From STEm to steM: Developing the Landscape of Teacher Learning for STEM Education

by

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Abstract

The new Irish Primary Curriculum Framework introduces STEM as one of five broad curriculum areas, and publication of a STEM specification is imminent. Traditionally, STEM content has been taught as discrete disciplines across the sectors, with initial teacher education (ITE) being no exception. However, the new focus on integrated and interdisciplinary approaches has created an impetus to re-examine how we explore the STEM disciplines in ITE. This dissertation presents an action inquiry to prepare preservice teachers for the new demands of STEM education. Participants were two groups of preservice teachers (PSTs) (n=30 and n=28) undertaking a mathematics education specialism as part of their undergraduate programme. This dissertation reports on two 12-week integrated STEM interventions. While both modules differed in their approach, common themes were generated throughout.

Findings across both modules indicate that purposefully designed, interdisciplinary STEM education experiences at the ITE level can create informed, confident STEM teachers ready to take on new integrated teaching roles. Opportunities to engage as learners of integrated content supported participants in developing the required STEM literacies and exposed them to the rich and ambitious pedagogies necessary for effective classroom implementation. Collaborative field practices corroborated this learning as they witnessed theory play out in practice and observed the benefits for children. Challenges were also noted as the PSTs negotiated the blurry boundaries of STEM education. This dissertation reports on the difficulties in positioning meaningful mathematics within integrated tasks. Responsive to these challenges in the first iteration of this module, the subsequent design forefronted mathematics as the central discipline. Journeying with these preservice teachers from the lecture room to the primary classroom and back allowed me to examine their evolving understanding of STEM education over time and observe the development of their STEM teacher identities. Implications for ITE and STEM education are discussed.

Declaration

I hereby declare that this dissertation represents my own work and has not been submitted in whole or in part, by me or another for the purpose of obtaining a qualification at any university or third level institution. I am the author of this dissertation and the principal author/co-author of the five articles which form its core.

Signature: 

Michelle Fitzpatrick

Date: 1st May 2024

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Dedication

To my wonderful children, Bill and Róisín,

Although I'm sure you will never read it, this is for you. Thank you for your patience while I was distracted, burned dinners and picked the shortest bedtime stories. I promise to do better now that 'Mom's big project' is finished.

Love always,

Mom

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List of Abbreviations

CODAP	Common Online Data Analysis Platform
DCG	Design and Communication Graphics
DE	Department of Education
DES	Department of Education and Skills
EB	Emerging Bilingual
EDP	Engineering Design Process
EU	European Union
GOI	Government of Ireland
IASE	International Association for Statistics Education
ICMI	International Commission on Mathematical Instruction
IES	Irish Educational Studies
ITE	Initial Teacher Education
IJMEST	International Journal of Mathematical Education in Science and Technology
JSDSE	Journal of Statistics and Data Science Education
MIREC	Mary Immaculate Research Ethics Committee
NCCA	National Council for Curriculum and Assessment
NCTM	National Council of Teachers of Mathematics
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
PD	Professional Development
PDST	Professional Development Service for Teachers
PISA	Programme for International Student Assessment
PST	Preservice Teacher
SATS	Survey of Attitudes Towards Statistics
SE	STEM Educator
SERJ	Statistics Education Research Journal
SFI	Science Foundation Ireland
STE	Science, Technology and Engineering
STEAM	Science, Technology, Engineering, Art and Mathematics
STEM	Science, Technology, Engineering and Mathematics
TEL	Technology Enhanced Learning
TG	Technical Graphics
UDL	Universal Design for Learning
UNICEF	The United Nations International Children's Emergency Fund

Research Communications

Commissioned reports

Leavy, A., Carroll, C., Corry, E., **Fitzpatrick, M.**, Hamilton, M., Hourigan, M., LaCumbre, G., McGann, R. & O'Dwyer, A. (2022). *Review of Literature to Identify a Set of Effective Interventions for Addressing STEM and the Arts in Early Years, Primary and Post Primary Education Settings*. A report commissioned by the Department of Education. Available at https://www.gov.ie/pdf/?file=https://assets.gov.ie/96986/f05f7b2f-e175-442e-85e9-4a2264391843.pdf#page=null

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Peer-reviewed Journal Articles

Fitzpatrick, M. (2024). Drawing the past to envision the future: Supporting the development of primary STEM teacher identity. *Irish Educational Studies*. http://dx.doi.org/10.1080/03323315.2024.2359693

Fitzpatrick, M. & Leavy, A. (accepted for publication). Reciprocal interplays in becoming STEM learners and teachers: preservice teachers' evolving understandings of integrated STEM education. *International Journal of Mathematics Education in Science and Technology*

Fitzpatrick, M., Leavy, A., & Hourigan, M. (under review). "Rather than Simply Learning Statistics, We Aimed to Learn About the Bees, From the Bees": An Exploration of the Factors Influencing the Development of Positive Teacher Attitudes Towards Statistics, *Journal of Statistics and Data Science Education*

