really long-winded questions … maybe* *five rows and columns of matrices… a Matlab computer can do it quite quickly'.* In addition, the focus group students pointed out that it may be required when they cover various topics as they progress through their study programmes. For example, Donal said '*in the next years, for example, there is digital signal processing, so you can use it for that and most likely we will be using it for that'*. In addition, they recognised the value of being able to use Matlab in their future careers. For example, Gearóid was able to identify how Matlab might be useful for his intended branch of engineering '*Yeah I think I would use it cos I want to do Robotics maybe prosthetics … the guy who teaches us mechanical says there is a lot of matrices in there and a lot of … simultaneous equations, so I will have to model all this stuff '*. Clearly the students had become aware of the usefulness of Matlab in their engineering discipline.

The inductive analysis also revealed three new themes: Coding in Matlab, Cognitive Engagement and the Last two lab assessments. These are discussed in the three sections below and followed by a response to RQ7.4.

7.5.1 Coding in Matlab (x=20)

Students were given Matlab code that they could manipulate to solve the problems in the lab. Having to manipulate the code in Matlab emerged as a theme within the analysis process. For example, Ronan said *'for every question we would have had … basic code that we could copy but still we would have to manipulate that ourselves'.* However, all of the students expressed difficulties in manipulating the code, and understanding what the code was doing, as pointed out by Niall:

'*… we were told to like change certain variables and other than that I didn't really change much because I didn't understand the code …so I thought if I change more things it wouldn't work ... I tried it a few times but the graph just went completely crazy and it didn't work so I changed them back'*.

Even when the students were provided with simplified versions of the code, they were unable to use it, as articulated by Gearóid: '*I wasn't really able to understand cos the code for integration is like two pages long and … it's just complicated. I don't know if it's overcomplicated, but they gave us a simplified version and I didn't understand it. '*.

As discussed in Section 7.4, students considered that they were not given enough instructions on how to code in Matlab. Gearóid compared the EM114 module to their C programming module '*…in our C programming class we have lectures where they teach us … what (a) function does'* and went on to say that his peers who have not previously done programming '*find the C programming class easier than the Matlab class'*.

Finally, Donal, who put in a sustained effort to learn how to use Matlab, referred to the fact that using the code did not help them use the affordances of Matlab *'…they are not really teaching you how to use the Matlab … You are just repeating the steps that you are shown'* and that the given code was complicated.

'… for example … the codes that we were given when we were asked to find the minimum and maximum points … but you don't need to write all that complicated code because the Matlab has a function which … basically does everything for you'.

He would have preferred to be shown how to use the functions within Matlab.

7.5.2 Cognitive engagement (x=22)

The students did attempt to learn how to use Matlab as evidenced in the number of segments (x=18) coded to the *Learn by self* node. All of the students discussed how they cognitively engaged with the Matlab resource. This is illustrated by Ronan who put effort into manipulating the code until he could figure out how it worked,

' *… by playing around with it* [the code] *I think you learn a lot more how to use it... maybe mess around with this part or that part and then see … it has changed that figure …what is controlling that part of what that code is doing*'.

Learning by oneself, or with one's peers, requires cognitive effort and is an indicator that a student has engaged cognitively (M. Bond & Bedenlier, 2019). Two of the students used online tutorials and resources provided by Mathworks to help them use Matlab to solve mathematical problems. Donal found online tutorials to help him learn how to use the Matlab functions himself *'… there are tutorials online…on the Matlab website … you spend time on it, it takes a bit of understanding because it's not straight forward '*. Barra enrolled on a course to learn Matlab *'…I am trying to develop my Matlab skills, I am enrolled in an online course on Udemy for Matlab*'.

Three of the students referred to having worked with their friends to try and understand what the code was doing. Niall consulted with his classmates on how to use Matlab '*…it just seemed easier to see if other people were having the same problem '*. Gearóid worked with his friends to try and develop an understanding of the code *'… cos the code was so hard I was working along with my friends*'.

Gearóid took a different approach:

'... I think it kinda forced me to understand the concept of doing it on paper ... and then by doing that I got an understanding of what the code was doing … I could look at that and then insert certain things which help me … I would still like to be able to sit down and make the code out of my head'.

Gearóid, who had earlier expressed his preference for pen and paper when solving problems, said that he tried to understand the code by doing out the problems with pen and paper, but that he would still not be able to write the code himself.

These are instances where the students clearly put in an effort into understanding the code, but they still found it difficult to use.

7.5.3 Last two lab assessments (x=20)

The students completed six labs in total. When analysing the focus group data, it became evident that students found the last two labs very difficult; therefore, the "Last two labs" node was created. Gearóid expressed how difficult the last two labs were when he said '*then in the last two … we are just completely ...blown out of the water…*'. Barra referred to being able to do the first few labs himself: '*in the first … homeworks… we were coming up with our own code rather than using the code that was provided by the lecturers ….',* but then goes onto say, '*but when it got to stuff like … sequences…series, integration then we couldn't figure out how to do that, so we had no choice but to use the plagiarism … ourselves…*'.

This idea of 'plagiarism', or just duplicating the code given to them without exploring it, is echoed by Gearóid who said '*… like for the first (*set of*) labs I was like Yes I am doing this…up to the…second last two labs … (*then*) I didn't write my own code… I just cut and pasted it in and got the assignment done ...*'.

In fact, four out of the five students did not use their own Matlab code in their solutions for the last two labs but resorted to other methods to solve the problems, as outlined by Barra and Gearóid when referring to plagiarising or copying the answer. Both Niall and Ronan solved the last two labs without using Matlab, as it was simpler '*I found that doing them without the Matlab code was a lot easier*' (Niall).

7.5.4 Response to RQ7.4

In response to RQ7.4, further information about student engagement with Matlab has emerged from the analysis of the focus group data. A number of the indicators of engagement identified by Bond and Bedenlier (2019, p. 3) were evident within the students' comments. All five students discussed how they tried to understand and use the Matlab code provided, demonstrating cognitive engagement indicators. Students were '*purposeful*' about their work and were *'trying to understand*' how the code worked. Three of the students engaged with their peers, *'learning from peers'*, to try and collaboratively figure out the Matlab code. Two of the students looked for online resources and courses, '*doing extra to learn more'*, to help them develop their use of Matlab. This concerted effort to learn how to use Matlab demonstrates the students' desire to effectively use Matlab. In addition, all of the students clearly understood the relevance of being able to use Matlab, both in their current programme of study and their future careers: '*sees relevance'* is considered an indicator of affective engagement (M. Bond & Bedenlier, 2019, p. 3). Finally, their behavioural engagement was evidenced by the '*effort*' and '*attempting*' demonstrated by the students' accounts of using Matlab, as well as the fact that they had completed their assignments (M. Bond & Bedenlier, 2019, p. 3).

This analysis of the focus group data revealed specific factors that negatively affected students' use of Matlab. They found coding difficult and were unable to fully understand the function of the various codes. Only one student managed to use Matlab for the last two labs; the remainder found the given code too complex to manipulate, and either simply copied and pasted it, or solved the problems without using Matlab. Further evidence emerged that students identified the need for specific guidance and tutorials on the use of Matlab in order to overcome the difficulties they had with the Matlab code. Gearóíd referred to the benefit of tutorials they received as part of the C programming module and suggested that having similar ones on the Matlab code may have helped them to use Matlab effectively. It is clear that despite the fact that lecturers provided Instructions & Purpose, as classified within the TeRMEd framework (Table 7.2.1), students considered this inadequate in enabling them to use Matlab effectively.

In the conclusion below, the use of the TeRMEd framework to help integrate and evaluate Matlab within this module is discussed.

7.6 Discussion and conclusion

The purpose of this stage of the research was to determine if the TeRMEd framework could be applied beyond the scope of the NF-funded project and be used more widely by lecturers in the field. The outcomes, discussed in the previous sections, have shown how the TeRMEd framework was used to plan the integration of Matlab, and that the subsequent student survey data, classified within the TeRMEd framework, helped the practitioner evaluate the integration of Matlab. In addition, the focus group data revealed specific features of the Matlab integration that impacted on student success with Matlab. These outcomes contribute to answering RQ3: *How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?*

The use of the TeRMEd framework by a practitioner to implement Matlab has shown how the framework supported the lecturer in planning the technology-enhanced resource integration. The aim of the module, EM114, was to develop students' abilities to solve numerical problems. The lecturer had identified Matlab, a MAS technology, as a relevant technology type to be used by students to solve numerical problems. Using the categories from the TeRMEd framework, a number of aspects of the integration that were required to support the module objectives were identified: the type of learning required; the associated level of cognition and task control; the didactical practices; and the formative assessment techniques. In addition, using the categories and subcategories of the Implementation section of the TeRMEd framework, factors that support student engagement through technology integration were taken into account. This activity, on the part of the lecturer, can be considered as part of the learning design required to realise the EM114 module. Practitioners need guidance in learning design in order to effectively implement technologies in their classrooms (Conole, 2013; Dimitriadis & Goodyear, 2013), and the TeRMEd framework provided this guidance for the lecturer.

Using the decisive factors of student engagement identified in Chapter 5, the TeRMEd framework classifications of the planned use of Matlab were used to predict that students would use Matlab to achieve the module learning outcomes. Specifically, students would do mathematics while engaging with the technology, complete the associated assignments, and the instructional supports and formative assessment provided would enable students to use Matlab proficiently (Tables 7.2.2-5). The subsequent evaluation data showed how students engaged behaviourally, evidenced by the post-module usage data in Table 7.3.2. However, the classification of this post-module survey data identified that students had difficulties using Matlab (Table 7.3.2: Usable and Navigation values 23% and 24% respectfully), and the analysis of the associated comments indicated that students perceived the instructions on the use of Matlab to be inadequate. On the other hand, students understood the necessity or purpose of Matlab (Table 7.3.2 Useful value 70%) in solving the mathematical problems they were presented with. Despite the difficulty students had with using Matlab, nearly half of them recognised that it enhanced their learning (Table 7.3.2 Learnability 46%). This evaluation can be used by the lecturer as an indication of how he might improve the next iteration of the resource. Even though he had provided instruction on Matlab (Table 7.2.2) and there were lab assistants available to give feedback (Table 7.2.5), students still had problems using Matlab. One future adjustment that the lecturer could make would be to provide more guidance on the use of Matlab. In this sense the lecturer is enabled to use the framework well, by his initial planning of the Matlab implementation to support the desired learning outcomes and subsequent evaluation to pinpoint aspects that need attention in further implementations.

However, the focus group data elicited more nuanced information about specific problems students had with Matlab. Students reported that they found the manipulation of Matlab coding difficult, and particularly for the last two labs, students found it hard to work out what the code was doing. This analysis points to the need to adequately inform practitioners about the level of instruction required for students when using MAS technologies. A number of educational researchers have pointed to the need for teachers to structure technology use in order that students can fully exploit the mathematical tool (Drijvers, 2016; Pierce & Stacey, 2010; Smith et al., 2020; Thomas et al., 2017; Trgalová et al., 2018). Schemes to support instrumental orchestration have been explored in the context of secondary education (Artigue, 2002; Drijvers et al., 2013; Hoyles & Noss, 2003) and to a lesser extent in higher education (Jupri et al., 2016; Oates, 2009; Thomas et al., 2017). The schema examined in the literature are somewhat theoretical and complex, and while useful for researching the cognitive elements of the technology implementation, may not be readily accessible to a practitioner interested in integrating technologies into their modules. Nevertheless, lecturers should carefully consider what instructions are required and in this instance perhaps provide a lecture on coding concepts prior to using Matlab within the class.

The focus group data also revealed interesting aspects of the students' engagement with Matlab. It is clear, from the analysis of the data in Section 7.5, that students demonstrated behavioural, affective and cognitive engagement with Matlab. Students put effort into learning to use Matlab through consultation with peers and searching for online help. All of the students recognised the usefulness of Matlab, both within their programme and going forward into their careers, demonstrating how the Lecturer Instructions on Purpose was effective in this regard (Table 7.2.2). In addition, students were able to highlight the value of Matlab for visualisation, completing more accurate calculations, and checking the correctness of calculations done by hand. This latter evidences that the task design completed by the lecturer took advantage of the technology affordances as was planned within the Technology section classifications (Table 7.2.3), and further supports the effective use of the framework in this instance.

The TeRMEd framework has proved useful to practitioners for both the planning and evaluation stage of integrating a technology-enhanced resource. In the planning phase, it was used to assist learning design to exploit the affordances of the Matlab technology to support the module objectives of EM114. In the evaluation stage, it was used to identify that students had difficulties using Matlab. The comments from the survey identified that students' perceived lack of instruction inhibited their use of Matlab. The value of using the TeRMEd framework has been further highlighted by the outcomes of the focus groups; which also provided details on students' problems with Matlab. While classifying Matlab within the TeRMEd framework and gathering the survey data requires a certain amount of effort from the lecturer, it is within the scope of their normal practices i.e. planning and evaluating their teaching. On the other hand, doing focus groups as part of regular practice would add considerable additional workload for the practitioner. Use of the TeRMEd classifications with the short survey and examination of the students' grades associated with the module should suffice to give the lecturer ample information to modify subsequent iterations of a technology integration.

Using technology at university requires pedagogical change (Beetham & Sharpe, 2020) if the affordances of technology are to be exploited and the needs of the ever-connected students are to be met (Conole, 2013; Goodyear, 2015; Laurillard, 2012). The TeRMEd framework can be used to assist practitioners in designing effective technology integration. Goodyear (2015) argues that supporting lecturers in using effective design practices improves the quality of higher education. Effective use of the TeRMEd framework classifications enabled this lecturer to plan a supportive learning environment, an element of effective teaching that involves '*creating situations that are conducive to learning*' (Goodyear, 2015, p. 30). The use of the TeRMEd framework to support evaluation of the technology integration can be used by the lecturer to ensure future iterations of this technology integration are more successful. This latter step has been identified by Goodyear (2015) as necessary in successful design of technology use as he states that design '*… should, include (re-)designing evaluation instruments that are specifically tuned to picking up exactly the right kind of data to feed the next round of design decisions*' (Goodyear, 2015, p. 32). The TeRMEd classification framework has proved to be an evaluation instrument that provides both the pre-teaching and post-teaching design activities that support effective technology integration discussed by Goodyear (2015).

The overall findings from the PhD study are considered in the next and final chapter of the thesis: Chapter 8 Discussions and Conclusions.

Chapter 8 Discussion and Conclusions

8.1 Introduction

This PhD dissertation has described a classification framework, the TeRMEd framework, that can be used by practitioners to plan and evaluate the effectiveness of their use of technology to support mathematics learning in first-year undergraduate non-specialist mathematics modules. In the development of this framework, the focus on factors that impact student engagement with technology supports a well-documented phenomenon: that student engagement fosters success in higher education (M. Bond et al., 2020; Fredricks & McCloskey, 2012; Schindler et al., 2017). Providing additional supports for this student cohort is crucial, as it is well known internationally that they are underprepared for the mathematics they encounter in first-year higher education, which can result in failure to progress (Faulkner et al., 2014; Liston et al., 2018; Loughlin et al., 2015; OECD, 2015) Technology-enhanced resources, such as those developed as part of the NF-funded project, are one such type of support. The TeRMEd framework can be used by practitioners to support students in successfully engaging with these types of resources.

The literature revealed that the provision of support resources, such as technology-enhanced resources, can be used to impact positively on student engagement in higher education, but that there is little evidence on how to integrate technology to best effect (M. Bond & Bedenlier, 2019; Conole & Alevizou, 2010; Henderson et al., 2015; Schindler et al., 2017). In mathematics education, there is a degree of uncertainty with regard to the benefits of using technology (OECD, 2015) and this has led to the call for frameworks of evaluation that can be used to determine what works and why (Dimitriadis & Goodyear, 2013; Drijvers, 2015; M. King et al., 2014; J. Lai & Bower, 2019). I identified two problem areas that emerged from the analysis of the literature: the first involved the need to identify factors that impact student engagement with technology, and the second concerned the need for a framework of evaluation that can support practitioners in integrating technology effectively. The first problem area stemmed from the lack of knowledge on how students engage with technology and what features of technology integration encourage student engagement with learning (Attard & Holmes, 2020; M. Bond & Bedenlier, 2019; Henrie, Halverson, et al., 2015). The second problem area arose from the need to leverage the affordances of technology to create educational activities that are based on proven pedagogy, and that can be evaluated as to their success (Conole, 2013; Dimitriadis & Goodyear, 2013; M. King et al., 2014).

As a result of the identification of these problem areas, I focussed the research in this PhD on the impact that technology integration has on student engagement, and on how best to use technology to support student engagement. The objectives of this research were:

(1) To review the current literature on the use of technology-enhanced resources by first-year undergraduate students in supporting their mathematics learning.
(2) To investigate how the effectiveness of such resources has been evaluated.
(3) To evaluate the effect the learning environment has on students' engagement with selected technology-enhanced resources.
(4) To develop a research-based evaluation framework that can be used by practitioners to determine the effectiveness of technology-enhanced resources that they develop for their students.

Based on the two problem areas identified, and the objectives of the research, I formulated the following three research questions:

RQ1: What are the key factors of technology-enhanced resources and their implementations that influence students' engagement with these resources?

RQ2: What are the key pedagogical features of technology-enhanced resource implementations that impact on student engagement with these resources?

RQ3: How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?

In order to address these research questions, I conducted a mixed-methods study within the context of the integration of technology-enhanced resources aimed at supporting mathematics learning in first-year undergraduate non-specialist mathematics modules. The research study consisted of five stages as outlined in Figure 8.1.1 below. Note this is a replica of Figure 4.2.1.

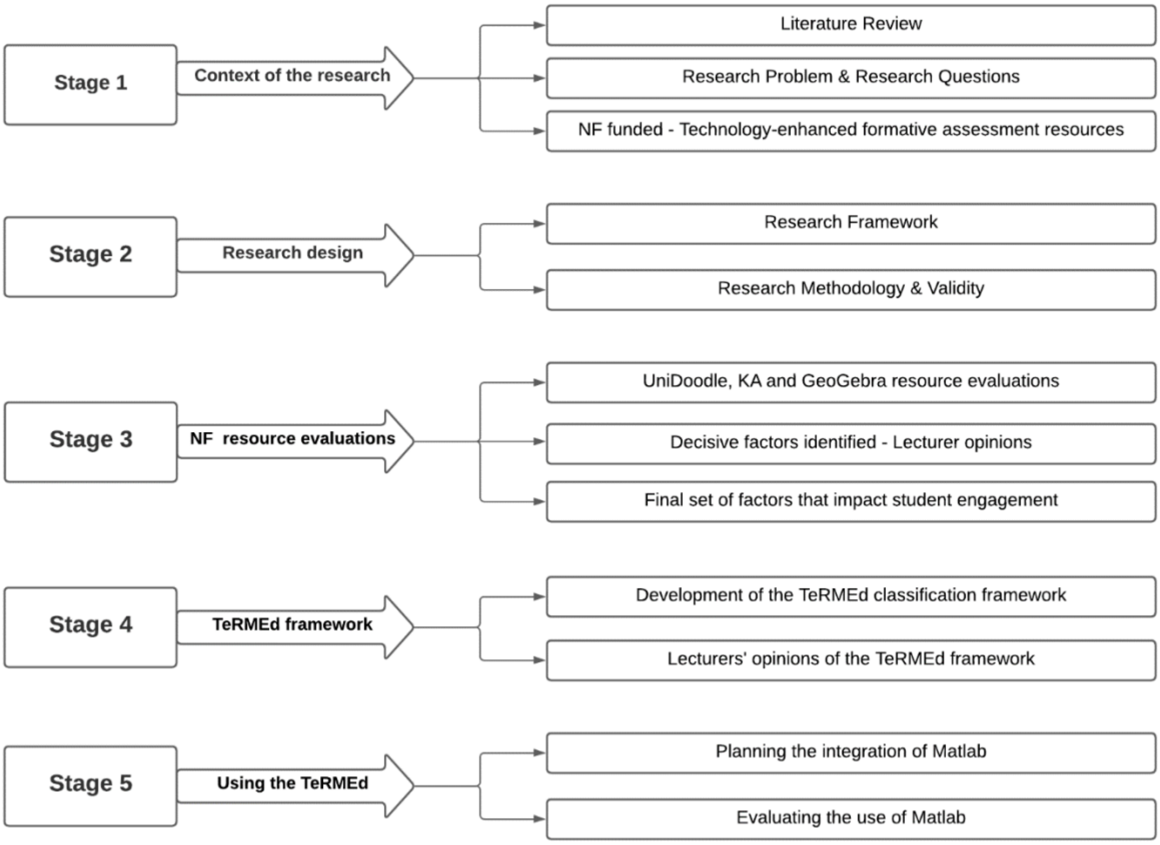


Figure 8.1.1: The five stages of the research project

The outcomes of the research were presented and discussed throughout Chapters 5 to 7. These outcomes are summarised and illustrated in the Figure 8.1.2.