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Peer-reviewed book chapter

Fitzpatrick, M., Cleary, C. & Leavy, A. (2024). Mathifying STEM or STEMifying Math? Challenges and possibilities for mathematics learning within integrated STEM contexts. In J. Anderson & K. Makar. (Eds.), *The Contribution of Mathematics to School STEM Education: Current Understandings* (pp. 113-133). Springer. https://doi.org/10.1007/978-981-97-2728-5_7

Published conference proceedings

Fitzpatrick, M. (2023, October 13-14). Mathematics for STEM and from STEM: Conceptualising successful mathematics integration in STEM education. In A. Twohill & S. Quirke (Eds.) *Proceedings of the Ninth Conference on Research in Mathematics Education in Ireland (MEI9).* DCU, Dublin. https://zenodo.org/doi/10.5281/zenodo.10062839

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Fitzpatrick, M. (2024, April 4-6). *'I want to be known as the teacher who does STEM': Supporting the development of STEM teacher identity* [Paper]. Education Studies Association of Ireland (ESAI) Conference: Education for more just societies: the roles of imagination, innovation and collaboration, Maynooth University, Ireland.

Leavy, A., Hamilton, M., Hourigan, M., **Fitzpatrick, M.**, Carroll, C., Corry, E., & McGann, R. (2024, April 4-6). *Revealing the features of effective STEAM practice: Using systematic review to demystify the acronym* [Paper]. Education Studies Association of Ireland (ESAI) Conference: Education for more just societies: the roles of imagination, innovation and collaboration, Maynooth University, Ireland.

Leavy, A., Hourigan, M., & **Fitzpatrick, M.**, Treacy, M., & Harmon, M. (2024, April 4-6). *"Thank you! Hope this helped": The voices of children about their experiences of primary mathematics* [Paper]. Education Studies Association of Ireland (ESAI) Conference: Education for more just societies: the roles of imagination, innovation and collaboration, Maynooth University, Ireland.

Chapter 1: Introduction

1.1 Introduction

This article-based dissertation examines preservice primary teachers' (PSTs) evolving understandings of integrated STEM (Science, Technology, Engineering and Mathematics) education and their emerging STEM teacher identities. Using action research inquiry, this study also seeks to identify characteristics of effective learning experiences that contribute to developing STEM-literate PSTs. Chapter 1 sets this research in context by providing the background and rationale for this study. The aims and objectives of the research project are presented. The structure of this dissertation is outlined, and the fundamental components of each chapter are identified.

1.2 Personal statement

Having graduated with a Bachelor of Education in 2006, I worked as a primary school teacher until 2017, before taking up a seconded position with (the then-named) Professional Development Service for Teachers (PDST). I initially began the role as a *Primary Numeracy Advisor*. However, the mathematics team soon became the *Primary STEM* team in line with educational policy development. The team's initial efforts centered around the reintroduction of professional development (PD) in the area of *science*; a subject that had not been offered by the Department of Education support services since the introduction of the 1999 science curriculum.

While relatively comfortable with the subject area of science, the term "STEM education" was new to me. As we grappled with the policy documents and literature, and received some initial training in the area, I struggled (as did the team) to reach a shared understanding and conceptualisation of the term. Furthermore, while I had become more confident as a mathematics teacher-educator, I questioned how well I was positioned (with just a developing understanding of STEM education), to offer support to teachers and schools in this emerging area. In an effort to upskill and improve my own STEM literacy, I sought further professional development in the field. I was drawn to the MA in STEM Education at Mary Immaculate College and audited the STEM education modules on that programme in 2019/2020. I was immersed in rich conversations about key STEM pedagogies and perspectives, issues of policy and participation, and the role of community outreach and engagement. By engaging with lecture material and current research literature, hearing about my peers' experiences of implementing what they were learning in their own classroom, and engaging with teachers during in-school support within my own role, my understanding of STEM education and what it could look like in practice began to develop.

As my understanding grew, so too did my curiosity. As each experience answered one of my many 'STEM education questions,' it raised another. It was evident that integrated STEM education posed many challenges for educators and teacher educators globally. STEM education held huge potential for rich teaching and learning in the classroom. Yet, what that would look like in an Irish classroom, without a designated curriculum for guidance, was proving difficult for teachers. There was certainly an enthusiasm for such approaches, yet constraints around curricular demands, teacher knowledge, space, resources, and time, kept integrated STEM education down the list of priorities. I too was trying to make sense of all this, as I developed my own STEM teacher identity (and, simultaneously, my STEM teacher-educator identity).

The MA in STEM Education also sparked my interest in research, and halfway through I applied for the Structured PhD in Education. In September 2020, I began working as Teaching Fellow in Science Education within the Department of STEM Education at Mary Immaculate College, and the following year became a Teaching Fellow in STEM Education. Working primarily in mathematics education, my curiosity continued to develop. I had always been interested in the affective domain, and how a teacher's beliefs and attitudes influence their practice and vice versa. However, as I was now working in the field of initial teacher education (ITE), my population of interest shifted from in-service to preservice teachers. Just as I had wanted to improve my own practice as a PD facilitator, it became obvious that my research study should relate to, and inform, my practice in ITE.