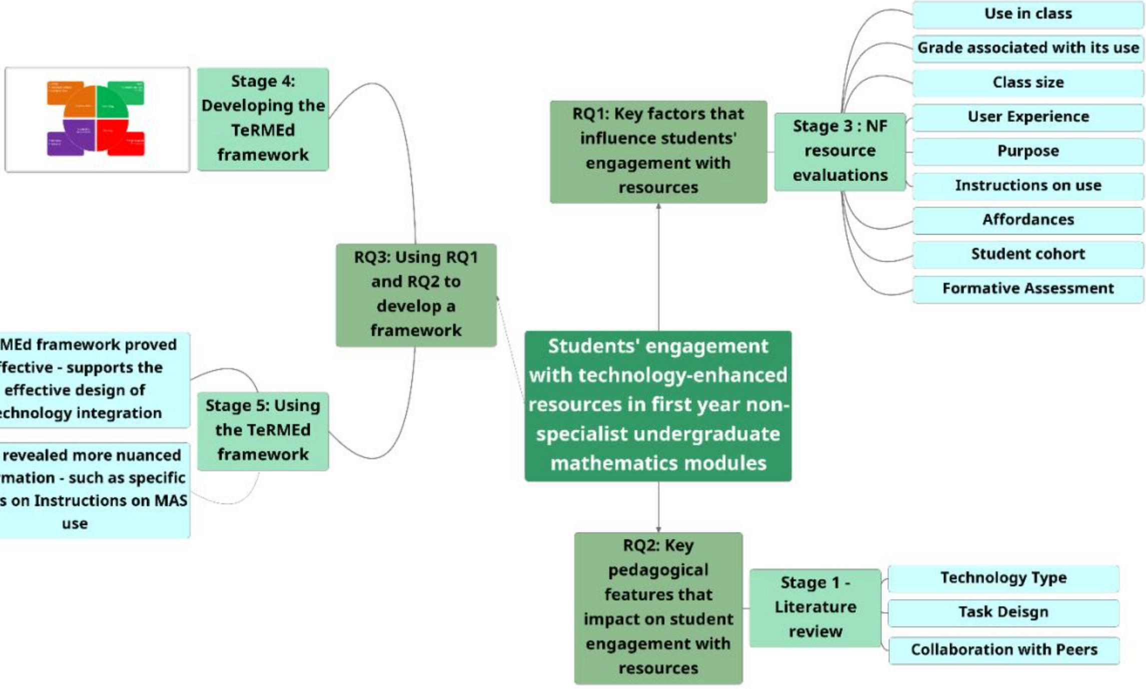


Figure 8.1.2: Overall outcomes of the research project

The outcomes are colour-coded as light blue, with the exception of the TeRMEd framework. The research questions and associated stages of the research are colour-coded in shades of green.

I took an holistic approach to student engagement in this research study. The study recognises that both structural and psycho-social factors impact on student engagement which results in both short and long term academic and social outcomes (Kahu & Nelson, 2018). While I acknowledge this triangle of engagement (Yang et al., 2018), the focus of this thesis is on what Bond and Bedenlier (2019, p. 5) refer to as the microsystem level, or the '*relationships between the learner-teacher-content*'. Within this context, student engagement was examined through the lens of the three commonly-referred-to dimensions of engagement: cognitive, behavioural and affective (Fredricks et al., 2004). Indicators of engagement, measured and observed as a result of the evaluations of the resources, were used to explore why, and in what way, first-year undergraduate students engaged with the NF-funded project resources. Measures recorded within this study, such as students' views on whether their learning was enhanced, and the effort students put into learning, are recognised as indicators of engagement (M. Bond & Bedenlier, 2019; Fredricks et al., 2016; J. Lai & Bower, 2019). The engagement indicators observed and measured in this study were matched to those tabulated by Bond and Bedenlier (2019, p. 3) and are illustrated within the three engagement dimensions in Figure 8.1.3.

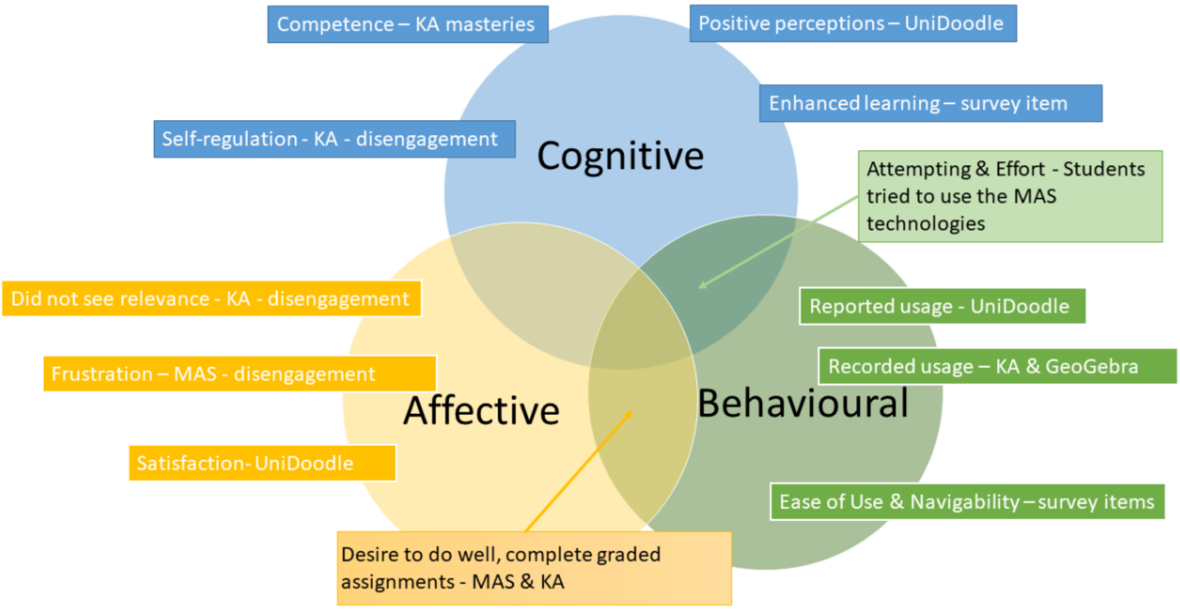


Figure 8.1.3: Indicators of engagement that were observed or measured in the study

The three dimensions of behavioural, affective and cognitive are colour coded. An arrow has been used to signal that the engagement indicator can be classified to two dimensions. Where disengagement was observed it is noted with the indicator.

While it is widely acknowledged that the three dimensions of engagement (cognitive, affective and behavioural) are interrelated, it is not always clear how the indicators used to measure engagement map to each dimension (Fredricks et al., 2016; Sinatra et al., 2015). Subsequent to their article containing the list of engagement indicators, Bond et al. (2020) acknowledged that there is disagreement in the literature on the alignment of the indicators and the dimensions. For example, effort is sometimes considered as an indicator for both behavioural and cognitive engagement (Fredricks et al., 2016). In addition, increased student engagement in one dimension may impact upon engagement in another; for example, cognitive engagement that results in academic success may bring about individual student satisfaction, increasing students' affective engagement (Fredricks et al., 2016; Sinatra et al., 2015). In recognition of this, the observed measures found in this study are taken to be indicators of more than one type of engagement where relevant, as illustrated by the Venn intersections in Figure 8.1.3. For example, I found that students' desire to achieve a grade, which is an indicator of affective engagement, impacts on their behavioural engagement, measured by the indicator of usage of the technology enhanced resource. Placing the indicators within a diagram such as shown in Figure 8.1.3 allows consideration of all three dimensions of engagement in an integrated manner, and contributes to the discussion on the need to consider engagement holistically (Attard & Holmes, 2020; M. Bond & Bedenlier, 2019; Yang et al., 2018). It also serves to connect the measures observed and the resultant student engagement, which has been lacking in previous studies (Schindler et al., 2017; Sinatra et al., 2015). Many of the mathematical education studies focus on one type of engagement, such as cognitive (Trenholm et al., 2019), affective (Steen-Utheim & Foldnes, 2018) and behavioural (Kanwal, 2020). While these studies are informative as to the benefits or otherwise of technology, by examining all three dimensions of engagement, I have explored student engagement with mathematics educational technology in a more integrated manner, an approach that is required in order to fully understand student engagement (M. Bond & Bedenlier, 2019; Fredricks & McCloskey, 2012; Henrie, Bodily, et al., 2015; Kahu, 2013; Sinatra et al., 2015).

In the following three sections, the outcomes relating to each of the three research questions are discussed in more detail. The significance of these research outcomes are then considered, followed by the limitations of the study and areas of future research. The final section provides a conclusion to the PhD work.

8.2 Answer to RQ1

RQ1: *What are the key factors of technology-enhanced resources and their implementations that influence students' engagement with these resources?*

A comparison of the engagement indicators observed and measured in the various implementations of the NF-funded project resources revealed the following nine factors that impact on student engagement, as illustrated in Figure 8.1.2 above.

- use in class
- grade associated with use
- class size
- user experience
- purpose
- instructions on use
- student cohort
- affordances
- formative assessment

Factors such as ‘use in class’, ‘grade associated with its use’, ‘affordances’, ‘instructions on use’ and ‘formative assessment’ have all been identified as contributing to the success or otherwise of technology-enhanced resource implementations in mathematics education (Buteau et al., 2010;

Galligan et al., 2015; Herbert et al., 2019; Pierce & Stacey, 2010; Thomas et al., 2017; Trenholm et al., 2015; Yang et al., 2018).

While 'usability' or the 'user experience' of technology has long being acknowledged as being important in the commercial world (O'Brien & Toms, 2010; Rohrer, 2014) and increasingly in education (JISC, 2015; Slade & Downer, 2020; Squires & Preece, 1999), there has been little exploration of its impact on students' use of technology within mathematics education. I This study examined user experience through the intersection of learning and usability as outlined by Zaharias and Poylymenakou (2009) and found that ease of use, learnability and usefulness impacted on students' views of the resources. Students rated UniDoodle higher on the User Experience scales than the other resources and both recorded and reported usage of UniDoodle was relatively high. Students using the MAS technologies found them hard to use which impacted student engagement with those resources. While Thomas et al. (2017) also observed the 'ease of use' factor, where students selected Desmos for graphing over the harder-to-use GeoGebra app, this was not something they had taken into account prior to the study. While the necessity of usability may appear obvious, it needs explicit attention when designing technology activities for the class; the technology needs to be 'easy to use' if students are to engage successfully with it.

Consideration of 'class size' has not been given much attention in the mathematics education technology literature and has emerged from this study as an important factor when using technology to support mathematics learning. Smaller class sizes, in the case of the UniDoodle1 and KA2 trials, enabled the lecturer to facilitate more formative assessment, than in the larger classes, and thestudents in these smaller classes were more satisfied with the supportprovided by the lecturer. Students' perception of teacher support is known to impact on engagement (M. Bond & Bedenlier, 2019); thus the factor of 'class size' has been corroborated through the wider education literature.

There is little focus within the mathematics educational technology literature on the importance of informing students about the purpose of the use of the technology within their mathematics module. This factor of 'purpose' was evident for the NF resources that were not used in class, as students struggled to see why they should engage with the resources. This was a strong theme in the interviews with students using the GeoGebra tasks: they did not appear to know how using the resource supported their learning. Knowledge of the relevance of the material and resources in use is known to impact the successful use of technology (M. Bond & Bedenlier, 2019; Martin et al., 2019), and can therefore be identified as a factor in student engagement.

The final factor that emerged is ‘student cohort’. The students involved in this study were registered on a mathematics module as part of their first-year undergraduate programme in disciplines other than mathematics. For many of these students, the focus is on passing the exam, as noted from both the student and lecturer interviews. Lecturers suggested that this student cohort do not recognise that they need support, and to some extent, the lecturers did not really expect the students to engage with the supplementary resources. Students expressed a similar view, with many of the students on the KA trials saying that they did not need the resources. While all student cohorts are liable to disengage from the use of supplementary resources, the specific educational background of a student cohort should be acknowledged when integrating technology (O’Sullivan et al., 2015). Educational backgrounds and their influence on cognitive engagement with technology has been identified by Geiger (2016) in the use of CAS technology, and by Drijvers (2015) in secondary education. In higher education, there is an increasing focus on the diversity of the student population and frameworks such as that promoted by CAST on Universal Design for Learning (Meyer et al., 2014) are having an impact on how practitioners design their courses. Thus, ‘student cohort’ can be taken as a factor in student engagement with resources.

In this section, the factors found in this study that impacted on student engagement with the NF resources were discussed. These include both pedagogical practices, such as assigning a grade to the use of the technology, and the educational setting, such as the size of the class. In the next section, further pedagogical features that impact student engagement will be examined.

8.3 Answer to RQ2

RQ2: *What are the key pedagogical features of technology-enhanced resource implementations that impact on student engagement with these resources?*

Within higher education, many educational researchers have called for the implementation of technology to leverage the pedagogical benefits of its use (Bayne, 2014; Conole & Alevizou, 2010; Dimitriadis & Goodyear, 2013; Selwyn, 2010), and this has also been reflected in the literature on mathematics education (Attard & Holmes, 2020; Drijvers, 2018; Jaworski & Matthews, 2011; Oates, 2016; Thomas et al., 2017). As discussed in the previous section, the evaluations of the NF resources highlighted a number of pedagogical features of technology-enhanced resources that are important factors in student engagement. In addition, I examined the literature to identify any further pedagogical features that had not emerged as a response to RQ1. The final set of pedagogical features identified are illustrated in Figure 8.1. 2. and listed below with a reference to the relevant equivalent factor, if any, identified from the NF resource evaluations.

- Didactical contract (purpose, use in class, grade towards assessment)

- Educational background (student cohort)
- Instrumental Orchestration (instructions on use)
- Technology affordances (affordances)
- Technological communication (formative assessment)
- Technology type
- Task design
- Collaboration with peers

The importance of pedagogical changes, such as careful design of task and management of the classroom, have been discussed within the context of secondary education (Drijvers, 2015; Pierce & Stacey, 2010). Using their Framework for Engagement in Mathematics (FEM), Attard and Holmes (2020) identified pedagogical changes required when using technology within mathematics education. They outlined two important elements that impact on student engagement: pedagogical relationships and pedagogical repertories. Pedagogical relationships refer to the communication and rapport between students and their teachers, and pedagogical repertories are the didactical practices enacted by the teacher (Attard & Holmes, 2020, p. 2). The pedagogical features that I identified in this research study encompass many of the elements of the FEM framework, but also adds to mathematical education practioners' understanding of what specifically is required for technology to work. For example, Attard and Holmes (2020) suggest that teachers should provide challenging tasks and student-centred technology as part of their repertories. This study has highlighted the need for lecturers to take advantage of the affordances of technology to support the tasks they design (Handal et al., 2012; Thomas et al., 2017), and to carefully consider the instructions and guidance required by students in order to enable students to successfully engage with the technology and the mathematics they are learning (Jupri et al., 2016; Thomas et al., 2017). The pedagogical relationships that Attard and Holmes (2020) refer to include the need for communication with students and the provision of feedback. By specifically identifying factors such as the technology types and associated affordances, that support formative assessment and collaboration with peers, this work has extended the understanding required to support pedagogical relationships.

When considered together, the list of 12 factors identified as a response to RQ1 and RQ2 provide a comprehensive response to Drijvers (2015) question as to "what works and why" in terms of technology integration in mathematics education. Following an analysis of six cases of technology integration in secondary mathematics, Drijvers (2015, p. 147) concluded that '*three factors emerge as decisive and crucial: the design, the role of the teacher, and the educational context*'. Within this study, I found that the design of tasks requires the selection of a technology type that supports the required complexity of the task and/or provides formative assessment. The role of the teacher is encompassed both in the didactical contract, and the orchestration of the associated activities such as the communication and collaboration supported by the technology. Finally, the factors of student cohort, technology use inside and outside the class, and a grade associated with technology use, are all part of the educational context. In addition, this research has identified the importance of the user experience and class size when integrating technology in mathematics education.

8.4 Answer to RQ3

RQ3*: How can the outcomes of RQ1 and RQ2 be used to develop a framework that practitioners can use to evaluate the effectiveness of their implementations of technology-enhanced resources?*

The TeRMEd framework was developed in response to a call for frameworks of evaluation that can be used to determine the benefits of technology integration in both higher and mathematics education (M. King et al., 2014; Monaghan et al., 2016). I used the12 decisive factors of successful technology integration, found in response to RQ1 and RQ2, for the foundation of the categories required in such a framework. While these factors identified specific features of technology integrations, the analysis of the literature in Chapter 2 facilitated the grouping of these features into categories and subcategories. This resulted in the need to address four areas: the implementation details; the type and affordances of the technology; the intended types of mathematical learning; and the formative assessment supported. Figure 8.4.1 illustrates how the 12 factors identified in response to RQ1 and RQ2 have been captured by these four areas.

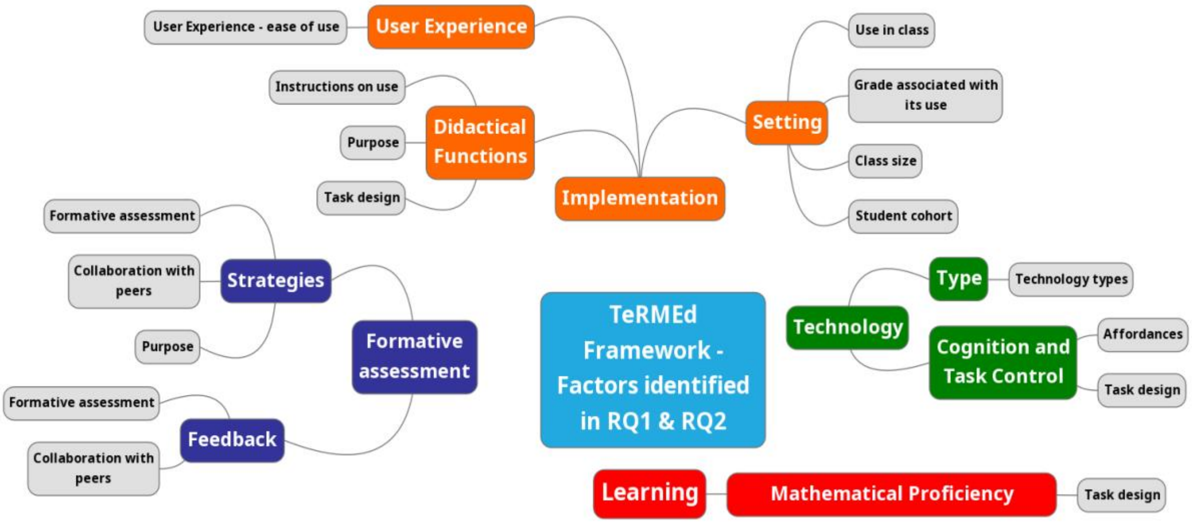


Figure 8.4.1: Contribution of the 12 factors to the development of the TeRMEd framework.

There was no overarching framework that encompassed all of these areas within the literature, hence the I developed TeRMEd classification framework which is illustrated in Figure 8.4.2 below. Note this is a replica of Figure 6.2.1 contained in Chapter 6.

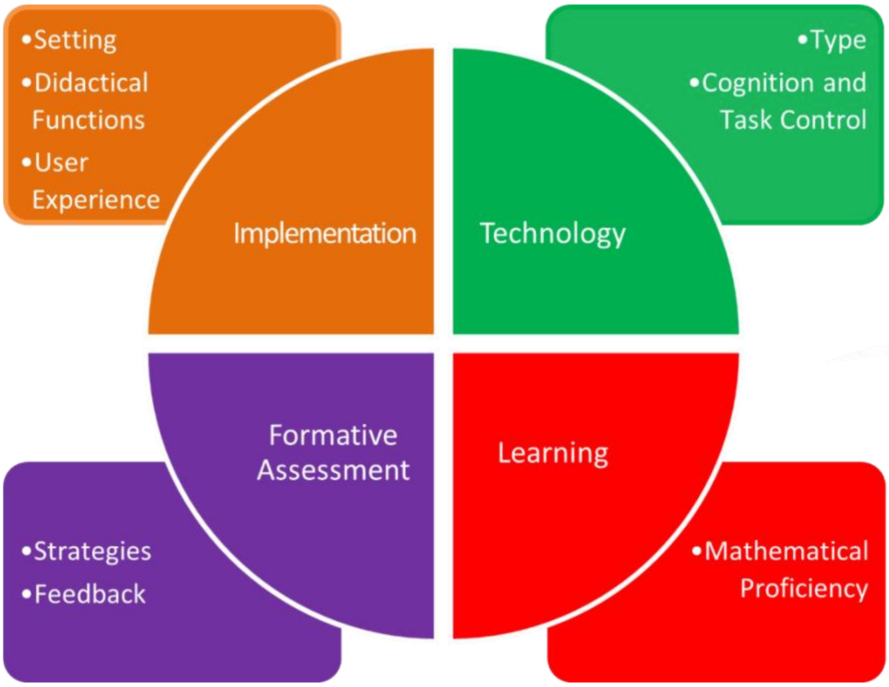


Figure 8.4.2: The TeRMEd classification framework

Each section has a number of categories and subcategories (the subcategories are not illustrated here, but can be viewed in Tables 6.3.1 - 6.6.1).

The Implementation section was used to capture aspects of the educational context, didactical contract, and mathematical practices that are necessary when integrating technology resources (Drijvers, 2015; Pierce & Stacey, 2010; Thomas et al., 2017). Setting contains those educational context factors that were found to impact students' engagement throughout this research project. The Didactical Functions category is used to describe the pedagogical functionality and support the teacher envisages for the technology. While the subcategories for User Experience stem from the need to consider usability of educational technology (M. Bond & Bedenlier, 2019; JISC, 2015; Squires & Preece, 1999), they also serve to obtain students' views on the technology use after integration. The latter facilitate student evaluation of the technology integration.

The second section of the TeRMEd framework, the Technology section, was used to focus on the need to account for the types of technology that are available and the affordances associated with them that stemmed from the research carried out in response to RQ1 and RQ2.

The Learning section came about because of the need to determine what is meant by developing students' mathematical understanding and the way in which it can be interpreted when developing resources. This is important as there are many different definitions of what is meant by mathematical understanding (National Research Coucil, 2001; Pirie & Kieren, 1994; Skemp, 1976). The Mathematical Proficiency definition from the NRC (NRC 2001, pp. 115–145) was chosen as it best matched the NF-funded project's focus on developing conceptual understanding and procedural fluency (O'Shea, Breen, Brennan, et al., 2016).

Finally, the Formative Assessment section encompasses some of the factors identified in response to both RQ1 and RQ2, but also captures the formative assessment features that technology can bring to education. These include two well-known features: strategies that support formative assessment (Wiliam & Thompson, 2008), and types of feedback (Hattie & Timperley, 2007). In addition, the direction of the feedback was included as it was considered important within the NF-funded resource evaluation analysis.

The pragmatic nature of this study necessitated the investigation of the validity of the TeRMEd framework for use by practitioners (Worren et al., 2002). The survey of lecturers involved in the NF-funded project revealed that, for them, the framework did indeed capture best practice and encompassed many of the features they generally consider when planning technology integrations. In addition, they highlighted new (for them) features, such as types of Mathematical Proficiency, and Formative Assessment strategies, that they would consider in future technology integrations. The TeRMEd framework received a positive response from these lecturers, and they all intend to use it for planning and evaluating future technology integrations.

Through using TeRMEd classification of the Matlab interevention, as part of the planning and evaluation of the use of this technology, Matlab, in a first-year engineering module, I demonstrated the value of the TeRMEd framework. For example, the successful use of the TeRMEd framework in facilitating the design of tasks that used the affordances of the technology was demonstrated by students' comments on the value and usefulness they associated with Matlab for completing complicated calculations. It was also clear that students had been able to see the relevance of Matlab, both for now and in their future programme and careers, which was facilitated by the provision of Lecturer Instructions on 'purpose'. Indeed, Attard and Holmes (2020, p. 3) have stated within the FEM that students engage more when they see the relevance of mathematics to their current and future lives. The use of the student survey 'user experience' values highlighted that despite the provision of Lecturer Instructions on 'instruction', and the use of Matlab in the class with lab assistant support, students found Matlab hard to use. The lecturer can use this information to reconsider the nature of the 'instruction' this student cohort requires to effectively use a MAS technology such as Matlab.

This section has given a response to RQ3 in that it has demonstrated how responses to RQ1 and RQ2 were used to develop the TeRMEd framework, and that practitioners can use the TeRMEd framework to plan and evaluate the effectiveness of their technology integrations. In the next section, the significance of this framework will be explored.

8.5 Significance of the TeRMEd framework

While many of the classifications of the TeRMEd framework can be completed prior to the integration of the technology within a mathematics module, there are a number of user experience subcategories that are populated using student evaluations (Section 6.3.3). It is this unique feature of the classification framework that enables the practitioner to reflect on the success or otherwise of the technology integration from their students' point of view. When presented with the TeRMEd framework classification and user experience evaluations of the NF resources, the lecturers involved in the NF project voiced surprise at some of the evaluation data. Individual lecturers suggested how they might use this information to improve the next iteration of the technology integration. They planned to modify some of the technology integration features contained within the TeRMEd classifications, those that predicted more successful engagement with the resources. For example, within the KA trials, one of the lecturers stated that he would allocate a grade towards its use for future iterations, and another said she would consider how better to tailor the type of feedback that was provided through the technology. While these recommendations with respect to technology integration have been acknowledged in the literature (M. Bond & Bedenlier, 2019; Drijvers, 2015; Thomas et al., 2017), practitioners may not be overtly aware of them. Indeed, the provision of the detailed feedback classification within the TeRMEd framework can help practitioners carefully design feedback interventions to ensure students' performance is enhanced rather than attenuated, as has been shown in prior studies (Hattie & Timperley, 2007; Kluger & DeNisi, 1996). Thus, including these features in a framework such as the TeRMEd framework means that practitioners will have them to hand when developing resources.

An emphasis on instructional design processes that support effective pedagogical practices is considered essential in enabling educators to leverage the affordances of technology (Conole, 2013; Goodyear, 2015; Laurillard, 2012). Indeed, it has been found that design which exploits the pedagogical affordances of technology enhances student engagement (Yang et al., 2018). By embedding pedagogical practices that are known to support student engagement with technology within the TeRMEd framework, practitioners can use the framework to support their instructional design process. All the lecturers involved in the NF project indicated they would use the TeRMEd framework when planning future uses of technology within their teaching. Some of the lecturers suggested that they were unaware of certain pedagogical features, such as Didactical Functions, and the various strands of Mathematical Proficiency. The use of the TeRMEd framework has prompted them to further investigate these pedagogical practices for future technology integrations.

Instructional design principles, used when developing resources, include the need to determine the learning objectives of the module, and to incorporate pedagogical practices that support students in achieving these objectives (M. Allen & Sites, 2012; Branch & Kopcha, 2014; Dousay, 2017). The TeRMEd classification has shown its value when used as a tool to guide, or design, the development of the Matlab integration in a first-year engineering module. Careful consideration of the categories and subcategories allowed the lecturer to focus on using the technology to achieve the learning objectives of the module. Despite this consideration, it emerged from the post-evaluation data that students found the resource difficult to use and learn from. While the lecturer had provided instructions on the use of Matlab, and there were a number of tutors available in the labs to support the students, this did not appear to be sufficient for students to use Matlab effectively. Matlab is a MAS technology (Pierce & Stacey, 2010) and it is known that students have difficulty using and learning from such technologies (Jupri et al., 2016; Thomas et al., 2017). In the literature concerning the integration of such technologies in mathematics education, the need for instrumental orchestration and schema to support students' use of MAS technologies has been discussed (Jupri et al., 2016; Thomas et al., 2017). This need has been evidenced as a result of the use of the TeRMEd framework. In both instances of MAS use, GeoGebra and Matlab, students reported that they found the instructions on its use insufficient. The use of the TeRMEd framework to design the integration of Matlab, and the subsequent student evaluations, has highlighted the need for practitioners to further consider how to support students' use of MAS technologies.

One of the key additions of the TeRMEd framework to the discourse on how best to integrate technologies in education is the inclusion of 'User Experience' as a category. Features such as the usability and learnability of course materials are increasingly recognised as having an impact on student engagement (M. Bond & Bedenlier, 2019; JISC, 2015; Squires & Preece, 1999; Zaharias & Polymenkau, 2009). It was the students' perceived view that the GeoGebra tasks and Matlab code were hard to use that prompted exploration of this theme in subsequent student interviews. This revealed that students found that their inability to use such technologies impacted on their successful engagement with the resources, a factor that the lecturers involved can take on board for future iterations of the technology integration. For example, the lecturer involved in the GeoGebra trials stated that she would take account of Usability and Learnability in future technology integrations. Another example is where one of the lecturers commented that the feature of the accessibility of the resource was outside her control. Knowing and acknowledging this allows the practitioner make informed choices with regard to the selection of technology. There is increasing recognition that instructional design needs to take on aspects of software design, such as a focus on user experience requirements (Adnan & Ritzhaupt, 2018; Svihla, 2018). Indeed, in the recent Irish National Digital Experience (INDEx) Survey, one of the key findings was students' request for consistency and improved navigability across the institutional VLEs (NF, 2020). It is thus timely to include such features in a classification framework such as the TeRMEd framework.

I have shown that the use of the TeRMEd framework for technology integration within undergraduate mathematics education is beneficial in terms of both design and evaluation. Practitioners expend considerable time developing such resources (Quinn et al., 2015; Trenholm et al., 2015, 2016); the use of the TeRMEd framework, as discussed, can help ensure that this work is put to best effect.

8.5.1 Limitations of the TeRMEd framework

There are, of course, some limitations to the TeRMEd framework that should be acknowledged. Firstly, to date, it has been found that the User Experience, from the student perspective, is both dependant on the technology and on the support provided by the lecturers in its use. However, in the TeRMEd framework, the User Experience of the technology has not been examined through the lens of usability heuristics that commonly apply in the design of user interfaces and educational software (JISC, 2015; J. Nielsen, 2020) and this is an area of future work. Secondly, the definitions of the subcategories within the User Experience category may be interpreted and implemented in different ways by users, based on how they decide to capture student opinion. In terms of variability between uses, this category is therefore far more dynamic than the others. Finally, the TeRMEd framework is large with many categories and subcategories, and this might make it somewhat unwieldly to use initially, although this will become easier with familiarity. Overall, these limitations in no way outweigh the contribution made by the creation of the TeRMEd framework in terms of more accurate categorisation of technology-enhanced resources in mathematics education to support student engagement.

8.6 Limitations of the research

As with any research study, there were a number of methodological limitations that had the potential to impact on the outcomes of this study. It is important, as a researcher, to acknowledge these limitations and reflect on the influence they have on the conclusions drawn from the work (J. H. Price & Murnan, 2004). The aim of the research was to investigate student engagement with technology-enhanced resources within the context of first-year undergraduate mathematics modules. This PhD study stemmed from the NF-funded project, which was bound by certain constraints. The types of resources that were developed, the timeframe within which to trial and evaluate them, and the student cohort involved in the project were outside the control of this researcher.

While the types of resources and associated tasks that formed part of the NF-funded project were decided upon by the lecturers, they were selected based on a research phase of the NF-funded project. A survey conducted in April 2015 formed the basis of two published papers on the problematic topics identified by students and their lecturers (Ní Shé et al., 2017a), and the types of resources used and those requested by students and lecturers involved in first-year undergraduate non-specialist mathematics modules across the island of Ireland (Ní Shé et al., 2017b). In addition, the NF-funded project requirements stipulated that the resources would use formative assessment techniques supported by technology. These factors ensured the resources were developed to support the needs of the student cohort under consideration in this thesis, using appropriate and relevant tasks that utilised technology affordances.

The development of the survey used to ascertain students' views of the resources was embedded in the belief, researched through the literature, that usability and learnability are important characteristics of educational technology (Zaharias & Poylymenakou, 2009). This resulted in a 48-item survey with five dimensions: Background, Usability, Engagement, Learning, and Confidence. Due to the nature of the NF-funded project, the lecturers involved in the project modified the survey according to their needs. This resulted in the availability of only four items (not including background items) commonly asked across all the different resources. This limited the ability to refine and hone the survey using common statistical analysis such as Chronbach and Factor analysis. However, the eventual aim of the commonly-asked questions was to populate the TeRMEd framework with a view to enabling a practitioner to identify aspects of technology integration that require attention in future iterations. In that context, they have proven sufficient to determine students' views of the usability and learnability of the resource integration.

The development of the TeRMEd framework was completed after the NF-funded project ended, which impacted on the availability of similar contexts within which to conduct further research. While the lecturers gave their opinions of the usefulness and relevance of the TeRMEd framework, it was not possible to afford them the opportunity to redesign the NF resources with the TeRMEd classifications in mind. An opportunity did arise to test the TeRMEd framework within a similar context, the use of Matlab within a first-year engineering mathematics module, however further such evaluations of the TeRMEd framework are required before it can become a recognised instrument to support the design and evaluation of technology integrations.

The data gathered for this study largely encompasses self-reported data in the form of surveys and interviews. It can be difficult to independently evaluate the veracity of claims made with such data. Methods of triangulation, such as the usage data gathered, were used. This data confirmed the students' views that they are more likely to engage with a resource which has a grade associated with its use. While students involved in the MAS trials claimed they did not get sufficient instruction and support on its use, the lecturers involved had provided support. This diversity of opinion has been interpreted within this thesis as a need for further instrumental orchestration of the technology. However, it may be that, even with such support, this cohort of students do not effectively engage with MAS technologies. The question as to whether students would effectively engage with MAS technologies even if they receive further instruction requires further investigation.

Finally, as discussed in the literature review student engagement with technology has many influencing factors, which go beyond the actual integration of technology within the classroom. The sociocultural context of the learning environment impacts on the effectiveness of technology integrations (Kahu & Nelson, 2018). Within the context of the NF-funded project, it was not possible to examine all the factors that impacted student engagement, as the responsibility of this researcher was the evaluation of the NF-funded resources. While this necessitated a focus on a narrower set of student engagement influences, it served to concentrate the outcomes into the development of a framework, the TeRMEd framework, that targeted the specific areas of design and evaluation.

8.7 Further Research

The previous section presaged a number of avenues of further research. Specifically, four main areas were identified: further evaluation of the TeRMEd framework applied to the design and evaluation of technology enhanced resources in undergraduate mathematics; investigation of the degree, and nature, of instruction required by students to enable them effectively engage with MAS; the exploration of the wider sociocultural influences on student engagement with technology; and the possible use of the TeRMEd framework in other disciplines.

While the TeRMEd framework was developed as a result of an in-depth research study and literature review, further research into its practicability as a resource to support the design and implementation of effective resources is an obvious next step. Indeed, it could prove valuable to investigate the relative benefits of using the TeRMEd framework, before or after a first implementation of a resource. The document developed for the lecturer survey on the TeRMEd (see Appendix E) could serve as a first draft of an operational guide for the TeRMEd framework.

Evaluation of its use within similar contexts would validate the TeRMEd framework as a tool for practitioners. Such research, and subsequent publications, would serve to disseminate the TeRMEd framework to practitioners in this field. A first step towards this dissemination was taken during CETL MSOR 2019, where the TeRMEd framework was presented and well received (Ní Shé et al., 2019a). In addition, the TeRMEd framework has introduced User Experience into evaluation frameworks in a novel way. Further exploration of this category, and how it is populated, is required to ensure emerging areas in instructional design such as UDL (CAST, 2018) and Usability heuristics (JISC, 2015; J. Nielsen, 2020) are explored.

The issue of students as 'digital natives' has been explored extensively in the literature since the term was first coined by Prensky (2001). While students are ever connected to technology, they do not always have skills necessary to use educational technology effectively (M. Bond & Bedenlier, 2019; Smith et al., 2020; Yang et al., 2018). Further research is required to investigate the divergent opinion of students and lecturers, with respect to the level of instruction required to use MAS within this study. The question remains as to whether it is mainly the students' motivation, or the level of instrumental orchestration required that impacts on their effective use of MAS.

In an ideal research world, the investigation of student engagement with technology would encompass all factors that impact on such engagement. Issues such as the individual students' experiences with education technology in a pre-university context, within other modules of their programme, and in a self-selected manner need further investigation. In addition, the technological cultural norms embedded in their social context, families, university and disciplines may have a bearing on their effective engagement with technology. Such a study would require a much broader research question with less focus on a particular set of resources.

Finally, the TeRMEd classification framework that emerged from this research could be used in a wider context, not only within other higher education mathematics contexts, but in other disciplines. Many of the categories and subcategories defined within the TeRMEd framework can apply, with some minor adjustment, to any technology integrated into education. For example, the didactical functions could be replaced by pedagogical opportunities that are pertinent to the specific discipline, such as when podcasts are used to support language learning with authentic materials (Rosell-Aguilar, 2007). The Learning section currently contains only mathematics-specific material, but could instead contain categories of the discipline-specific understanding or learning required: for example, in language learning, there may be a reference to grammatical skills, vocabulary (Alqahtani, 2015) and communicative competence (Canale, 1983). Further consultation with discipline-specific experts and research literature in those areas is required to modify the TeRMEd classification framework for such use. The modified form of the TeRMEd framework could then be used and evaluated in future technology integration projects undertaken in those disciplines.