A determining factor in devising the research questions in this dissertation was my participation in a collaborative research project with colleagues in the Department of STEM Education. Funded by the Department of Education (see Appendix A), this systematic literature review (Leavy et al., 2022) sought to identify effective interventions in STEM and the Arts across the early childhood, primary and post-primary education sectors. I worked on

Phase 2 with three other researchers, which involved hand-screening over 2000 publications. We were immediately confronted with the challenge of operationalising what was meant by "STEAM" or "STEM and the Arts". It further highlighted to me the difficulties posed by integrated approaches. If research in STEM and STEAM education was struggling to provide clarity on the integrated nature of the field, how could teachers be supported to enact meaningful integration in the classroom? By this point, it was also evident that curricular reform in Ireland was set to embrace integrated STEM as an official area in the primary curriculum, as outlined in the Draft Primary Curriculum Framework (National Council for Curriculum and Assessment (NCCA), 2020). An opportunity to coordinate a mathematics specialism module presented an ideal research site to examine ways in which we can support the development of integrated STEM teachers during ITE.

1.3 Rationale for this research

The past two decades have been marked by a growing momentum to advance STEM education nationally and internationally. Initially propelled by economic imperatives, Irish policy discourse at the beginning of this century focused on promoting STEM careers to feed and maintain the 'STEM pipeline' (e.g. Government of Ireland (GOI), 2006; 2009). A STEM Education Review Group, established in 2013, was tasked with reviewing STEM education in the Irish school system. This led to a series of consultations and reports, culminating in the introduction of specific 'STEM education policy' in Ireland, as evidenced by the *STEM Education Policy Statement* (Department of Education and Science (DES), 2017a) and the *STEM Education Implementation Plans* (DES, 2017b; GOI, 2023). STEM education policy sets out a vision that

> Ireland will be internationally recognised as providing the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence, and persistence, along with the excitement of collaborative innovation. (DES, 2017a, p.12)

To achieve this ambitious vision, the policy development and action areas are set across four pillars. Pillar 1 seeks to *nurture learner engagement and participation*; Pillar 2 is concerned with *enhancing early year education and teacher skills* and building capacity; Pillar 3 relates to the *support of STEM education practice*; while Pillar 4 acknowledges the need to *use evidence to support STEM education*. STEM education has continued to remain a focus of the educational policy landscape with commissioned work by the DE addressing *Gender Balance in STEM* (Goos et al., 2020) and *STEM and the Arts* (Leavy et al., 2022). These reviews, along with numerous other reviews, consultations and reports (DES, 2020; Department of Education (DE), 2022; 2023a; 2023b; 2023c), have led to the most recent *STEM Implementation Plan to 2026* (GOI, 2023), which sets out renewed targets and actions for STEM education in Ireland under the four key pillars.

STEM policy is now converging with curricular reform in Ireland. In line with the aims of STEM education, our new Primary Curriculum Framework "embodies society's broadly held view of what a curriculum should provide for our children as we look further into the 21st century" (NCCA, 2023a, p. 3). It recognises the fundamental role of education in preparing active citizens who are ready to contribute to local and global priorities. The Framework outlines seven key competencies central to children's learning to support the development of necessary knowledge, skills and dispositions needed to become empowered, critical decision-makers (see Figure 1.1).

Figure 1.1
Key Competencies (source: Primary Curriculum Framework (NCCA 2023a))

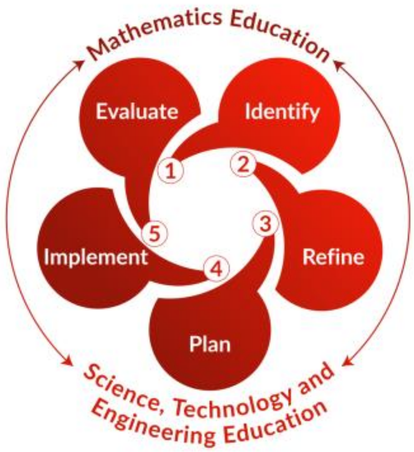
As illustrated in Chapter 2, these competencies echo many of the skills and dispositions promoted in the literature on STEM education. Indeed, the Framework positions STEM as one of five broad curriculum areas. This signifies the first inclusion of the term "STEM" in the Irish primary curriculum and highlights a commitment to STEM education in the primary sector. The Framework's broad curriculum areas, its embedding of key competencies and the move to a learning outcomes model recognise that children live in an integrated world where most problems require applying knowledge and skills from multiple areas. By advocating for more integrated approaches, the Framework encourages the use of "fruitful themes, interdisciplinary skills, big ideas, and real-world problems" as starting points for integrated learning and teaching (NCCA, 2023a, p. 26).