8.8 Contribution and Conclusion

In order to capture the contribution of this PhD work, the significant findings, outcomes and areas of future research are listed below:

Significant Findings:

- Observations and measures taken as a result of technology-enhanced resource evaluations can be used to examine students' engagement with technology.
- User experience is an important factor when considering student engagement with educational technology.
- The factors that impact student engagement with technology can be encapsulated within an effective framework of evaluation.

Significant Outcomes:

- a comprehensive list of factors that impact first-year students' engagement with technology-enhanced resources used to support their learning in non-specialist mathematics modules
- a framework of evaluation, the TeRMEd classification framework, that can be used by practitioners to design and evaluate the use of technology integrations in undergraduate non-specialist mathematics modules

Future Research:

- comprehensive evaluation of the use of the TeRMEd classification framework by practitioners
- exploration of the possible extension of the use of the TeRMEd classification framework to other disciplines
- investigation of motivational aspects of student engagement that impinge on their ability to use MAS technologies
- identification of influencing factors outside the learner-teacher context that impact on first-year undergraduate students' engagement with technology-enhanced resources for non-specialist mathematics modules

8.8.1 Conclusion

The aim of this research was to explore why, and in what way, first-year undergraduate students engage with selected technology-enhanced resources to support their learning of mathematics for non-specialist mathematics modules and to determine what factors of the implementation environment impact on this engagement. The research outcomes have illustrated that this aim has been achieved. The factors that impact on student engagement with technology in this context can be categorised into four topics. The first contains those implementation factors, such as the educational setting, the didactic functions used and the usability of the technology from the student perspective. The second category concerns the types of technology to be used and the affordances of the technology to support relevant tasks. The type of learning required when using the resource is the third topic. Finally, the formative assessment strategies used, and the nature of the feedback provided, were found to impact on student engagement. Some of the factors that emerged have been corroborated within the mathematics education literature, and others within student engagement literature. Factors such as class size and user experience, that were identified in this study, have not previously been identified within this context. In addition, no previous study has considered all of these factors in a holistic framework of the three dimensions of student engagement.

As a result of the identification of these factors, the TeRMEd classification framework was developed. This framework encompasses all of these factors in a manner that it can be used by practitioners to design and evaluate technology integrations that will encourage student engagement. The research to date on the use of the framework is promising. The lecturers involved in the NF project highly rated the TeRMEd framework as a tool they would use in future technology integrations. It was used successfully in an integration of Matlab in a first-year engineering module. Further use of, and research into the use of, the TeRMEd framework is required in order to establish it as the go-to tool for practitioners.

8.9 Final Reflections

This PhD study has brought this researcher on a journey: from that of a mathematics support practitioner with a desire to improve the educational outcomes of students who struggle with mathematics, to a reflective researcher who understands the value of well-designed research, the necessity of a critical approach to research, and the hard work that it entails!

This researcher has learnt a lot along this journey, not least the carrot and stick approach adopted by her two supervisors. Thank you both.

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Appendices

Appendix A **Student Surveys Items**

A.1 Questionnaire for Stage 3 of the research project.

The questionnaire used for the student survey was designed to encompass the four dimensions of: Confidence in mathematical ability, Engagement with learning or technology to support learning, Enhanced Learning as a result of using the resource and the Usability of the technology resource. In addition, student background data was gathered. A review of the literature in the area revealed a number of different scales that had been used for technology intervention evaluation. The items used in the questionnaire for this study were selected based on this literature, and reworded for both face and content validity within the context of the NF-funded project resources evaluations. Table A.1 lists the final 48 items that were selected for use across the project, the literature source on which it was based, and the dimension associated with each item.

Table A.1: The items selected for the questionnaire

Question/Item used		Source based on	Dimension
1	Course you are attending	Ní Shé et al. (2017a)	Background
2	Student Id Number	Ní Shé et al. (2017a)	Background
3	Gender	Ní Shé et al. (2017a)	Background
4	Are you a mature Student	Ní Shé et al. (2017a)	Background
5	Indicate the level of Mathematics that you have completed in the Leaving Certificate	Ní Shé et al. (2017a)	Background
6	I have a mathematical mind	Fogarty et al. (2001)	Confidence
7	When I have difficulties with mathematics, I know I can handle them	Fogarty et al. (2001)	Confidence
8	I found the first Diagnostic Test easy	Fogarty et al. (2001)	Confidence
9	The feedback on my first Diagnostic Test helped me to identify skills that I needed to improve	Han and Finkelstein (2013), Richardson et al. (2014)	Engagement
10	I worked hard to improve these mathematical skills	McGeorge et al. (2008)	Engagement
11	I worked hard to improve my understanding of key mathematical concepts	McGeorge et al. (2008)	Engagement
12	I used the Maths Learning Centre to help me prepare for the Diagnostic Re-test	Strachota (2014), Ní Shé et al. (2017a), Zaharias and Poylymenakou (2009)	Engagement
13	I found the support provided by the Maths Learning Centre useful	McGeorge et al. (2008)	Learning
14	I used Khan academy to help me prepare for the Diagnostic Re-test	Strachota (2014), Ní Shé et al. (2017a), Zaharias and Poylymenakou (2009)	Engagement
15	I used the Khan academy playlist that was provided in Moodle to help me find appropriate resources in Khan Academy.	Zaharias and Poylymenakou (2009)	Engagement

Question/Item used		Source based on	Dimension
16	I prefer to use alternative online resources	Fogarty et al. (2001)	Engagement
17	I feel that I have improved my understanding of fundamental mathematical concepts	Richardson et al. (2014), McGeorge et al. (2008), Han and Finkelstein (2013)	Confidence
18	I improved my score on the second Diagnostic Test	Richardson et al. (2014), McGeorge et al. (2008), Han and Finkelstein (2013)	Confidence
19	Using Khan Academy enhanced my learning of the subject	Richardson et al. (2014), McGeorge et al. (2008), Strachota (2014), Han and Finkelstein (2013)	Learning
20	The following Khan academy features helped me to better understand key concepts [Khan Academy videos]	Richardson et al. (2014), Strachota (2014)	Learning
21	The following Khan academy features helped me to better understand key concepts [Khan Academy quizzes]	Richardson et al. (2014), Strachota (2014)	Learning
22	Khan Academy quizzes allowed me to test my mathematical ability	King and Robinson (2009a), Zaharias and Poylymenakou (2009), Han and Finkelstein (2013)	Learning
23	Khan Academy quizzes allowed me to get instant feedback on what I knew	Richardson et al. (2014), Zaharias and Poylymenakou (2009)	Learning
24	Khan Academy quizzes allowed me to get instant feedback on what I didn't know	Richardson et al. (2014), Zaharias and Poylymenakou (2009)	Learning
25	Khan Academy mastery challenges provided opportunities for self-assessment that advanced my learning	McGeorge et al. (2008), Robinson et al (2009), Zaharias and Poylymenakou (2009)	Learning
26	I found the Khan academy playlist that was provided in Moodle useful	King and Robinson (2009a), Zaharias and Poylymenakou (2009), McGeorge et al. (2008), Han and Finkelstein (2013)	Learning
27	It was clear to me what I needed to accomplish from using the Khan academy playlist in Moodle	Richardson et al. (2014), Zaharias and Poylymenakou (2009)	Usability
28	It was clear to me what I could gain from using the Khan academy playlist in Moodle	Richardson et al. (2014), Zaharias and Poylymenakou (2009)	Usability
29	The Khan Academy Playlist in Moodle helped me to focus on what I should be learning in preparation for the Diagnostic Re-test	McGeorge et al. (2008), Zaharias and Poylymenakou (2009), Han and Finkelstein (2013)	Learning
30	The Khan Academy Playlist in Moodle helped to identify key mathematical concepts that I need to understand better	McGeorge et al. (2008), Han and Finkelstein (2013), King and Robinson (2009a),	Learning

	Question/Item used	Source based on	Dimension
31	The Khan Academy Playlist in Moodle encouraged me to think more deeply about the mathematical skill I require during my course.	Richardson et al. (2014), King and Robinson (2009a)	Engagement
32	The Khan Academy playlist in Moodle helped me get instant feedback on what I knew	Richardson et al. (2014), McGeorge et al (2008)	Learning
33	The Khan Academy playlist in Moodle helped me get instant feedback on what I didn't know	Richardson et al. (2014), McGeorge et al (2008)	Learning
34	The Khan Academy Playlist in Moodle was useful in helping me to navigate my way through Khan academy	Zaharias and Poylymenakou (2009), Han and Finkelstein (2013)	Usability
35	I preferred to navigate my own way to appropriate material in Khan Academy	Zaharias and Poylymenakou (2009)	Usability
36	For me it was easy to use the Khan academy playlist that was provided in Moodle	Zaharias and Poylymenakou (2009), McGeorge et al. (2008), Richardson et al. (2014)	Usability
37	I always used the Khan Academy Playlist in Moodle to help me navigate to relevant resources within Khan academy	Zaharias and Poylymenakou (2009)	Usability
38	The links provided in the Khan Academy Playlist in Moodle always brought me to relevant resources within Khan Academy	Zaharias and Poylymenakou (2009)	Usability
39	There were too many technical difficulties in moving between the Khan Academy Playlist in Moodle and Khan Academy	Richardson et al. (2014), Strachota (2014)	Usability
40	I was able to direct my learning using this Khan academy playlist in Moodle	Richardson et al. (2014), Zaharias and Poylymenakou (2009)	Learning
41	The layout of the Khan Academy Playlist in Moodle into topics is helpful.	Zaharias and Poylymenakou (2009), Strachota (2014)	Usability
42	When using the Khan Academy Playlist in moodle, I preferred to systematically work my way through all of the links provided on a given topic	Zaharias and Poylymenakou (2009)	Usability
43	When using the Khan Academy Playlist in Moodle I usually tried the quizzes first.	Zaharias and Poylymenakou (2009)	Usability
44	As a result of the Diagnostic test/ Re-test cycle I feel that my mathematical skills have improved	Fogarty et al. (2001)	Confidence
45	Khan Academy is a useful resource which I will use when I encounter problem topics in future mathematics modules	Richardson et al. (2014),	Learning
46	Khan Academy Playlist such as the one provided in Moodle are useful	McGeorge et al. (2008), Richardson et al. (2014)	Usability
47	Using the Khan Academy playlists provided in Moodle has increased my confidence in my ability to complete 1st year mathematics successfully	Fogarty et al. (2001)	Confidence

Question/Item used		Source based on	Dimension
48	Please comment below on any aspect of the survey and/or the (NF-funded project resource)		Open

A.2 Items per trial

As noted within the main body of the thesis, the individual lecturers involved in the NF-funded project resources decided, in conjunction with this researcher, on the number of items to be used in the trials. These are listed below for each of the different resource type trials.

A.2.1 UniDoodle Trials

Both UniDoodle trials used the same questionnaire that contained 42 items in total. The items were modified to focus on particular features of ARS and were based on the literature in this area (Han & Finkelstein, 2013; S. O. King & Robinson, 2009a; MacGeorge et al., 2008; Richardson et al., 2014). The list of items is shown in Table A.2

Table A.2: List of items used in the students' survey for UniDoodle trials.

No.	Item
Q1	Gender
Q2	Indicate if you enrolled as a Mature student
Q3	Indicate the level at which you studied Leaving Certificate Mathematics
Q4	I regularly have difficulty with mathematics
Q5	When I have difficulties with mathematics, I know I can handle them
Q6	Using the UniDoodle app in class is fun
Q7	The use of the UniDoodle app helped me to be active in class
Q8	The fact that my answers were anonymous encouraged me to submit my responses in class
Q9	The UniDoodle app has encouraged me to attend lectures
Q10	I used the UniDoodle app most times when it was used in class
Q11	Because we used the UniDoodle app I prepare for class more than I would otherwise
Q12	The UniDoodle app makes me think more about the course material during my lectures
Q13	I found it useful to be able to draw sketches with the UniDoodle app
Q14	I found this method of interaction between students and lecturer effective
Q15	Using the UniDoodle app in lectures wasted too much time
Q16	I would recommend that the lecturer continue to use the UniDoodle app
Q17	The use of the UniDoodle app allows lecturers to identify problem areas
Q18	Because of the UniDoodle app I am more certain about how I am performing in the class
Q19	Using the UniDoodle app enhanced my learning of the subject
Q20	The UniDoodle app allowed me to get instant feedback on what I didn't know
Q21	The UniDoodle app allows me to better understand key concepts
Q22	The feedback provided by the lecturer after completing a UniDoodle question helped improve my understanding of the concepts covered

No.	Item
Q23	The feedback provided by the lecturer after completing a UniDoodle question helped me focus on what I should be learning in the course
Q24	The UniDoodle app helped me check whether I am understanding the concepts as well as I thought I was
Q25	For me it was easy to use the UniDoodle app
Q26	I was easily able to navigate the content in the UniDoodle app
Q27	There were too many technological problems using the UniDoodle app
Q28	I rarely had to seek help to use the UniDoodle app
Q29	Text and graphics are legible
Q30	The help is written clearly
Q31	I get distracted with other apps on my phone once I have taken my phone out in class
Q32	I tend to look at what other students beside me are doing with the app before I submit a response myself
Q33	I regularly find it too slow to upload my response
Q34	I often have difficulty with the wireless connection
Q35	I am afraid that I will use my call credit when submitting a response
Q36	I rarely have a smartphone with me in class
Q37	I never have a smartphone in class
Q38	By the time I have completed my response the lecturer has moved on
Q39	What was for you the balance of advantages vs. disadvantages of the use of this UniDoodle app for this module of your course?
Q40	How useful do you find the use of the UniDoodle app in class?
Q41	Using the UniDoodle app in class has increased my confidence in my ability to complete this module successfully
Q42	Please list the benefits, drawbacks or any other suggested uses of the UniDoodle app. Feel free to add any other constructive comments re the use of the UniDoodle app

A.2.2 GeoGebra trials

Both GeoGebra trials contained the same items, though GeoGebra 1 was administered online using a Google Form, and the questionnaire in GeoGebra 2 was paper-based, and distributed and collected in class. The lecturer involved in this trial wanted to curtail the number of items in the questionnaire and hence selected those items that most related to the evaluation of aspects of the interactive tasks that she was interested in for future development work. There were 14 items asked as shown in Table A.3.

Table A.3: List of items used in the students' survey for GeoGebra trials.

No.	Item
Q1	Institution Name
Q2	Gender
Q3	Are you a mature Student?

No.	Item
Q4	Indicate the level of Mathematics that you have completed in the Leaving Certificate
Q5	I used the GeoGebra Interactive tasks regularly, even when they were not assigned as homework
Q6	It was clear to me what I could gain from using the GeoGebra Interactive tasks
Q7	It was clear to me what I needed to accomplish when using the GeoGebra Interactive tasks
Q8	The Interactive tasks in GeoGebra allow me to better understand key concepts
Q9	I used the feedback provided by the Interactive tasks in GeoGebra to identify key mathematical concepts that I need to understand better
Q10	I found the sliders useful in the GeoGebra Interactive tasks
Q11	For me it was easy to use the Interactive tasks in GeoGebra
Q12	How useful do you find the use of Interactive tasks in GeoGebra?
Q13	Using the Interactive tasks in GeoGebra has increased my confidence in my ability to complete 1st year mathematics successfully
Q14	Please comment below on any aspect of the survey and/or the use of the Interactive tasks in GeoGebra

A.2.3 KA1 trial

The three KA trials had different questionnaires, though there were many of the same items asked across the different trials. The KA1 trial was used in a trial where the students were given a pre and post diagnostic test, with access to mathematics resources, including the KA, during the interval between tests. Therefore, some of the questionnaire items were focussed on that specific part of the trial. There were 49 items in the KA1 trial as shown in Table A.4.

Table A.4: List of items used in the students’ survey for the KA1 trial.

No.	Item
Q1	Institution Name
Q2	Course you are attending
Q3	Student Id Number
Q4	Gender
Q5	Are you a mature Student
Q6	Indicate the level of Mathematics that you have completed in the Leaving Certificate
Q7	I have a mathematical mind
Q8	When I have difficulties with mathematics, I know I can handle them
Q9	I found the first Diagnostic Test easy
Q10	The feedback on my first Diagnostic Test helped me to identify skills that I needed to improve
Q11	I worked hard to improve these mathematical skills
Q12	I worked hard to improve my understanding of key mathematical concepts
Q13	I used the Maths Learning Centre to help me prepare for the Diagnostic Re-test
Q14	I found the support provided by the Maths Learning Centre useful
Q15	I used Khan Academy to help me prepare for the Diagnostic Re-test

No.	Item
Q16	I used the Khan Academy playlist that was provided in Moodle to help me find appropriate resources in Khan Academy.
Q17	I prefer to use alternative online resources
Q18	I feel that I have improved my understanding of fundamental mathematical concepts
Q19	I improved my score on the second Diagnostic Test
Q20	Using Khan Academy enhanced my learning of the subject
Q21	The following Khan Academy features helped me to better understand key concepts [Khan Academy videos]
Q22	The following Khan Academy features helped me to better understand key concepts [Khan Academy quizzes]
Q23	Khan Academy quizzes allowed me to test my mathematical ability
Q24	Khan Academy quizzes allowed me to get instant feedback on what I knew
Q25	Khan Academy quizzes allowed me to get instant feedback on what I didn’t know
Q26	Khan Academy mastery challenges provided opportunities for self-assessment that advanced my learning
Q27	I found the Khan Academy playlist that was provided in Moodle useful
Q28	It was clear to me what I needed to accomplish from using the Khan Academy playlist in Moodle
Q29	It was clear to me what I could gain from using the Khan Academy playlist in Moodle
Q30	The Khan Academy Playlist in Moodle helped me to focus on what I should be learning in preparation for the Diagnostic Re-test
Q31	The Khan Academy Playlist in Moodle helped to identify key mathematical concepts that I need to understand better
Q32	The Khan Academy Playlist in Moodle encouraged me to think more deeply about the mathematical skill I require during my course.
Q33	The Khan Academy playlist in Moodle helped me get instant feedback on what I knew
Q34	The Khan Academy playlist in Moodle helped me get instant feedback on what I did not know
Q35	The Khan Academy Playlist in Moodle was useful in helping me to navigate my way through Khan academy
Q36	I preferred to navigate my own way to appropriate material in Khan Academy
Q37	For me it was easy to use the Khan academy playlist that was provided in Moodle
Q38	I always used the Khan Academy Playlist in Moodle to help me navigate to relevant resources within Khan academy
Q39	The links provided in the Khan Academy Playlist in Moodle always brought me to relevant resources within Khan Academy
Q40	There were too many technical difficulties in moving between the Khan Academy Playlist in Moodle and Khan Academy
Q41	I was able to direct my learning using this Khan Academy playlist in Moodle
Q42	The layout of the Khan Academy Playlist in Moodle into topics is helpful.
Q43	When using the Khan Academy Playlist in Moodle, I preferred to systematically work my way through all of the links provided on a given topic
Q44	When using the Khan Academy Playlist in Moodle I usually tried the quizzes first.
Q45	As a result of the Diagnostic test/ Re-test cycle I feel that my mathematical skills have improved
Q46	Khan Academy is a useful resource which I will use when I encounter problem topics in future mathematics modules
Q47	Khan Academy playlists such as the one provided in Moodle are useful

No.	Item
Q48	Using the Khan Academy playlists provided in Moodle has increased my confidence in my ability to complete 1st year mathematics successfully
Q49	Please comment below on any aspect of the survey and/or the Khan Academy playlist provided in Moodle

A.2.4 KA2 trial

In the KA2 trial, the Khan Academy Mastery feature was used by the lecturer to set challenges to students in relation to the material covered on vectors and matrices in a first-year undergraduate computer science mathematics module. Hence some of the items in the questionnaire were tailored to reflect the KA Mastery element of the trial. Nonetheless, there was also an overlap with many of the questions asked in the other two KA trials. See Table A.5 for a list of the 29 items asked.

Table A.5: List of items used in the students' survey for the KA2 trial.

No.	Item
Q1	Course you are attending
Q2	Student Id Number
Q3	Are you a mature Student
Q4	Indicate the level of Mathematics that you have completed in the Leaving Certificate
Q5	I have a mathematical mind
Q6	When I have difficulties with mathematics, I know I can handle them
Q7	I worked hard to develop the mathematical skills required for Mathematics 1
Q8	I used Khan Academy resources (quizzes/ videos) to help me to develop the mathematical skills required for Mathematics 1
Q9	I worked hard to develop my understanding of key mathematical concepts I met in Mathematics 1
Q10	I used Khan Academy resources (quizzes/ videos) to help me to develop my understanding of key mathematical concepts I met in Mathematics 1
Q11	I completed the Khan Masteries recommended for me as part of my Continuous Assessment for Mathematics 1
Q12	I only completed the Khan Masteries because they contributed to my Continuous Assessment for Mathematics 1
Q13	I always watched Khan Academy videos before attempting related Khan Academy quizzes
Q14	I found Khan Academy easy to use
Q15	Using Khan Academy enhanced my learning of Matrices
Q16	Using Khan Academy enhanced my learning of Vectors
Q17	The following Khan Academy features helped me to better understand key concepts introduced in Mathematics 1 [Khan Academy videos]
Q18	The following Khan Academy features helped me to better understand key concepts introduced in Mathematics 1 [Khan Academy quizzes]
Q19	Khan Academy videos help me to better understand what I needed to accomplish to complete Khan Masteries

No.	Item
Q20	Khan Academy quizzes allowed me to test my mathematical ability
Q21	Khan Academy quizzes allowed me to get instant feedback on what I knew
Q22	Khan Academy quizzes allowed me to get instant feedback on what I did not know
Q23	Khan Academy mastery challenges provided opportunities for self-assessment that advanced my learning
Q24	Completing Khan Academy Masteries as part of the Continuous Assessment for Mathematics 1 has help me to develop key skills in Matrices and Vectors
Q25	Including Khan Academy Masteries as part of the Continuous Assessment in Mathematics 1 is a good idea
Q26	I would recommend Including relevant Khan Academy Masteries as part of the Continuous Assessment on other Mathematics modules
Q27	Completing Khan Academy Masteries has increased my confidence in my ability to complete Mathematics 1 successfully
Q28	Khan Academy is a useful resource which I will use when I encounter problem topics in future mathematics modules
Q29	Please comment below on any aspect of the survey and/or the Khan Academy playlist provided in Moodle

A.2.5 KA3 trials

The KA3 trial was run within a first-year undergraduate business mathematics module. Students were given access to the playlists via the institutional VLE, Moodle. Access was provided via a link contained in the mathematics Moodle module which took them to a separate Moodle module called Khan Academy Resources. Once students had established the navigation path, they could access the resources from either link. As recorded usage of the resources was low, the questionnaire was broken into two sections: the first section was for all students and the second was only for those who had stated that they had used the resource. There were 13 items, with two qualifier questions, in the first section and 12 in the second section. See Table A.6 for a list of the items asked in the KA3 survey.

Table A.6: List of items used in the students' survey for the KA3 trial.

No	Item
Q1	Course you are attending
Q2	Gender
Q3	Are you a mature Student
Q4	Indicate the level of Mathematics that you have completed in the Leaving Certificate
Q5	I regularly have difficulties with mathematics
Q6	When I have difficulties with mathematics, I know I can handle them
Q7	Did you ever access the Khan Academy Resources (KAR) module from within Loop?
Q7A	If not, why not?
Q8	Did you ever access the Khan Academy via the links provided in the KAR Loop module?

No	Item
Q8A	If not, why not?
Q9	I prefer to use alternative online resources (other than Khan Academy)
Q10	I prefer to use other resources, such as lecture notes, books and tutorial questions
Q11	I used the Mathematics Learning Centre
Q12	I feel that I have improved my understanding of some of the fundamental mathematical concepts required for MS136 by using these resources
Q13	Any further comments on the use of the Khan Academy or any other resources that helped you with module MS136
Q14	I used Khan Academy to help me overcome some of the difficulties I had last semester
Q15	Using Khan Academy enhanced my learning of mathematics
Q16	The videos in Khan Academy helped me to better understand key concepts
Q17	The quizzes in Khan Academy helped me to better understand key concepts
Q18	Khan Academy quizzes allowed me to test my mathematical ability
Q19	I used the Khan Academy playlist that was provided through the Loop module MS136 to help me find appropriate resources in Khan Academy
Q20	I preferred to navigate my own way to appropriate material in Khan Academy
Q21	For me it was easy to use the Khan Academy playlist that was provided in Loop
Q22	The layout of the Khan Academy playlist in Loop was helpful
Q23	When using the Khan Academy, I usually tried the quizzes last
Q24	Khan Academy is a useful resource which I will use when I encounter problem topics in future mathematics modules
Q25	Using the Khan Academy has increased my confidence in my ability to complete 1st year mathematics successfully
Q26	If you found the Khan Academy Resources helpful please explain why
Q26	If you did not find the Khan Academy Resources helpful please explain why not

Appendix B **Grades**

While it was not intended to attempt to measure student learning as a result of using the NF-funded project resources, grade data was available in relation to the KA1 and KA2 trials. This data was analysed with a view to determining if students' grades followed a similar pattern to their engagement.

B.1 Diagnostic test results for KA1

First-year computer programming students (N=175) completed a diagnostic test (DT1) prior to being given access to the KA playlist and other mathematical support resources, in the KA1 trial. Five weeks later they completed a second diagnostic test (DT2).

There were 102 students who completed both tests. Of these, 65% of students improved their score in DT2, 8% got the same grade and 27% did better in DT1. There was a statistically significant improvement in grade as evidenced by the paired t-test DT1 (M=47.59), DT2 (57.38), t (101) = 5.74, ρ<0.001.

There were 18 students who had used the KA playlists and completed both diagnostic tests. Fifteen (83%) of these achieved a higher grade in DT2 than DT1. While this percentage (83%) is greater than the 65% in the total cohort, a Fisher exact test did not show a statistically significant difference.

B.2 Student grades for KA2

In the KA2 trial, student grades for the module were recorded. The overall assessment had five elements: Class Test 1 (CT1) worth 10%; Class Test 2 (CT2) worth 10%; Tutorial attendance and Test (TT) worth 10%; Khan Academy Mastery challenges achieved (KM) worth 10% and a terminal exam worth 60%. Table B.1 contains the central tendency values for the various elements of the test.

Table B.1: Student measures of central tendency for each of the grade elements in the linear algebra module.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
CT1 (10%)	78	.00	100.00	44.8205	29.61605
CT2 (10%)	80	.00	100.00	42.3500	28.24177
TT (10%)	80	.00	100.00	70.5125	35.81492
KM (10%)	80	.00	100.00	49.5290	35.26222
Exam (60%)	80	.00	97.00	38.6530	26.41328
Exam and CA (100%)	80	.00	97.80	43.7976	25.49758
Valid N (listwise)	78				

A statistically significant correlation between the KM grade and the Exam was found, $r(79) = 0.56$, $\rho<0.001$.

In addition, student time spent on the KM challenges was recorded, see Table A5.1.3 above. The median time spent by students was 421.0167 minutes. Students who spent greater than the median time achieved an average KM grade of 73.87% and those who spent less than the median achieved an average of 33.1%. When students spent longer on the KA learning materials they achieved a higher grade.

In both trials, KA1 and KA2, students with higher engagement also achieved higher grades.

Appendix C **GeoGebra analysis**

C.1 GeoGebra Interview Protocol

After the analysis of the student survey and the recorded usage data from the GeoGebra 2 trial, an interview protocol was designed to elicit further information from the students about their use of the GeoGebra tasks during the semester. The interviews were semi-structured, so while the themes were adhered to, the specific questions were not always asked of each individual student. See Table C.1 for the themes and specific questions asked.

Table C.1 Interview protocol used in the GeoGebra 2 trial focus group interview.

General Area	Guiding Specific Questions
Student Background	What is your course of study? What level of mathematics had you coming into higher education? How confident are you in your mathematical ability?
GeoGebra prior to higher education	Had you used GeoGebra prior to higher education? If so, where, how useful did you find it, how easy was it to use?
GeoGebra use this year in MT101 module	Did you use GeoGebra at all, or regularly? Why or why not? If so, which tasks and why those? How much time did you spend on using GeoGebra? Why, Why not, useful or helpful? In what way did you find it helpful? Do you think it helped in your understanding/learning of the mathematics associated with module?
Transformation task associated with the Assignment sheet.	Did you access and use this task? Why, why not, useful, or helpful? In what way?
Limits of piecewise and Numbas quiz	Did you access and use this task? Why, why not, useful, or helpful? In what way?
Derivatives Quiz	Did you access and use this task? Why, why not, useful, or helpful? In what way?
Demo of tasks discussed	Does the task help in your understanding? If so, in what way?
User experience of tasks, while being demonstrated	Which features work and which do not? Labelling, slider function, variation in function on screen, knowing what to do

General Area	Guiding Specific Questions
Encouraging use	What would be needed for you to use these GeoGebra tasks more? What would encourage the use of technology tools in general for mathematics education?
Using other resources	What other resources do you use, (focus on technology)? How useful are they? What do they help you with? What about them draws you in? What resources did you use for exam preparation? How and when do you use a search on the internet?

Appendix D **NF trial characteristics**

D.1 NF-funded resource characterisations

In order to distinguish between the different NF-funded resources, they were characterised by the lecturers involved in the project, along with this researcher, during and/or after the trial of the resource. The agreed set of characteristics are: Trial name; Type of Technology; No of students; Context of use; Type of Task; Type of Formative Assessment; Grade for its use. Table D.1 contains the details for each of the seven trials.

Table D.1: Characterisation of the NF-funded resources during the trials.

Trial name	Type of Technology	No. of students	Context of use	Type of tasks	Type of formative assessment	Grade for its use
UniDoodle1	ARS	12	Regular use in class	Karnaugh maps – understanding & problem solving	Group and peer, strategies for solving problems	No
UniDoodle2	ARS	151-165	Used 4 times in class	Calculus and linear algebra - understanding & problem solving	Group and peer, strategies for solving problems	No
GeoGebra1	CAS	476	Outside class on VLE mainly as support	Differential calculus - understanding	Individual, exploratory for understanding, and correctness	One graded, 12 non-graded
GeoGebra2	CAS	396	Outside class	Differential calculus - understanding	Individual, exploratory for understanding, and correctness	Three graded, five non-graded
KA1	Khan Academy playlists	176	Outside Class	Diagnostic Test/Retest Cycle – support methods & procedures	Individual, correctness	No, but grade associated with diagnostic test
KA2	Khan Academy	80	In and outside class	Linear Algebra - support	Individual, group,	Yes, 10%

Trial name	Type of Technology	No. of students	Context of use	Type of tasks	Type of formative assessment	Grade for its use
	Mastery Challenges			methods & procedures	correctness, and strategy	
KA3	Khan Academy Playlists	335	Outside Class	Business Mathematics - support methods & procedures	Individual, correctness	No

Appendix E **Practitioner Research**

After the TeRMEd framework was developed, the lecturers involved in the project were asked to give their opinions of the TeRMEd framework and its potential value within their practice. The NF-funded resources were classified within the framework, and the values from the NF-resource evaluations were used to populate the associated User Experience values in the TeRMEd framework. The lecturers were given a document that explained the TeRMEd framework and the classification of the NF-funded resources within the framework. They were then asked to complete a survey that was made available online. The details of both are outlined in the following two sections.

E.1 Lecturer TeRMEd description for survey

The TeRMED Classification Framework

Introduction

The Technology-enhanced Resources for Mathematics Education (TeRMEd) framework was developed using the outcomes of the surveys completed during the National Forum for the Enhancement of Teaching and Learning in Higher Education (NF) project

(https://www.teachingandlearning.ie/project/assessment-for-learning-resources-for-first-year-undergraduate-mathematics-modules/), the descriptions of the various resources trialled during the NF project, and from the literature in this area.

There are four sections in the TeRMEd framework: Implementation, Technology, Learning and Formative Assessment. Each section contains a number of categories and sub-categories that describe a particular characteristic of the use of the technology-enhanced resource. The Implementation section characterises the educational setting, the didactical functions of the technology use and the user experience. The technology type, and the level of cognition and user task control afforded by the technology are defined in the Technology section. The characteristics of the types of expected mathematical proficiency are covered in the section on Learning. The different aspects of formative assessment supported by the resource are characterised in the Formative Assessment section. See Figure E.1 for an illustration of the sections and categories of the TeRMEd framework.

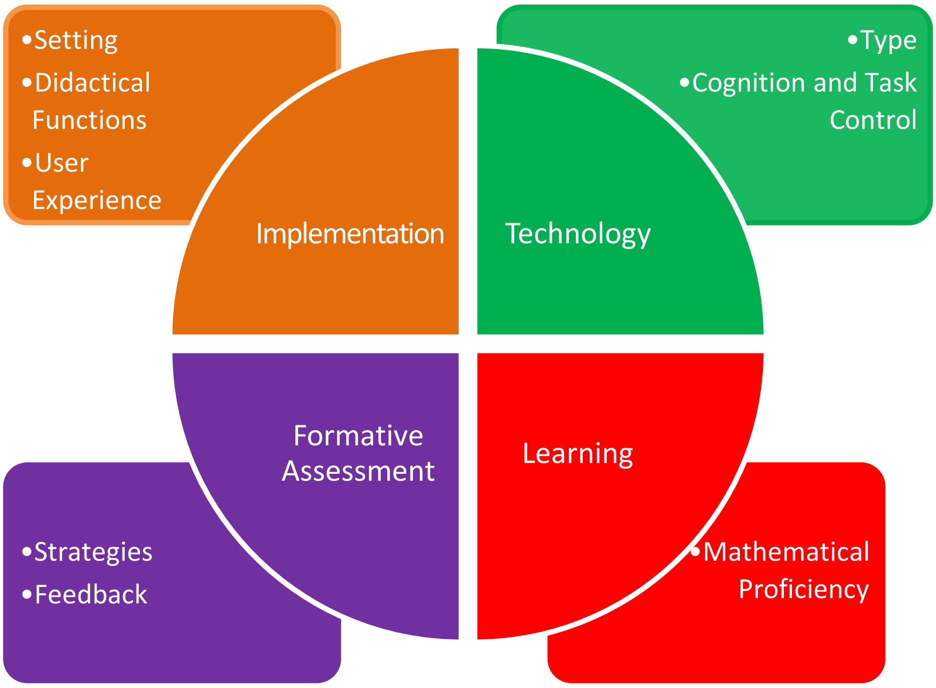


Figure E.1: The TeRMEd framework

The classifications of the NF resources within the TeRMEd framework are presented in the next section of this document. This is followed by brief descriptions of the categories and sub-categories of the four TeRMEd framework sections along with an explanation of how the classifications for the NF resources were determined.

Classification of the NF resources within the TeRMEd framework

Each of the categories within the TeRMEd framework has a number of subcategories. The values for the subcategories are selected from either; a set of options, a value obtained as a result of a survey item, or a ✓ that indicates that the particular sub-category applies. The classifications for the NF resources were determined using select outcomes of the surveys and the descriptions of the NF resources. Table E.1 contains the classifications for many of the resources that were trialled under the NF project.

Table E.1: Classification of the NF resources in the TeRMEd framework.

S	C	Sub-category	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2	Matlab
Implementation	Setting	Class Size	small	large	large	medium	large	large	large	medium
		Use in Class	Lecture only	Lecture only	Study time only	Lecture and study time	Study time only	Study time only	Study time only	Lecture and study time
		Summative Assessment	No	No	No	Yes	No	Yes	Yes	Yes
		Student Cohort	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist
	Didactical Functions	Do								✓
		Learn - practise skills			✓	✓	✓			✓
		Learn – concepts	✓	✓				✓	✓	
		Lecturer Instructions	Instructions & Purpose	Instructions & Purpose	Purpose	Instructions & Purpose	Purpose	Purpose	Purpose	Instructions & Purpose

S	C	Sub-category	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2	Matlab
	User Experience	Navigation	91.67%	84.38%	17.31%	N/A	36.36%	N/A	N/A	24%
		Usable	91.67%	91.67%	47.62%	51.35%	45.45%	58.70%	30.45%	23%
		Learnability	91.67%	56.70%	26.61%	61.11%	47.06%	53.33%	55.09%	46%
		Accessibility	Static	Static	Static	Static	Static	Dynamic	Dynamic	Static
		Consistency	Static	Static	Static	Static	Static	Dynamic	Dynamic	Static
		Visual Design	Static	Static	Static	Static	Static	Dynamic	Dynamic	Static
		Technologically ready	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic
		Useful	100.0%	72.8%	33.3%	52.8%	45.5%	48.9%	49.8%	70%
		Usage	100.0%	83%	17%	99%	10%	92% & 50%	87% & 60%	~100%
Technology	Type	Communication Tool	✓	✓		✓				
		MAS						✓	✓	✓
		CAA			✓	✓	✓	✓	✓	
		Instructional Material			✓	✓	✓			
	Cognition and Task	Productive								✓
		Explorative	✓	✓				✓	✓	✓
		Instructive			✓	✓	✓			
Learning	Mathematical Proficiency	Conceptual Understanding	✓	✓				✓	✓	✓
		Procedural Fluency			✓	✓	✓			✓

S	C	Sub-category	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2	Matlab
		Strategic Competence								✓
		Adaptive Reasoning								
		Productive Disposition								
Formative Assessment	Formative Assessment Strategies	Clarifying and sharing learning intentions	✓	✓	✓	✓	✓	✓	✓	✓
		Engineering effective classroom discussion	✓	✓		✓				
		Providing immediate feedback	✓	✓	✓	✓	✓	✓	✓	✓
		Activating students as instructional resources for one another	✓	✓						
		Activating students as owners of own learning			✓		✓	✓	✓	
	Feedback	Feedback Type	FT	FT	FT	FT	FT	FT	FT	FT
			FP	FP		FP				FP
									FR	

S	**C**	**Sub-category**	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
			FS	FS	FS	FS	FS	FS	FS	FS
		Feedback Direction	Lecturer to student	Lecturer to student		Lecturer to student				Lecturer to student
					Technology to student	Technology to student	Technology to student	Technology to student	Technology to student	Technology to student
			Student to student	Student to student						

Description of sub-categories and options

Descriptions of the options for the categories and sub-categories of the TeRMEd framework sections are given below. The relevant subset of Table A.1, relating to a particular section or category of the TeRMEd NF resources classifications, is presented alongside the explanations. The classifications are determined in different ways depending on the category and these are explained as they occur. Within the framework, and where appropriate, a ✓ is used to indicate which sub-category applies to a particular use of the resource.

Implementation Section

Setting: This describes the particular class and module setting where the resource is used.