Indeed, the significance of these integrated approaches embedded in recent education policy and primary curriculum frameworks are echoed by children themselves. In a recent consultation with children and school communities on *STEM Education and the Primary School Curriculum* (NCCA, 2023b), children advocated for hands-on, discovery learning, experimentation and more outdoor learning activities. They sought more opportunities for collaboration and group work, recognising that "STEM learning is better done with others" (p. 21). We reported similar findings in a consultation with children on their experiences of learning mathematics (Leavy et al., 2023a; see Appendix B). The participants in this study (3rd – 6th class children) desired collaborative, student-led learning opportunities, including playful mathematical experiences. They were critical of an over-reliance on textbooks that led to a focus on drills and procedures, with senior classes challenging the perception that reform-based approaches are not relevant to them. They consistently communicated a desire for more engaging learning approaches to promote their interest in and enjoyment of mathematics. Central to this was a keen awareness of the role of context in mathematics. Children took great joy in describing classroom experiences that used a rich context to situate mathematical learning, demonstrating a keen appreciation for the role of mathematics in everyday life. High value was attributed to mathematics strands with the most real-world relevance for them. In contrast, children tended to devalue strands for which they could not recognise a real-world application. Therefore, a strong mandate was evident across classes for more meaningful and context-driven mathematics to be used in schools. With its focus on collaborative, real-world problem solving, integrated STEM education provides a framework that responds to these demands (such potential is further discussed in Chapters 2, 5 and 6).

The most recent addition to this evolving curriculum landscape is the publication of the Draft Science, Technology and Engineering Education Specification for primary and special schools for consultation (NCCA 2024). The rationale for the STE specification recognises children's natural curiosity and affinity for investigation, design and creation. It aspires to support children's understanding of the world, by connecting with their experiences and interests, drawing on real-world problems and contexts. The STE curriculum aims to nurture agency in children by promoting decision-making, risk-taking, adaptability and resilience. Not only does this document outline a revised science curriculum, it represents the first official curriculum inclusion of the strands *Technology* and *Engineering* within Irish primary education. This is supported through the key pedagogical practices identified in the specification, including *Scientific Inquiry, Design Thinking* and *Computational Thinking.* Furthermore, it sets a mandate for STEM in the classroom, through both the inclusion of the strand *Nature of STEM,* and the addition of a framework for the inclusion of *Integrated STEM* in the classroom. The draft specification posits integrated STEM learning as an opportunity for children to connect their learning across the four disciplines. While *mathematics* has its own published curriculum document, it is envisaged that once published the *STE curriculum* will "sit alongside the Primary Mathematics Curriculum (NCCA 2023c) to comprise the new primary Science, Technology, Engineering and Mathematics (STEM) curriculum area" (NCCA, 2024, p.1). Integrated STEM will offer opportunities to "apply, reinforce and consolidate the knowledge and skills they have acquired" in the other disciplines (p.28). By promoting integrated STEM in the primary classroom, the proposed curriculum seeks to: support active problem-solving that requires the application of science, technology, engineering and mathematics; promote ethical and responsible approaches to STEM that strive for sustainability; support children in fostering a *STEM mindset* by providing experiences that demand the consideration of alternative perspectives; and develop children's *STEM literacy* through meaningful learning experiences that allow for the connection and application of STEM knowledge, in turn preparing children for active participation in society. To support the enactment of such ambitious aims in the classroom, the draft curriculum frames an approach to integrated STEM learning through five phases (as illustrated in Figure 1.2), from identifying a problem of interest and a focus for investigation, through a cycle of planning, implementation and evaluation.

Figure 1.2

An approach to integrated STEM learning (from NCCA, 2024, p. 29)



While there is general agreement on the benefits of high-quality integrated STEM experiences, such as the development of problem-solving skills, the strengthening of productive dispositions and the enhancement of key competencies (detailed in Chapters 2, 3 and 4), there is also evidence to suggest that poor integrated STEM teaching "damages prospects for both disciplinary learning and learning of transversal skills" (Murphy et al., 2023, p.8). Despite teachers' reported enthusiasm for STEM education, many feel ill-prepared for integrated approaches (Hourigan et al., 2022; Shernoff et al., 2017). The challenges of integrated STEM are well documented (O'Dwyer et al., 2023; Margot & Kettler, 2019; Nesmith & Cooper, 2019) with common barriers for teachers cited such as curriculum overload, teachers' own subject content and pedagogical knowledge, and concerns about how to effectively integrate the STEM areas. Another challenge identified in the literature, relates to maintaining a balance between the disciplines in integrated STEM (English, 2016), with teachers reporting significant difficulties in incorporating authentic interdisciplinary mathematics (Arnone & Hanuscin, 2018; Tytler et al, 2019, 2023).

To date, there has been a gap between policy, curriculum and classroom practice (Hourigan et al., 2022). While the gap between policy and curriculum may be closing, teachers need support in shifting from traditional, teacher-centred practices to inquiry-, project-, and problem-based approaches associated with STEM education (McLoughlin et al., 2020). We are reminded that despite the global turn to STEM (Freeman et al., 2019), STEM education itself is an embryonic area of research (English, 2016; Goos, 2023). In a vastly under-theorised field (Rennie et al., 2020), there remains a dearth of research on STEM teaching and STEM teachers (Li & Anderson, 2020; Margot & Kettler, 2019). This is particularly relevant in terms of primary teacher education, with Corp et al. (2020) alerting the research community that research on every aspect of elementary STEM teacher preparation is needed.