Class Size: The size of the class in the case of a lecture, or, the student instructor ratio in the case of a lab: *Small < 30, 30 ≤ Medium < 100 or Large ≥ 100*

Use in Class: Describes whether the resource is used in *Lecture only, Study time only or Both lecture and study time.*

Summative Assessment: Is there a grade associated with the use of the resource: *Yes or No*.

Student Cohort: This describes the broad student cohort, whether they are taking the mathematics module as part of a specialist or non-specialist undergraduate programme. The latter is often referred to as service mathematics: *Non-specialist or Specialist*.

The options selected for the Setting sub-categories are determined from the descriptions of the NF resource trials and are shown in Table E.2.

Table E.2: Classification of the NF resources within the Setting category of TeRMEd.

Sub-category	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2	Matlab
Class Size	small	large	large	medium	large	large	large	medium
Use in Class	Lecture only	Lecture only	Study time only	Lecture & study time	Study time only	Study time only	Study time only	Lecture & study time
Summative Assessment	No	No	No	Yes	No	Yes	Yes	Yes
Student Cohort	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist	Non-specialist

Didactical Functions

This describes how the lecturer puts the resource into effect, the pedagogical practices that are used.

Do: the functionality related to doing mathematics, where work that could be done by hand is done by the technology;

Learn – practice skills: the functionality provided to practice skills;

Learn – concepts: the functionality that supports the development of conceptual understanding (Drijvers, 2015, p. 3)

Lecturer Instructions. This refers to support provided by the lecturer on how to use the resource. Specifically, it refers to the provision of instructions and/or tutorials on the use of the technology, and explanations of the purpose of using the technology within the module. *Instructions, Purpose, Instructions & Purpose, None*.

The values used for the Didactical functions category depend on both the limitations of the technology in use, and on how the lecturer implements it. For example, some technologies do not allow mathematics to be done, therefore Do will never apply.

The sub-categories that apply for the Didactical Function classifications are determined from the descriptions of the NF resource trials and are shown in Table E.3.

Table E.3: Classification of the NF resources within the Didactical Function category of TeRMEd.

Sub-category	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
Do								✓
Learn - practise skills			✓	✓	✓			✓
Learn – concepts	✓	✓				✓	✓	
Lecturer Instructions	Instructions & Purpose	Instructions & Purpose	Purpose	Instructions & Purpose	Purpose	Purpose	Purpose	Instructions & Purpose

User Experience

This category refers to the overall experience of the user, in this case the student, when using the resource

Navigation: Learners can navigate their way around the resource without seeking help

Usable: The learner's perception of how easy to use they find the resource

Learnability: The learner's perception of how their learning has been enhanced using the resource

Accessibility: The resource is accessible and follows UDL principles

Consistency: There is a consistency of terminology, design and functionality within the resources

Visual Design: The screen is easy to read and information is placed in the optimal places to attract the learner's attention

Technologically ready: The resource is free from technical problems

Useful: Learners perception of how useful they find the resource within the context

Usage: Percentage of learners who used the resource

The User Experience sub-category options are illustrated in Table E.4. These options are determined in different ways which are explained below.

Table E.4: The User Experience category options.

Section	**Category**	**Sub-category**	**Options**
Implementation	User Experience	Navigation	Likert scale
		Usable	Likert Scale
		Learnability	Likert Scale
		Accessibility	Dynamic or Static
		Consistency	Dynamic or Static
		Visual Design	Dynamic or Static
		Technologically ready	Dynamic or Static
		Useful	Likert Scale
		Usage	Recorded by technology or lecturer

The values for the Likert scale sub-categories are calculated as the percentage of respondents who selected Strongly Agree or Agree to each of the relevant Likert scale items, illustrated in Table E.5.

Table E.5: Items asked in the survey matched to TeRMEd subcategories.

Items	**SA**	**A**	**N**	**D**	**SD**	**Equivalent TeRMEd sub-category**

For me it was easy to use *the technology-enhanced resource* *						Usable
Using *the technology-enhanced resource** enhanced my learning of the mathematics required in *my maths module***						Learnability
I was easily able to navigate the content in *the technology-enhanced resource**						Navigation
I found that *the technology-enhanced resource** is a useful resource for supporting my mathematics learning						Useful

* term in italics can be replace with the name of the resource, i.e. UniDoodle.

**replace with name of module within which the resource was used.

Usage statistics may differ for different technologies and lecturer requirements. For UniDoodle it was estimated by the lecturer, or self-reported by students as responses to a survey item. In the case of GeoGebra and KA, we calculated the percentage of usage based on the number of students who accessed a link to the resource at least once during the semester. The other User Experience sub-categories will be known prior to an evaluation. A Static value implies that the sub-category is controlled by the particular application or software in use. For example, the Khan Academy will/should have its own checks for these parameters, and even if they do not, the lecturer cannot change them. However, in the case of creating GeoGebra tasks, there is room for the practitioner to consider Visual Design, Accessibility and Consistency. Thus, the sub-category is set to Dynamic.

The values determined for the NF resource classifications in the User Experience category of the TeRMEd framework are shown in Table E.6.

Table E.6: Classification of the NF resources within the User Experience category of TeRMEd.

Sub-category	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2	Matlab
Navigation	91.67%	84.38%	17.31%	N/A	36.36%	N/A	N/A	24%
Usable	91.67%	91.67%	47.62%	51.35%	45.45%	58.70%	30.45%	23%
Learnability	91.67%	56.70%	26.61%	61.11%	47.06%	53.33%	55.09%	46%
Accessibility	Static	Static	Static	Static	Static	Dynamic	Dynamic	Static
Consistency	Static	Static	Static	Static	Static	Dynamic	Dynamic	Static
Visual Design	Static	Static	Static	Static	Static	Dynamic	Dynamic	Static
Technologically ready	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic
Useful	100.0%	72.8%	33.3%	52.8%	45.5%	48.9%	49.8%	70%
Usage	100.0%	83%	17%	99%	10%	92% & 50%	87% & 60%	~100%

Technology Section

This category is used to describe the technology and its functionality. There are two categories within this section, each with a number of subcategories.

Type

Communication Tools: Technologies that support electronic communication between the various agents involved in the teaching and learning process: lecturer, student, technology and networks. The UniDoodle tool was used in class by lecturers to communicate the questions and subsequent sample responses to the students. The KA was used in the KA2 trial to communicate the student's grade on mastery challenges and to suggest further challenges to be taken. This feature was not implemented in the other KA trials.

Mathematical Analysis Software (MAS): MAS is increasingly being used to help students explore the relationships between multiple representations of mathematical objects (Breda & Santos, 2016) and it encompasses mathematical tools such as dynamic geometry, computer algebra systems, computation and mathematical modelling (Pierce & Stacey, 2010). Both Matlab and GeoGebra can be classified as MAS.

Computer-Aided-Assessment (CAA): CAA has been defined as 'the use of computers in the assessment of student learning' Bull and McKenna (2004, p. xiv) and is often enabled through the use of multiple choice questions. Online quizzes are built into the KA.

Instructional Videos: Often called online instructional videos, these may be a recorded video of a lecture, or purposefully produced videos that explain mathematical concepts and/or procedures. Videos are built into the KA.

The sub-categories that apply for the NF resource classifications in the Technology Type category of the NF project resources are shown in Table E.7.

Table E.7: Classification of the NF resources within the Technology Type category of TeRMEd.

Sub-category	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
Communication Tool	✓	✓		✓				
MAS						✓	✓	✓
CAA			✓	✓	✓	✓	✓	
Instructional Material			✓	✓	✓			

Cognition and Task Control

This category defines the complexity of the tasks that can be performed using the resource. These are based on the work of Handal et al. (2013). They defined three clusters of cognition and control.

Productive: The learner is required to produce a mathematical artefact, such as a programme that performs a mathematical function. This requires the highest level of cognition and gives learners most control. Students in the Matlab trial were required to produce programming code that performed mathematical functions.

Explorative: Explorative engages the learner in guided discovery. This was the primary function of GeoGebra, students were allowed vary sliders that helped them explore mathematical concepts. This was also used in Matlab, students were given programming code that performed specific mathematical functions and then asked to explore how changes to the variables impacted on the outputs.

Instructive: Instructive requires the lowest cognition and is mainly used for drills and practice. This is the primary function of KA, videos and quizzes that focus on practising skills.

The sub-categories that apply for the NF resource classifications in the Cognition and Task Control category of the NF project resources are shown in Table E.8..

Table E.8: Classification of the NF resources within the Cognition and Task Control category of the TeRMEd framework.

Sub-category	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
Productive								✓
Explorative	✓	✓				✓	✓	✓
Instructive			✓	✓	✓			

Learning Section

The learning section describes the type of mathematical understanding that can be supported by the resource.

Mathematical Proficiency:

There is no general consensus for mathematical understanding in the literature. The NF project focussed on developing resources that support both the idea of Understand and Do, as investigated using surveys in April 2015 (Ní Shé et al., 2017). The NRC (2001, p. 115 - 145) uses the term "mathematical proficiency" to bring together five strands that are considered necessary for anyone to learn mathematics successfully. This definition was found to best describe the mathematical understanding supported through the use of the NF project resources. Within the framework a ✓ is used to indicate which strand applies to a particular use of the resource. These strands, interwoven and interdependent, are summarised as follows:

- "Conceptual understanding: comprehension of mathematical concepts, operations, and relations;
- Procedural fluency: skill in carrying out procedures flexibly, accurately, efficiently, and appropriately;
- Strategic competence: ability to formulate, represent, and solve mathematical problems;
- Adaptive reasoning: capacity for logical thought, reflection, explanation, and justification;
- Productive disposition: habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy" (NRC, 2001, p. 116).

The types of mathematical understanding supported by the NF resources is shown in the Mathematical Proficiency classifications as shown in Table E.9..

Table E.9: Classification of the NF resources within the Mathematical Proficiency category of the TeRMEd framework.

Sub-category	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
Conceptual Understanding	✓	✓				✓	✓	✓
Procedural Fluency			✓	✓	✓			✓
Strategic Competence								✓
Adaptive Reasoning								
Productive Disposition								

Formative Assessment

One of the aims of the NF project was to develop formative assessment techniques and resources that consisted of online activities and interactive tasks that would improve student mathematical understanding. The formative assessment section of the TeRMEd framework describes how the resources implement the formative assessment techniques. This section has two categories, each with a number of subcategories or options. These are outlined below.

Formative Assessment Strategies

These are based on strategies put forward by Wiliam and Thompson (2007) to support formative assessment in education. The FaSMEd project modified these strategies for the specific use of technology-enhanced formative assessment in secondary mathematics education (FaSMEd, 2016). The five strategies are:

1. Clarifying and sharing learning intentions
2. Engineering effective classroom discussion
3. Providing immediate feedback
4. Activating students as instructional resources for one another
5. Activating students as owners of own learning

The Formative assessment strategies supported by the NF resources are illustrated Table E.10.

Table E.10: Classification of the NF resources within the Formative Assessment category of the TeRMEd framework.

Sub-category	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
Clarifying and sharing learning intentions	✓	✓	✓	✓	✓	✓	✓	✓
Engineering effective classroom discussion	✓	✓		✓				
Providing immediate feedback	✓	✓	✓	✓	✓	✓	✓	✓
Activating students as instructional resources for one another	✓	✓						
Activating students as owners of own learning			✓		✓	✓	✓	

Feedback

There are two sections to Feedback, Type and Direction which are explained below.

Feedback Type

Feedback is defined as information about the gap between the actual level of student knowledge and understanding, and the desired level. In order for feedback to be effective, it must be used (William, 2011). Hattie and Timperley (2007) examined evidence relating to the effectiveness of feedback and proposed a model of the properties of feedback and the circumstances in which it can be used to greatest effect. Hattie and Timperley (2007) identified four levels at which feedback should be focussed. These are the four options of the Feedback Type sub-category.

FT: Feedback about the task (FT) which relates to the correctness of a response and the need to acquire new or different knowledge.

FP: Feedback about the process (FP) which is aimed at the learning process and may provide cues to students about task strategies.

FR: Feedback about self-regulation (FR) which is aimed at developing students' self-assessment skills and is known to be very powerful in enabling students identify the gap in their knowledge and encouraging them back to the task with more commitment.

FS: The fourth level of feedback identified by Hattie and Timperley (2007) is Feedback about the Self (FS) and is related to self-efficacy.

Within the framework Feedback Type in use by the NF resources trialled is indicated by using its initialism.

Feedback Direction

This sub-category is used to denote where the feedback types, described previously, are generated and transmitted to the student. Table E.11 illustrates the options available for the Feedback Direction sub-category. One or all of these may apply.

Table E.11: Options that are used within the Feedback Direction sub-category of the TeRMEd framework.

Section	**Category**	**Sub-category**	**Options**
Formative Assessment	Feedback	Feedback Direction	Lecturer to student
			Student to student
			Technology to Student

The options selected for the NF resource classifications in the Feedback Category of the NF project resources are shown in Table E.12.

Table E.12: Classification of the NF resources within the Formative Assessment category of the TeRMEd framework.

Sub-category	**UniDoodle1**	**UniDoodle2**	**KA1**	**KA2**	**KA3**	**GeoGebra1**	**GeoGebra2**	**Matlab**
Feedback Type	FT	FT	FT	FT	FT	FT	FT	FT
	FP	FP		FP				FP

Sub-category	UniDoodle1	UniDoodle2	KA1	KA2	KA3	GeoGebra1	GeoGebra2	Matlab
							FR	
	FS	FS	FS	FS	FS	FS	FS	FS
Feedback Direction	Lecturer to student	Lecturer to student		Lecturer to student				Lecturer to student
			Technology to student	Technology to student	Technology to student	Technology to student	Technology to student	Technology to student
	Student to student	Student to student						

E.2 Practitioner Survey

Table E.13 contains the questions asked of the lecturers who had been involved in the development of the NF-funded project resources.

Table E.13: List of questions in the practitioner survey.

No	Question
Q1	Email address
Q2	I consent to partaking in this study
Q3	Implementation Section: Did you take the following into account when planning the use of the resource? [Class Size]
Q4	Implementation Section: Did you take the following into account when planning the use of the resource? [Use in Class]
Q5	Implementation Section: Did you take the following into account when planning the use of the resource? [Summative Assessment]
Q6	Implementation Section: Did you take the following into account when planning the use of the resource? [Student Cohort]
Q7	Implementation Section: Did you take the following into account when planning the use of the resource? [Didactical Practice of Do, Learn - Practice Skills or Learn Concepts]
Q8	Implementation Section: Did you take the following into account when planning the use of the resource? [The necessity to specifically inform students of the value of engaging with the resource]
Q9	Implementation Section: Did you take the following into account when planning the use of the resource? [The provision of a set of instructions on the use of the resource]
Q10	Implementation Section: Did you take the following into account when planning the use of the resource? [Running a dedicated class on the use of the resource]
Q11	Implementation Section: Did you take the following into account when planning the use of the resource? [Navigation]

No	Question
Q12	Implementation Section: Did you take the following into account when planning the use of the resource? [Usable]
Q13	Implementation Section: Did you take the following into account when planning the use of the resource? [Learnability]
Q14	Implementation Section: Did you take the following into account when planning the use of the resource? [Accessibility]
Q15	Implementation Section: Did you take the following into account when planning the use of the resource? [Consistency]
Q16	Implementation Section: Did you take the following into account when planning the use of the resource? [Visual Design]
Q17	Implementation Section: Did you take the following into account when planning the use of the resource? [Technologically Ready]
Q18	Implementation Section: Did you take the following into account when planning the use of the resource? [Useful]
Q19	Implementation Section: Did you take the following into account when planning the use of the resource? [Usage]
Q20	Please qualify any of your responses to the above question if you have something that you would like to add. Refer to the particular item if it is relevant.
Q21	Technology Section: Did you take the following into account when planning the use of the resource? [The type of tool you planned to use]
Q22	Technology Section: Did you take the following into account when planning the use of the resource? [Whether the tool was instructive, explorative or productive?]
Q23	Please qualify any of your responses to the above question if you have something that you would like to add
Q24	Learning Section: Did you take any of the following strands of learning into account when planning the use of the resource? [Conceptual Understanding]
Q25	Learning Section: Did you take any of the following strands of learning into account when planning the use of the resource? [Procedural Fluency]
Q26	Learning Section: Did you take any of the following strands of learning into account when planning the use of the resource? [Strategic Competence]
Q27	Learning Section: Did you take any of the following strands of learning into account when planning the use of the resource? [Adaptive Reasoning]
Q28	Learning Section: Did you take any of the following strands of learning into account when planning the use of the resource? [Productive Disposition]
Q29	Please qualify any of your responses to the above question if you have something that you would like to add
Q30	Formative Assessment strategies category: Did you take any of the following strategies into account when planning the use of the resource? [Clarifying and sharing learning intentions]

No	Question
Q31	Formative Assessment strategies category: Did you take any of the following strategies into account when planning the use of the resource? [Engineering effective classroom discussion]
Q32	Formative Assessment strategies category: Did you take any of the following strategies into account when planning the use of the resource? [Providing immediate feedback]
Q33	Formative Assessment strategies category: Did you take any of the following strategies into account when planning the use of the resource? [Activating students as instructional resources for one another]
Q34	Formative Assessment strategies category: Did you take any of the following strategies into account when planning the use of the resource? [Activating students as owners of own learning]
Q35	Please qualify any of your responses to the above question if you have something that you would like to add
Q36	Feedback category: Did you take into account the type and direction of feedback when planning your use of the resource [Feedback Types]
Q37	Feedback category: Did you take into account the type and direction of feedback when planning your use of the resource [Feedback Direction]
Q38	Please qualify any of your responses to the above question if you have something that you would like to add
Q39	Select which of the responses best describes your reaction to each of the values calculated from the student data, and input into the User Experience category of the TeRMEd framework. [Navigation]
Q40	Select which of the responses best describes your reaction to each of the values calculated from the student data, and input into the User Experience category of the TeRMEd framework. [Usable]
Q41	Select which of the responses best describes your reaction to each of the values calculated from the student data, and input into the User Experience category of the TeRMEd framework. [Learnability]
Q42	Select which of the responses best describes your reaction to each of the values calculated from the student data, and input into the User Experience category of the TeRMEd framework. [Useful]
Q43	Select which of the responses best describes your reaction to each of the values calculated from the student data, and input into the User Experience category of the TeRMEd framework. [Usage]
Q44	Navigation: Please explain what you would have expected your students to say about navigating your resource. How does this differ from the results of the survey?
Q45	Usable: Please explain what you would have expected your students to say about the usability of your resource. How does this differ from the results of the survey?
Q46	Learnability: Please explain what you would have expected your students to say about whether the resource enhanced their learning of mathematics for the module. How does this differ from the results of the survey?
Q47	Useful: Please explain what you would have expected your students to say about how useful they found the resource for learning mathematics. How does this differ from the results of the survey?

No	Question
Q48	Usage: Please indicate roughly what percentage of your students you would have expected to use the resource. How does this differ from the results of the survey?
Q49	Answer the following question if you had a different opinion than your students, for any of the values. Can you explain why student views on the resources was different than you anticipated? Refer to the particular value if it is relevant.
Q50	Did the TeRMEd framework enable you identify any factors, relating to the use of the technology-enhanced resource you trialled, that you had not previously considered
Q51	If you answered yes, please indicate which of the TeRMEd factors you had not considered and why not
Q52	Do you think that you missed anything when planning the use of your resource that might have improved the outcomes of students' use of the resource now that you have examined the TeRMEd classifications?
Q53	If so, what were they?
Q54	How might the examination of the TeRMEd classifications of your resource that you completed as part of this survey impact on your plans for future implementations of this resource?
Q55	Please comment on any aspect of the TeRMEd framework that you think might contribute to its success as a tool for you in the future
Q56	Please add any other comments you may have that relate to this research

Appendix F **Matlab trial**

There were two main elements to the research conducted as part of the Matlab trial. The first was the student survey and the second the focus group interviews. The instruments used to gather the data are contained in the two sections below.