1.4 Conceptualisation of integrated STEM education

Integrated STEM in this dissertation is generally conceptualised as the integration of two or more of the STEM disciplines (Honey et al., 2014; Murphy et al., 2023; Sanders, 2009), driven by a real-world problem (Kelley & Knowles, 2016; Roehrig et al., 2021; Stohlmann et al., 2012) to enhance the development of much needed 21st century skills (Beswick & Fraser, 2019; Maass et al., 2019; Stehle & Peters-Burton, 2019; Bybee, 2013). However, as will be highlighted in Chapter 9, my own conceptualisations and understandings of integrated STEM education have evolved over the course of the studies that make up this dissertation. This is discussed in section 9.2.4.

1.5 Research aims

This dissertation responds to Corp et al.'s (2020) call for more evidence into the types of field experiences and in-class activities that are "most proficient in preparing elementary teachers to effectively teach integrated STEM" (p. 346). The research also aims to contribute to the new policy pillar actions as laid out in the *Implementation Plan to 2026* (GOI 2023) by;

- Pillar 1: Supporting primary preservice teachers (PSTs) to design and implement integrated STEM lessons that *nurture learner engagement and participation* (Chapters 4 and 5) particularly in relation to underrepresented groups (Emerging Bilingual learners, Chapter 6).
- Pillar 2: To *build teacher capacity* for integrated STEM during Initial Teacher Education (ITE) (Chapters 4-8)

- Pillar 3: To *support STEM education practice* by cultivating a STEM culture during ITE that enables PSTs to become active and reflective STEM learners and teachers (Chapters 4-8)
- Pillar 4: To contribute to the *evidence base to support STEM education* by providing empirical findings on STEM teacher education (Chapters 4, 7 and 8) and classroom innovations (Chapters 5 and 6) that will “inform practice and contribute to the ongoing development of curriculum, policy and teacher education” (GOI, 2023, p.23).

This dissertation’s research problem, research aims, and chapter alignment are presented in Figure 1.3.

Figure 1.3

Aligning research problem, aims and dissertation chapters

Research Problem:

- Integrated STEM education is fast becoming an integral part of our primary school curriculum. Despite the advocacy for STEM in national and international policy discourse and the growth of STEM education as a research field, we know very little about preparing teachers for the inevitable demands of integrated STEM teaching and learning
- There is a call for more evidence on what is being done, and more research into what is effective in preparing STEM literate PSTs (Corp et al., 2020; Shernoff et al., 2017)
- The recent publication of the Primary Mathematics Curriculum (NCCA, 2023c) due for implementation in September 2024, has just been followed by the publication of a new draft *STE Education* specification (NCCA, 2024) for consultation. When published, it is envisaged that the *STE curriculum* will "sit alongside the Primary Mathematics Curriculum to comprise the new primary Science, Technology, Engineering and Mathematics (STEM) curriculum area" (NCCA, 2024, p.1). Given the underrepresentation of mathematics as one of the four disciplines in STEM (English, 2016; Fitzallen, 2015), and indeed the challenges teachers face in integrating meaningful mathematics teaching and learning in integrated STEM tasks (Tytler et al., 2019), more research is needed to examine effective ways of foregrounding the *M* in STEM

Research Aims (RA):

1. To examine PSTs' evolving understandings of integrated STEM education
2. To explore and support the development of PSTs' STEM teacher identity
3. To identify effective learning experiences that contribute to the development of PSTs' STEM literacy
4. To design a mathematics-focused integrated STEM intervention for PSTs that aims to maintain disciplinary balance, by foregrounding statistics education within the unit.
5. To measure the influence of an integrated STEM unit on PSTs' attitudes to statistics.

Publications/chapters that address research aim:

RA1: Chapters 4- 8

RA2: Chapter 8

RA3: Chapters 4,5,7,8

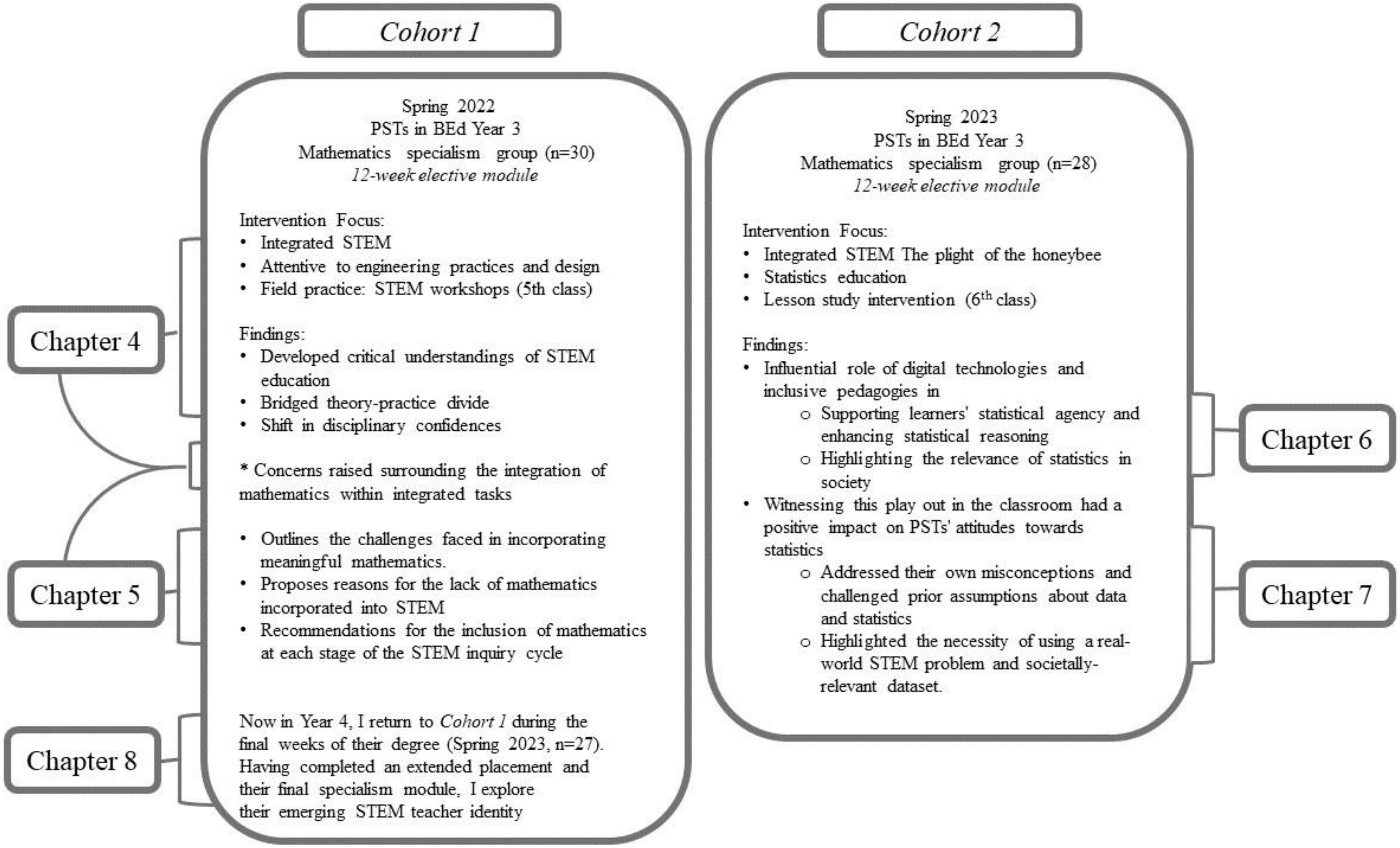
RA4: Chapters 6 and 7

RA5: Chapter 7

This dissertation presents five research publications reporting the findings of two separate teacher education interventions completed in academic years 2021/2022 and 2022/2023 (see Figure 1.4). Participants are two groups of mathematics education specialism students undertaking their studies in a department of STEM Education. *Cohort 1* undertook a 12-week specialism module focusing on integrated STEM in the third year of their undergraduate programme (Spring 2022). *Cohort 2* engaged in a modified version of this module the following year (Spring 2023), which sought to capitalise on key findings and reflections from *Cohort 1*. Therefore, this dissertation is grounded in action inquiry. *Action inquiry* has been described as any ongoing and empirically based attempt to improve practice; a cycle that involves "systematically oscillating between taking action in the field of practice, and inquiring into it" (Tripp, 2005, p.2). This study reports on several closely connected action inquiries. As this dissertation is interested in changing STEM teacher education "practices, how we understand them, and the conditions that shape them" (Kemmis, 2009, p.463), it adopts an action research approach. Taking a wide lens to the overall dissertation presents two action research cycles (*Intervention 1* and *Intervention 2*). Through its cyclical, spiraled approach, action research was chosen as a means of introducing "change to practice and help refine understandings that create and connect to theory" (Whitehead, 2017, p.390). Each paper across Chapters 4-8 has specific embedded research questions which focus the grain size on a particular aspect of the research undertaken. Individual studies sought to garner insights into PSTs' evolving understandings of STEM education, key learning experiences that reportly led to these changes, their observations of integrated STEM in the classroom and their emerging STEM teacher identities. These insights in turn, informed the overall action research study by identifying challenges and opportunities for STEM teacher education, thus building on the cycles of inquiry, and by contributing to its overarching goal of improving practice in ITE. The research design and the rationale for its methodological considerations are presented in Chapter 3.

Figure 1.4

Overview of interventions and findings, and their associated chapters



1.6 Dissertation structure and objectives

This dissertation presents nine chapters and supplementary documents.

Chapter 1:

This chapter provides an introduction to the STEM educational landscape and offers a rationale for undertaking this study. The aims and objectives of the thesis are also included, and the thesis structure is outlined.

Chapter 2:

This chapter presents a critical review of the pertinent literature on STEM education, integration, STEM literacy and the positioning of mathematics in STEM education. It serves as a foundation for the individual studies within this dissertation. Relevant literature is further detailed within the context of each study.

Chapter 3:

Chapter 3 provides an overview of the research design and methodological considerations of this study. It outlines the data generation tools utilised within the study and provides a rationale for their use.

Chapter 4:

This chapter reports on a 12-week integrated STEM intervention designed for a group of third year PSTs enrolled in a mathematics education elective in Spring 2022 (referred to in this dissertation as *Cohort 1*). Using pre-/post intervention data from surveys and STEM task analysis documents, as well as reflective journal entries, the study reports on 30 PSTs' initial understandings of integrated STEM education and explores the evolution of their understandings across the intervention, discussing key learning experiences that reportedly led to these changes.

> **Article:**
> **Fitzpatrick, M.** & Leavy, A. (accepted for publication). Reciprocal interplays in becoming STEM learners and teachers: preservice teachers' evolving understandings of

integrated STEM education. *International Journal of Mathematics Education in Science and Technology*

Objectives:

- To examine what primary PSTs understand by integrated STEM education
- To explore the evolution of these understandings across a 12-week intervention
- To establish key learning experiences and features of the intervention, as identified by the PSTs, that contributed to these changes.

Chapter 5:

This chapter details the challenge of incorporating rich mathematical teaching and learning in integrated STEM tasks. Set in the same intervention as reported in Chapter 4, we detail the difficulties faced by *Cohort 1* during field work as they subsequently attempted to identify, and plan for, meaningful and appropriate mathematics integration.

Article:

Fitzpatrick, M., Cleary, C. & Leavy, A. (2024). Mathifying STEM or STEMifying Math? Challenges and possibilities for mathematics learning within integrated STEM contexts. In J. Anderson & K. Makar. (Eds.), *The Contribution of Mathematics to School STEM Education: Current Understandings*, (pp. 113-133). Springer. https://doi.org/10.1007/978-981-97-2728-5_7 **Objectives:**

- To outline the challenge of integration experienced by PSTs as they implement integrated STEM tasks in primary settings
- To retrospectively identify possible reasons for the lack of authentic mathematics teaching and learning during the STEM workshops
- To provide recommendations and suggestions for the purposeful integration of mathematics at each stage of the STEM inquiry cycle
- To offer a practical example of these recommendations by illustrating a worked example of a modified task.

Chapter 6:

This chapter reports findings from a second intervention, carried out 12 months later, in Spring 2023. It introduces a new group of third year PSTs (referred to as *Cohort 2* from this point). *Cohort 2* was also undertaking a mathematics specialism. Given the difficulties experienced by *Cohort 1* (Chapters 4 and 5), this module sought to position mathematics as the central discipline within an integrated STEM unit. A decision was made to nominate *statistics* as the mathematics strand that would lend itself to STEM integration. This chapter reports specifically on one of the five lessons designed and delivered as part of a Japanese Lesson Study cycle with 28 PSTs. It outlines the PSTs' and researchers' observations from the classroom and provides insight into the powerful role math action technologies can play in supporting young children's (particularly Emerging Bilingual Learners') statistical reasoning when analysing large non-traditional datasets, rooted in a sustainability context. By engaging children and PSTs in higher-order statistics education, this study successfully resituates mathematics as a central discipline in an integrated STEM task.

Article:

Leavy, A., Hourigan, M. & **Fitzpatrick, M.** (2024, in press). Exploring the plight of the honeybee: Using data sensors and CODAP to support emerging bilingual learners in reasoning about big statistical ideas. *Statistics Education Research Journal*

Objectives:

- To investigate the potential of statistics to act as a key integrator, allowing mathematics to take and maintain the lead role in an integrated STEM task.
- To examine how digital technologies support Emerging Bilingual Learners to meaningfully engage in statistical inquiry.
- To identify ways of supporting Emerging Bilingual Learners to develop conceptual understanding of big statistical ideas.
- To report the mathematics learning outcomes for children engaged in a statistics-focused integrated STEM context.

Chapter 7:

Situated in the same intervention (as chapter 6, *Cohort 2*), this chapter focuses on the impact of the STEM intervention on the PSTs themselves. Using a mixed method design, this chapter reports quantitative findings from the *Survey of Attitudes Towards Statistics (SATS-36)* and qualitative descriptions highlighting the power of rich, driving STEM problems in promoting active citizenship and improving attitudes towards statistics.

Article:

Fitzpatrick, M., Leavy, A., & Hourigan, M. (under review). "Rather than Simply Learning Statistics, We Aimed to Learn About the Bees, From the Bees": An Exploration of the Factors Influencing the Development of Positive Teacher Attitudes Towards Statistics, *Journal of Statistics and Data Science Education*

Objectives:

- To examine how an integrated STEM context impacts PSTs' attitude towards the M in STEM
- To explore how integrated STEM engagement influences attitudes about disciplinary components (i.e. Statistics)
- To identify features of the STEM intervention that contribute towards these changes

Chapter 8:

This chapter revisits the PSTs from *Cohort 1* over a year later (in May 2023) as they approach the final weeks of their undergraduate programme. Having completed a STEM-focused mathematics education specialism over two years[1], PSTs were invited to reflect on their

[1] *Cohort 1* engaged in a second STEM intervention (Spring 2023) focusing on the mathematics discipline within integrated STEM. The intervention is not reported in this dissertation. However, a brief overview of the module is offered in chapter 8 to outline the context of the PSTs' overall STEM experience. Further details on this intervention can be read in a published conference paper (Fitzpatrick, 2023) included in Appendix C

emerging STEM teacher identities. Using *STEM story-lines* as an innovative graphing tool, *Cohort 1* take a retrospective look at past experiences and anticipate their future teacher selves, as they negotiate becoming integrated STEM teachers.