F.1 Matlab student survey

Confirmation of requirements as highlighted in the Plain Language Statement

Participant – please complete the following consent question

I have been informed of the context and background to this survey, including the plain language statement, and I am aware that there is no obligation on my part to complete this survey

(Circle Yes or No) Yes / No

Engagement and Learning

Please ***tick*** one option for each of the following questions which best describes your agreement or disagreement with the following statements.

Questions	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
I used the Matlab application regularly, even when it was not assigned as part of the EM114 module					
For me it was easy to use Matlab					
Using Matlab enhanced my learning of the mathematics required in EM114					
I was easily able to navigate the content in Matlab					
I found that Matlab is a useful resource for solving mathematics problems					
It was clear to me what I needed to accomplish when using Matlab within the EM114 module					
Using Matlab increased my confidence in my ability to complete 1st year mathematics successfully					

Background Data

Please ***circle*** the appropriate response

Gender	Female	Male	Prefer not to State
Indicate if you are enrolled as a Mature student	Yes	No	Prefer not to State

Indicate the level at which you studied Leaving Certificate (LC) Mathematics	Higher Level	Ordinary Level	Foundation Level	Did not take LC	Prefer not to State

Please comment below on any aspect of the survey and/or your use of Matlab

F.2 Matlab Interview Protocol

At the end of the semester, two focus group interviews were held with students who had attended the EM114 module to further explore their use of and experience with Matlab and their use of technology to support their mathematics learning in general. As these were semi-structured interviews, the themes were adhered to, however the specific questions were not always asked of each individual student. Table F.1 contains details of the interview protocol.

Table F.1: Interview protocol used in the Matlab trial focus group interview.

5. General Area	**Guiding Specific Questions**
Student Background	Do you use technology to support your learning in Mathematics? What resources? How do you select them? Where did you find about them? How useful are they? Did you use Matlab prior to EM114?
Use of Matlab in EM114	When did you start to use Matlab? Did you use it regularly? For what purpose did you use it? Did you always use Matlab to solve the problems for EM114? Did you find that Matlab helped in the development of your mathematical understanding and/or on how to solve numerical problems?
User Experience of Matlab	How did you learn to use it? Was the given code helpful? If you sought help, where did you get help with Matlab? Did you spend much time on developing your Matlab skills?
Further uses of Matlab	Did you use Matlab outside the EM114 module? If so, why and how? Do you think you will use Matlab in the future? If so, how and why?

5. General Area	Guiding Specific Questions
Encouraging use	How could the use of Matlab within the module be improved? What specific help would be required to ensure you can use Matlab effectively?

F.3 Codebook for Matlab Focus Groups

The focus group data recorded during the Matlab trial was transcribed and uploaded into NVivo for analysis. Two separate analyses were performed: the first was used to compare the focus group data with the outcomes of the Matlab students' survey; the second was to explore the data for further themes relating to student engagement with Matlab. The codebooks for each of these are presented below.

F.3.1 Codebook for Survey comparison Matlab

Table F.2 contains a list of the nodes and sub-nodes along with a node description, sample data coded to the node, and the number of segments coded at the nodes.

Table F.2: Codebook used for focus group comparison with survey.

Name	Description	Sample Coded Segment	No. of Segments
Negative_FG	This node is divided into sub-nodes with segments that contain negative sentiment towards use of Matlab within EM114.	N/A	N/A
NFG_Easy to Use	Segments in which students refer to having had difficulty in using or understanding the Matlab code that formed part of their labs.	'felt it like it got very difficult very quickly without much explanation'	22
NFG_Learnability	Segments in which students refer to using Matlab without enhancing their learning.	'… and your like ok, this is what it does and you put it in and you think it does it but then you don't understand the concept behind it , you don't understand how the computer does it'	6
NFG_Lecturer instructions	Segments where students refer to having been left in	'I think the only thing about it was we were thrown quite	9

Name	Description	Sample Coded Segment	No. of Segments
	the 'deep end' and/or having had insufficient instructions on the use of Matlab.	into the deep end straight off.’	
NFG_Useful	Segments where student refers to how they have not found Matlab useful in the context of the EM114 module.	‘I didnt use…as we could do out the questions without using Matlab’	8
Positive_FG	This node is divided into sub-nodes with segments that contain positive sentiment towards use of Matlab within EM114.	N/A	N/A
PFG_Easy to Use	Segments in which students refer to having been able to use and understand the Matlab code that formed part of their labs.	‘I find Matlab very easy in the beginning’	6
PFG_Learnability	Segments in which students refer to using Matlab to complete a task and/or enhance their learning.	‘…see what everything sort of does and maybe mess around with this part or that part and then see…its changed that figure by more decimals or being more accurate ‘	11
PFG_Lecturer instructions	Segments where students refer to having been given instruction on the use of Matlab.	‘I was asking a lot of questions to the instructors and stuff on what the code was doing so’	2
PFG_Useful	Segments where students refer to how they have or could find Matlab useful to solve mathematical problems.	‘I think the benefits of Matlab would be that for really long winded questions…four maybe five rows and columns of matrices ‘	22

F.3.2 Codebook for Inductive analysis of data Matlab

Inductive analysis was used to determine the themes emerging from the focus group data. Table M.2.1 contains the NVivo codebook created for this analysis. This Codebook contains the name of the node and sub-nodes, the description of the segments of data coded into the node, a sample of data coded at the node and the total number of segments coded for each node.

Table F.3: Codebook used for focus group comparison with survey inductive analysis of focus group.

Name	Description	Sample Coded Segment	No. of segments
Coding in Matlab	Segments where the student refers to the code in Matlab having a bearing on their work	'…but like having been given a question if we weren't given that base code, I think it would have been impossible for us to do.'	20
Cognitive Engagement	Created to illustrate where students put a sustained effort into using Matlab	N/A	22
Learn by self	Segments where student refers to successfully trying to F-6learn to use Matlab and the code without lecturer/lab help	'I have done two Matlab courses that they have for free'	18
Not Learn by self	Segments where student refers to unsuccessfully trying to F-6learn to use Matlab and the code without lecturer/lab help	'I tried to ask some other students but …, I feel they had the like the same as me where they were a little lost '	4
Last two labs	Segments where the student refers to the last two lab and assessments for EM114	'up to …the second last two labs the only time I didn't write my own code because it was just a lot of code and we had a lot of other stuff to do so I didn't have time to do '	20
Ease of Use	Contains the segments that refer to the user experience	N/A	45

Name	Description	Sample Coded Segment	No. of segments
Difficult to use	Segments where students refer to difficulties they had with Matlab, and/or they did not follow what the code was doing	'we were told to change certain variables and other than that I didn't really change much because I didn't understand the code so I thought if I change more things it wouldn't work. I tried it a few times, but the graph just went completely crazy and it didn't work so I changed them back'	22
Easy to use	Segments where the student refers to being able to use Matlab successfully	'by playing around with it I think you learn a lot more how to use it.. when you are given … intro code it tells you a little bit about what's going on'	6
Not enough guidance throughout the module	Segments where students refer to needing more help to enable them use Matlab	'I wasn't really able to understand cos the code for integration is like two pages long and so it's just complicated. I don't know if it's overcomplicated but they gave us simplified version and I didn't understand it'	17
Usefulness	Created to represent whether students had identified its purpose or use or usefulness for the future.	N/A	30
Matlab use outside of EM114	Segments where students refer to either having used or never used Matlab outside of EM114	'you would do it out as a homework and then you could use Matlab to actually like check your answer'	7
Purpose and future use of matlab	Segments where students refer to being able to identify the purpose of Matlab within EM114 or how it might be used in the future	'…it's going to be useful because looking at the subjects in the next year,… there is digital signal processing, so you can use it for that and most likely we will be using it for that'	20

Appendix G **Ethics**

G.1 Ethics Documents

This researcher compiled and applied for ethics in both DCU and MU for each of the evaluations. The lecturers involved in the AIT and DkIT trials applied for ethics within their own institutions with this researcher as a named researcher within the project. A list of the applications made, by this researcher, and notification documents are given in Table G.1 below. Following this one copy of an Informed Consent Form and Participation Information Leaflet are provided as a sample.

Table G.1: Details of the ethics applications applied for by this researcher.

Institution	Trial Name	Type of Approval Sought	Year of Application	Date of notification approval	Documents associated with this application
Maynooth University	GeoGebra1 and UniDoodle1	Student Survey, Usage Data, Focus Group Interviews	2015/ 2016	November 2015	MU DRAFT Tier 1 application form Final_Revsion 1_CNS Approval Letter SRESC-2015-086- Caitriona Ni She
Maynooth University	GeoGebra2	Student Survey, Usage Data, Focus Group Interviews, Task Based Interviews	2016/ 2017	November 2016	MU Tier 1 application form _Nov_2016_CNS SRESC-2016-091-Caitriona Ni She Approval Letter
Dublin City University	UniDoodle2	Student Survey and Task Based Interviews	2015/ 2016	March 2016	REC_Notification_Form_DCU_Semester 2_CNS_50 DCUREC2016_050 C. Ni She & E. Ni Fhloinn & C. Brennan (Notification)
Dublin City University	KA3	Student Survey	2015/ 2016	November 2016	REC_V1_Final_Notification_Form_CNS-238 DCUREC2015_238 C. Ni She (Notification)
Dublin City University	Matlab	Student Survey, Focus Group Interviews	2017/ 2018	January 2018	CNS_V1_rec_full_form_Dec_2017_199

Institution	Trial Name	Type of Approval Sought	Year of Application	Date of notification approval	Documents associated with this application
					DCUREC2017_199 Caitriona Ni She (notification)

G.2 Plain Language Statement – sample from Matlab Trial

Appendix A: Plain Language Statement: Survey

Engagement with Technology-enhanced Resources for Mathematics Education.

You are being invited to take part in a research study being carried out at Dublin City University. This survey is part of a PhD research project being carried out by Caitríona Ní Shé under the supervision of Dr Eabhnat Ní Fhloinn, School of Mathematical Sciences, DCU and Dr Ciarán Mac an Bhaird, Maynooth University. Dr Conor Brennan, School of Electronic Engineering, DCU, has agreed that this research can be carried out as part of his involvement with modules EM122 Engineering Mathematics II and EM114 Numerical problem solving for engineers. Caitríona Ní Shé, PhD student in the School of Mathematical Sciences, will carry out the research.

The overall aim of this research is to explore in what way, and how effectively, students use selected technology enhanced resources to support their learning of mathematics.

The outcomes of this research will inform mathematics educators on how best to design, develop and implement technology-enhanced resources. The research will increase our knowledge about how students engage with technology-enhanced resources and will inform practice in the field.

As part of your attendance on the EM114 module you were given access to Matlab to help solve numerical problems. The purpose of this survey is to evaluate the usefulness of this resource.

The survey is completely anonymous: we will not know which students provided which answers. This will ensure complete privacy of your responses. The survey results will only be used for the purposes of the research project. It is not envisaged that there are any risks to participants arising from involvement in the study.

All survey material will be held anonymously and used solely for research purposes. All data collected will be stored in a secure, confidential and anonymous manner on a password protected PC and will be destroyed after a 5 year period after completion of the project.

At any point during the completion of the survey you can withdraw from the research study. Findings will be available on a central website and will be forwarded to participating classes as a group, whether you partake or not.

For further details, including any questions about the results of this survey and the project as a whole, please contact:

Eabhnat Nί Fhloinn

School of Mathematical Sciences

Room X138A

extn. 7710

eabhnat.nifhloinn@dcu.ie

If you have any concerns about this study and wish to contact an independent person, please contact:

The Secretary,

Dublin City University Research Ethics Committee,

c/o Office of the Vice-President for Research,

Dublin City University,

Dublin 9.

Tel 01-7008000

G.3 Informed Consent Form – Sample from GeoGebra focus group.

APPENDIX 5: Informed Consent Form: Focus Group Interview

Assessment for Learning Resources for First Year Undergraduate Mathematics Modules

Informed Consent Form

Researcher Name: Caitríona Ní Shé,

Researcher email address: CAITRIONA.NISHE.2015@mumail.ie

Supervisor Name: Dr. Ciarán Mac an Bhaird

Supervisor email address: ciaran.macanbhaird@maths.nuim.ie

Telephone number of Supervisor: (01) 7083992

Confirmation of particular requirements as highlighted in the Plain Language Statement

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me)Yes/ No

I understand the information providedYes/ No

I have had an opportunity to ask questions and discuss this study Yes/ No

I have received satisfactory answers to all my questions Yes/ No

I am aware that my interview will be audiotapedYes/ No

I am aware that I may withdraw from the Research Study at any point. Yes/ No

Data Confidentiality: Audio recordings of the interviews will be transcribed and will not be made available to anyone outside the project team. All identifying characteristics of individuals, such as voice, are removed from the data during transcription before it is analysed.

All data collected will be stored in a secure, confidential and anonymous manner on a password protected PC and will be destroyed after a 10 year period after completion of the project. Findings will be available on a central website and will be forwarded to participating classes as a group, whether you partake or not.

'It must be recognized that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.'

Focus Group Interviews: The interview will take no longer than 45 minutes and will be held in the Department of Mathematics and Statistics at a mutually suitable time.

Participation is voluntary: you are not obliged to participate in the focus group interviews. There is no link between participation in this project and successful completion of any of your course modules.

6. **Contact for independent Advice:** If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the Maynooth University Ethics Committee at research.ethics@nuim.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner.

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project.

Participants Signature:

____

Appendix H **Usage**

The use of the NF-funded project resources was recorded for each trial. Details of the data recorded and the value calculated for usage are given in the sections below.

H.1 UniDoodle Usage

In the case of UniDoodle1, the lecturer observed that all 12 students engaged in this activity regularly. In the UniDoodle2 survey, 83% of the students responded either Strongly Agree (SA) or Agree (A) in response to the item '*I used the UniDoodle app most times when it was used in class*'. Therefore, a 100% usage is recorded for usage in the UniDoodle1 trial and 83% in the UniDoodle2 trial.

H.2 GeoGebra Task Usage

The total number of hits per task (or URL) and the total number of students who accessed each individual GeoGebra task was counted, and the percentage of the total student cohort who accessed the tasks, were calculated. Table H.1 contains data for the GeoGebra1 trial and Table H.2 for GeoGebra2 trial.

Table H.1: Descriptive statistics for the number of hits in the GeoGebra1 trial.

GeoGebra task	**Total No. of Hits**	**No. of students (N=467)**	**% of students**
Total number of hits (sum of below)	6317	467	100%
Quiz: Derivatives Quiz*	3855	430	92%
URL: Inputting functions in GeoGebra	715	233	50%
URL: Vertical Line Test	279	198	42%
URL: Graphs of Inverse Functions	231	170	36%
URL: Finding limits for piecewise functions	187	133	28%
URL: Finding the graphs of cos(x), sin(x) and tan(x).	172	119	25%
URL: Horizontal Line Test	167	115	25%
URL: Horizontal and Vertical Asymptotes	162	113	24%
URL: Limits and continuity for piecewise functions	139	108	23%
File: The graph of y=sin(ox)	133	103	22%
URL: Infinite Limits	124	100	21%
File: The graph of y=ksin(x)	113	86	18%
URL: Zoom In	40	37	8%

*This task was graded and due on Friday 11th December 2015.

Table H.2: Descriptive statistics for the number of hits in the GeoGebra2 trial.

GeoGebra task	**Total No. of Hits**	**No. of Students (N= 396)**	**% of students**
All links below	5303	396	100%
SCORM package: Derivatives Quiz*	1605	345	87%
Page: Graph Transformations**	907	312	79%
SCORM package: Limits of Piecewise Functions*	1474	284	72%
URL: Using GeoGebra	644	239	60%
URL: Vertical Line Test	202	136	34%
Page: Horizontal and Vertical Asymptotes	170	111	28%
URL: Horizontal Line Test	202	102	26%
Page: Zoom	99	79	20%

*These tasks were graded and due on 28th October 2016 and 9th December 2016.

**Students were asked to use this task as a learning resource when completing a written assignment that was due on 21st October 2016.

H.2.1 GeoGebra1 usage pattern

In order to determine if there was a pattern of engagement relating to the dates graded assignments were due, the number of hits per day was calculated. . The number of hits per day, by task (or URL link), is displayed as in Figure H.2.1 for GeoGebra1, where higher access for the graded Derivatives Quiz coincided with the due dates.

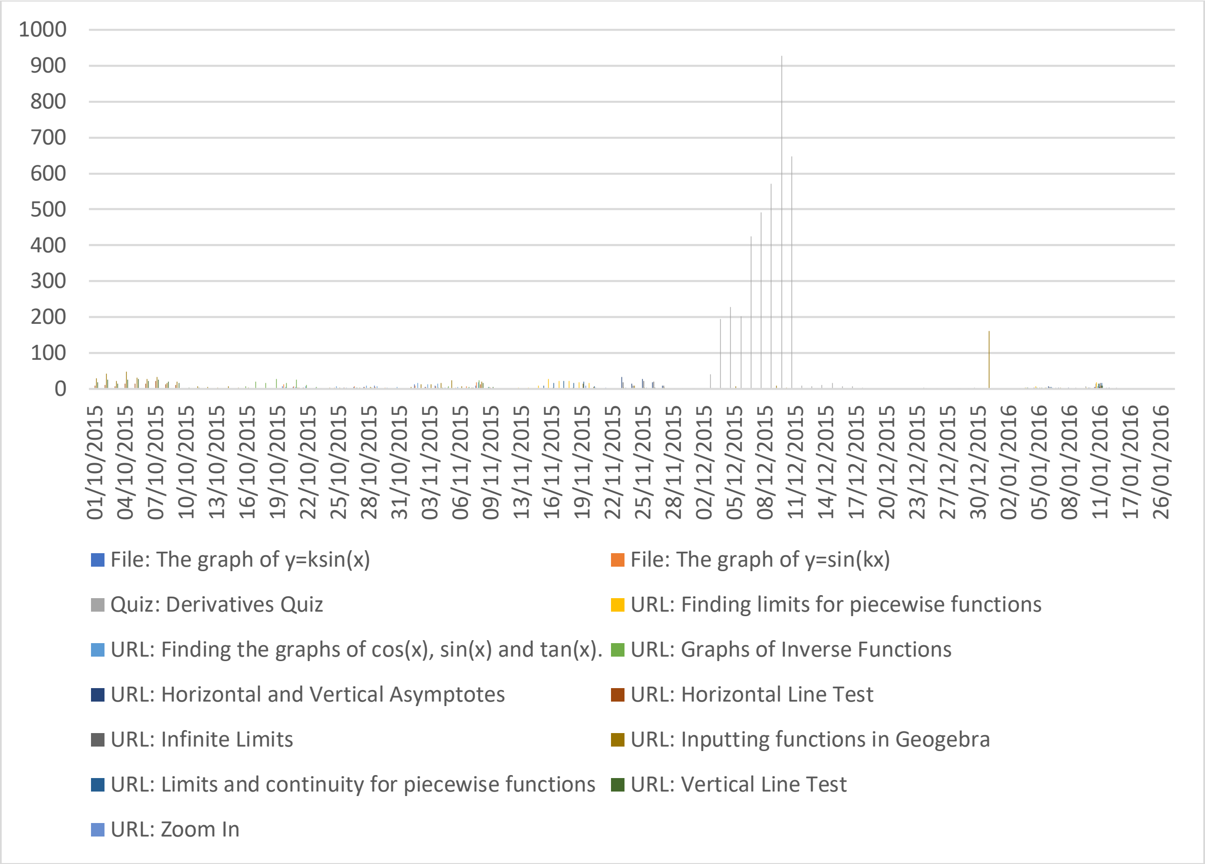


Figure H.2.1: Number of hits per day in the GeoGebra1 trial

H.3 Usage of the KA1 playlists

In the KA1 trial, students accessed the KA playlist through a specific Moodle module that was made available to them as an optional support. Usage data was retrieved from the Moodle logs. There were 175 students registered on the first-year computing programmes. Only 29 students (17%) accessed the KA playlists via Moodle, and there was a total of 780 hits to the KA playlist URLs.

H.4 Usage of the KA2 mastery challenges

In the KA2 trial, access to the KA was via the KA class application where Khan Academy Mastery Challenges were used. Students earned badges on completion of specific mastery challenges. Student usage was gathered using the log data provided in this KA class application. In this trial all, bar one student, registered and accessed the KA Mastery Challenges. This application was used in a tutorial class once a week under the supervision of the lecturer, and students also had access to it during their own time. Student usage data in the form of time spent on the various activities was available for each of the individual mastery challenges that were set by the lecturer. Table H.4 contains a summary of the time spent and badges earned for the group of 79 students.

Table H.4: Time spent and badges earned including central tendencies for each variable.

	Time Spent*	**Time Spent on Videos**	**Time Spent on Exercises and Challenges**	**Badges Earned**
Sum	39557.93	7428.45	30363.35	1193
Average	500.7333	94.03101	384.3462	15.10127
Max	2281.767	1581.567	1300.85	37
Min	12.91667	0	15.61667	1
Median	421.0167	32.76667	320.3333	15

*Time spent includes time spent on videos, exercises and challenges, and idle time between activities. Time was measured in minutes.

H.5 Usage of the KA3 playlists

In the KA3 trial, students were provided with access to a specific Moodle module containing the KA playlist URLs. Usage data was retrieved from the Moodle logs. In the KA Moodle module, students were first presented with an introductory page and then proceeded to the individual KA URL. As can be seen in Table H.5, the number of students who continued on to access a KA URL from the introductory page was small.

Table H.5: Activity report from the Moodle module during the KA3 trial, showing increased activity towards the exam held in late January 2016.

Date	**No. of students who accessed Introductory page in KA Moodle module (N=335)**	**No. of students who accessed at least 1 KA URL prior to date listed**
Jan 5th	133	14
Jan 11th	158	25
Jan 18th	182	37

H.6 Usage values calculated for all of the NF-funded resource trials

The final values recorded for the usage of the resources was calculated as the percentage of students who engaged with a resource in any way. This was considered by the team as the best way to report usage and reflects decisions made in similar studies (Howard et al., 2018; Trenholm et al., 2019). A copy of the table produced for Chapter 5 is reproduced below.

Table H.6: Percentage of students who accessed the resources during the time the resource was available.

Trial	% students who engaged in any way with resource
UniDoodle1 (n=12)	100%
UniDoodle2 (n=165)	83%
KA1 (n=175)	17%
KA2 (n=80)	99%
KA3 (n=335)	10%
GeoGebra1 (n=467) Graded Task	92%
GeoGebra2 (n=467) Non-Graded Task	50%
GeoGebra2 (n=396) Graded Task	87%
GeoGebra2 (n=396) Non-Graded Task	60%

Appendix I **Student survey**

I.1 Background Data of students who responded to the survey

In total, 637 students responded to the survey, almost 39% of the total student population involved in the trials. Background data relating to gender, mature student status and prior mathematics level was recorded. This is illustrated below in Table I.1.

Table I.1: Background data relating to the students who took the surveys.

Name of trial	**Total**	Gender		Mature Student		Level of Mathematics completed in the Leaving Certificate			
		Male	**Female**	**No**	**Yes**	**Higher**	**Ordinary**	**Foundation**	**Did not take LC maths**
KA1	115	107	8	97	17	18	81	11	5
KA2	37	Not asked	Not Asked	32	5	7	26	3	1
KA3	108	63	43	107	1	56	51	0	1
UniDoodle1	12	9	3	10	2	10	1	0	0
UniDoodle2	98	75	22	95	2	92	0	4	0
GeoGebra1	46	23	23	37	9	34	12	0	0
GeoGebra2	221	114	100	202	16	143	74	2	2

I.2 Fisher Exact Results for Common Survey Items.

Fisher exact tests were used to compare the distribution of responses (SA, A, N, D and SD) for the trials. The comparisons where significant differences were found are contained in Table I.2.1 (different resource types) and Table I.2.2 (different trials of the same resource types) below.

Table I.2.1 Significant differences found by Fisher tests comparisons between different resource types

Trial 1 (more positive response)	**Trial 2**	**Item**	**P value**
UniDoolde2	KA1	Resource Useful	p<0.001
UniDoodle2	GeoGebra2	Easy to Use	p<0.001
UniDoodle2	KA1	Easy to Use	p<0.001
UniDoodle2	KA2	Easy to Use	p<0.001
UniDoodle2	KA3	Easy to Use	p<0.001
UniDoodle2	GeoGebra1	Enhanced Learning	p=0.001
UniDoodle2	GeoGebra2	Enhanced Learning	p=0.006
UniDoodle2	KA1	Enhanced Learning	p<0.001

UniDoodle2	GeoGebra1	Increased Confidence	p=0.001
UniDoodle2	GeoGebra2	Increased Confidence	p<0.001
UniDoodle2	KA1	Increased Confidence	p=0.021
UniDoodle2	GeoGebra1	Resource Useful	p=0.001
UniDoodle2	GeoGebra2	Resource Useful	p=0.004
UniDoodle2	KA3	Resource Useful	p=0.007
UniDoodle1	KA1	Resource Useful	p<0.001
UniDoodle1	GeoGebra2	Easy to Use	p<0.001
UniDoodle1	KA1	Easy to Use	p=0.033
UniDoodle1	KA3	Easy to Use	p<0.001
UniDoodle1	KA1	Enhanced Learning	p<0.001
UniDoodle1	KA3	Enhanced Learning	p=0.016
UniDoodle1	GeoGebra1	Increased Confidence	p=0.006
UniDoodle1	KA1	Increased Confidence	p=0.001
UniDoodle1	KA3	Increased Confidence	p=0.013
UniDoodle1	GeoGebra1	Resource Useful	p=0.011
UniDoodle1	GeoGebra2	Resource Useful	p<0.001
UniDoodle1	KA2	Resource Useful	p=0.024
UniDoodle1	KA3	Resource Useful	p<0.001
KA3	GeoGeobra2	Easy to Use	p=0.044
KA2	GeoGebra2	Easy to Use	p=0.013
KA2	UniDoodle2	Enhanced Learning	p=0.001
KA2	UniDoodle2	Increased Confidence	p=0.013
KA1	GeoGebra2	Easy to Use	p<0.001
GeoGebra2	KA1	Enhanced Learning	p<0.001
GeoGebra2	KA1	Increased Confidence	p<0.001
GeoGebra2	KA3	Increased Confidence	p=0.010
GeoGebra2	KA1	Resource Useful	p=0.005
GeoGebra1	KA1	Easy to Use	p=0.001
GeoGebra1	KA3	Easy to Use	p<0.001
GeoGebra1	KA1	Enhanced Learning	p=0.019
GeoGebra1	KA3	Increased Confidence	p=0.007
GeoGebra1	KA1	Resource Useful	p=0.023
GeoGebra1	KA3	Resource Useful	p=0.002

Table I.2.2 Significant differences found by Fisher tests comparisons between same resource types

Trial 1 (more positive response)	**Trial 2**	**Item**	**P value**
KA3	KA1	Enhanced Learning	p=0.007
KA1	KA3	Easy to Use	p=0.009
KA3	KA1	Increased Confidence	p=0.015
KA3	KA1	Resource Useful	p=0.010
KA2	KA3	Enhanced Learning	p=0.000
KA2	KA3	Easy to Use	p=0.005

KA2	KA3	Increased Confidence	p=0.034
UniDoodle2	UniDoodle1	Enhanced Learning	p=0.016
UniDoodle2	UniDoodle1	Increased Confidence	p=0.008
UniDoodle2	UniDoodle1	Resource Useful	p=0.031
GeoGebra1	GeoGebra2	Easy to Use	p=0.000
GeoGebra1	GeoGebra2	Resource Useful	p=0.028

Appendix J **Rasch Analysis**

Rasch Analysis is a branch of Item Response Theory (see Edwards and Alcock (2010) and Bond and Fox (2007) for good introductions to this area). The Rasch Model assumes unidimensionality (consideration of a single trait); that is that it can be used to validate that a set of questions or items measures a single construct. Winsteps software was used to conduct the analysis and compute a range of fit statistics to check that the scales yielded reliable measures. This analysis was completed by Dr. Ann O'Shea of Maynooth University.

J.1 UniDoodle1 and 2 Rasch analysis

The UniDoodle1 and UniDoodle2 surveys had many items in common (see Table A.2 for a list of the items) and this allowed the grouping of the item statements into three scales: Formative Assessment, Ease of Use, and Learning and Engagement. Rasch Analysis was used to validate these scales and to create measures for each student on each scale.

To begin with, the infit and outfit statistics for each item on each scale were calculated. These are weighted and un-weighted mean square residuals respectively. Their value should be close to 1 and values between 0.6 and 1.4 are acceptable for Likert- type items (Edwards & Alcock, 2010, p. 73). Table J.1 below has the items for the Formative assessment scale, their measures, infit and outfit statistics, plus point-measure correlation (equivalent to the point biserial correlation - this measures the correlation between scores on an item with the average scores on the remainder of the test). Point-measure correlations should be greater than 0.3.

Table J.1: Fit Statistics and Measures of Items on the Formative Assessment Scale.

Item	Measure	Infit MNSQ	Outfit MNSQ	Point Measure Correlation
17	0.14	1.07	1	0.72
18	-0.82	1.03	1.06	0.64
20	0.61	1.04	0.96	0.7
22	0.29	1.08	1.13	0.62
23	-0.37	0.91	0.87	0.73
24	0.14	0.94	0.9	0.67

Note: the measures here describe how difficult the item is to disagree with (because 1 and 2 were coded as "agree", and 4 and 5 as "disagree") or equivalently how easy it is to agree with. So items with large negative measures are the ones the respondents found easiest to agree with.

Some other statistics that can help decide if a scale is reliable or not are the person and item reliability indices. The item reliability index estimates the chances of getting the same item measure ordering if the questionnaire was given to a similar group of students. This index is given on a scale running from 0 to 1. The person reliability index estimates how robust the person ordering would be if a similar test was used with the same group of students, and it is similar to the Cronbach alpha statistic. The item reliability for the Formative assessment scale was 0.88, the person reliability was 0.76. (It is advisable that these numbers be above 0.7).

The results of similar analysis for the other two scales can be seen in Tables J.2 and J.3. Note that on both of these scales, one extra item had been included but the fit statistics indicated that these items did not measure the same quantity as the other scale items so they were removed. When this was done, the item reliability for the Ease of Use scale was 0.95 and for the Learning and Engagement scale was 0.98; the person reliabilities for these two scales were 0.71 and 0.82 respectively.

Table J.2: Fit Statistics and Measures of Items on the Ease of Use scale

Item	Measure	Infit MNSQ	Outfit MNSQ	Point Measure Correlation
25	1.02	0.95	0.84	0.69
26	0.34	0.79	0.78	0.76
28	0.31	1.36	1.26	0.68
29	-0.18	0.93	0.93	0.74
30	-1.5	1.14	1.19	0.73

Table J.3: Fit Statistics and Measures of Items on the Learning and Engagement scale.

Item	Measure	Infit MNSQ	Outfit MNSQ	Point Measure Correlation
6	1.52	1.05	0.92	0.5
7	0.55	0.82	0.79	0.68
8	1.89	1.27	1.03	0.46
9	-0.63	1.22	1.26	0.59
11	-1.98	1.11	1.19	0.62
12	-0.38	1.24	1.14	0.7
13	0.45	1.09	1.03	0.54
14	0.87	0.73	0.65	0.72
15R	-0.88	1.35	1.46	0.61
19	-0.38	0.72	0.82	0.61
21	-0.22	0.73	0.76	0.63
41	-0.81	0.74	0.75	0.63

Since all three scales are reliable, the measures for each student on each scale were computed. This analysis allowed the comparison of the two groups of students. See Table J.4 and Table J.5.

Table J.4: Summary data for the scales.

Descriptive Statistics

	Institution	N	Mean	Std. Deviation	Std. Error Mean
Formative Assessment Measure	UniDoodle 2	98	-1.8188	1.65113	.16679
	UniDoodle 1	12	-3.4325	1.25283	.36166
Ease of Use Measure	UniDoodle 2	98	-2.7232	2.00247	.20228
	UniDoodle 1	12	-2.8842	1.88267	.54348
Learning and Engagement Measure	UniDoodle 2	98	-1.1997	1.17566	.11876
	UniDoodle 1	12	-2.4067	.80106	.23125

Table J.5: Comparison of the UniDoodle 1 and UniDoodle 2 groups.

t-test for Equality of Means

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Formative Assessment Measure	3.267	108	.001	1.61372	.49395	.63463	2.59282
Ease of Use Measure	.264	108	.792	.16100	.60880	-1.04575	1.36775
Learning and Engagement Measure	3.452	108	.001	1.20697	.34961	.51398	1.89997

We see from the t-tests for equality of means that there is no significant difference between the mean scores of the UniDoodle1 and UniDoodle2 cohorts on the Ease of Use measure, in fact both groups found the UniDoodle resource easy to use. There are statistically significant differences between the means of the groups on the Formative Assessment and the Engagement scales. In both cases, the UniDoodle1 students are more positive about the use of UniDoodle (note as “strongly agree” was coded at 1 and “strongly disagree” as 5, negative measure correspond to agreement with the statements and vice versa).

J.2 KA2 and KA3 Rasch Analysis

A learning scale measure was compiled for the KA2 and KA3 trials using items 14, 15, 16, 17 and 18 from the surveys. See Tables A.4.2.4 (Q10, Q15-18, Q20) and A.4.2.5 (Q14-Q18) for list of items. Note in KA2, Q15 and Q16 were amalgamated into one item, and all items relabelled to match the KA3 items. The infit and outfit statistics were calculated. See Table J.6.

Table J.6: Fit Statistics and Measures of Items on the Learning Scale.

Item	Measure	Infit MNSQ	Outfit MNSQ	Point Measure Correlation
14	-0.06	0.80	0.84	0.88
15	0.17	0.96	0.9	0.89
16	-0.36	1.41	1.46	0.79
17	-0.01	0.97	0.95	0.86
18	0.26	0.84	0.86	0.86

The person reliability for this scale is 0.86 and the item reliability is 0. The fit statistics for this scale show that item 16 has infit and outfit measures outside the recommended region so it was removed from the scale. Table J.7 has the details of the new scale.

Table J.7: Fit Statistics and Measures of Items on the Learning Scale (Q16 removed).

Item	Measure	Infit MNSQ	Outfit MNSQ	Point Measure Correlation
14	-0.18	0.99	1.08	0.88
15	0.10	1.05	1.00	0.90
17	-0.12	1.04	1.03	0.88
18	0.21	0.91	0.90	0.86

The items now have good fit statistics, but the person and item reliabilities are almost identical to the original (person reliability 0.85 and item reliability of 0). Since the infit and outfit statistics for item 16 are very close to the boundary value of 1.4 and the reliabilities do not improve when this question is taken out, it was left in. Table J.8 contains the summary statistics for this data.

Table J.8: Summary data for the KA Learning scale.

Descriptive Statistics

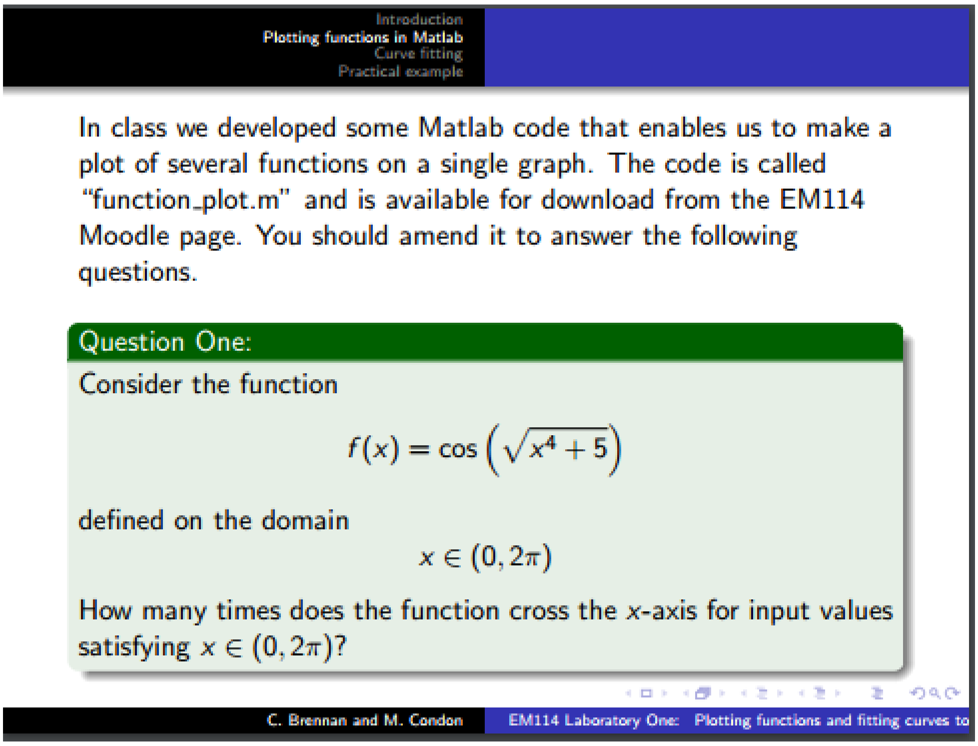
	Institution	N	Mean	Std. Deviation	Std. Error Mean
	DkIT	37	-1.9008	4.07489	.66991

Learning_measure_minus Q16	DCU	36	-.3808	2.39456	.39909
Learning_measure	DkIT	37	-1.3719	3.30833	.54389
	DCU	36	-.3208	2.05113	.34185

There was no significant difference between the means of the two groups on either of these scales.

Appendix K **Matlab Numerical Problems**

Students attending Module EM114 were required to solve numerical problems in a laboratory, using Matlab. Figure K.1 is an example of a problem posed to students as part of a laboratory.



Introduction
Plotting functions in Matlab
Curve fitting
Practical example

In class we developed some Matlab code that enables us to make a plot of several functions on a single graph. The code is called "function_plot.m" and is available for download from the EM114 Moodle page. You should amend it to answer the following questions.

Question One:

Consider the function

$$f(x) = \cos\left(\sqrt{x^4 + 5}\right)$$

defined on the domain

$$x \in (0, 2\pi)$$

How many times does the function cross the x-axis for input values satisfying $x \in (0, 2\pi)$?

C. Brennan and M. Condon   EM114 Laboratory One: Plotting functions and fitting curves to

Figure K.1: Sample problem to be solved using Matlab for students attending the EM114 module.