Article:

Fitzpatrick, M. (2024). Drawing the past to envision the future: Supporting the development of primary STEM teacher identity. *Irish Educational Studies.* http://dx.doi.org/10.1080/03323315.2024.2359693.

Objectives:

- To explore the emerging STEM teacher identity of PSTs who completed an integrated STEM-focused mathematics specialism as part of their undergraduate programme.
- To unveil the nature of influential experiences identified by the PSTs
- To identify the potential of an innovative narrative graphing activity in supporting the identity work of integrated STEM teachers.

Chapter 9:

This chapter synthesises the findings from the preceding studies. The dissertation's contribution to the current literature is presented both in terms of the mandate it sets for specific *integrated* STEM education during ITE, and in terms of the simultaneous affordances and challenges of STEM education, in particular the (re)positioning of mathematics within integrated STEM. Its implications for policy and practice are discussed and recommendations for future studies are offered.

Chapter 2: Literature Review

2.1 Introduction

This dissertation critically reviews the pertinent literature relating to the specific focus of each study across Chapters 4-8. The current chapter supplements those review sections by offering a discussion on some of this dissertation's overarching themes and issues. It provides an overview of integrated STEM education, detailing some of the cited affordances and challenges for learning and teaching STEM. It sets out the complex issues of *integration* and outlines what this dissertation means by the term *STEM literacy.* To set the context for the subsequent studies within this dissertation, Chapter 2 also presents the extant literature on the worrying position of mathematics in integrated STEM education and the literature on teacher education in STEM. Table 2.1 presents an overview of the literature reviewed across this dissertation.

2.2 Integrated STEM

The STEM movement was born in the 1990s. Originally termed *SMET* (Science, Mathematics, Engineering and Technology), the National Science Foundation (NSF) strategically combined the four disciplines in an effort to join forces and "create a stronger political voice" (STEM Task Force, 2014, p.9). For phonetical reasons (and the negative connotations of *smut*), the acronym was quickly recoined *STEM* (Sanders, 2009), and this term has gained traction and momentum ever since (Li et al., 2020; Li & Anderson, 2020; Martín-Páez et al., 2019). A recognised need for more STEM graduates with in-demand skillsets necessary for current and emerging job roles (World Economic Forum, 2020) and the rapid rise of global, wicked problems such as climate change and sustainability has highlighted the urgency for cultivating STEM competences to meet current and future challenges. Efforts to advance STEM education have intensified in recent years and, as English (2016) proclaims, "show no signs of abating" (p.1).

Table 2.1

Overview of the literature reviewed in this dissertation

Chapter 2	• Integrated STEM • Integrated curriculum • STEM literacy • Mathematics in STEM • Teacher education in STEM
Chapter 4	• Integrated STEM • Primary school teachers and STEM • Challenges of integrated STEM • STEM teacher education • Review of STEM teacher professional development (PD) interventions (to inform principles of effective STEM PD)
Chapter 5	• Integrated STEM • Characteristics of high-quality STEM education o problem-solving design and approaches o engineering design and practices o appropriate use of technology o use of real-world contexts to situate learning o interdisciplinary knowledge and connections across STEM disciplines o emphasis on pupil centred pedagogies o development of 21st century skills and key competencies. • Challenges of Integrated STEM: Role of mathematics
Chapter 6	• Relevance of statistics education • Informal inference at the primary level • Supporting inclusion in primary level statistics education • Emerging Bilingual Learners (EB learners) • Using digital technologies for statistics education and citizen engagement
Chapter 7	• Proliferation of data in society • Attitudes towards statistics • Teacher attitudes towards statistics • Measuring statistics • Factors impacting attitudes towards statistics • The role of technology and context in statistics education
Chapter 8	• STEM education in the Irish context • Move towards integrated STEM • STEM teacher identity • Future oriented identity • Teacher identity work

Yet despite the proliferation of STEM related policy as laid out in Chapter 1, STEM education itself remains a nascent field (English, 2017; Goos, 2023; Wan et al., 2023). STEM is an ill-defined area with considerable divergence in conceptualisations and understandings of STEM education (Breiner et al., 2012; Sanders, 2009; Kelley & Knowles, 2016; Holmlund et al., 2018; Li et al., 2020). Operationalisations of STEM range from the siloed, disciplinary approach (that sets each of the four S-T-E and M disciplines as individual stand-alone subjects) to a more holistic, transdisciplinary approach (Sanders, 2009; Bybee, 2013; Wan, 2023). Indeed, the literature on STEM education varies in its rationale for STEM, its interpretation of STEM, how it should be taught in schools, and how it should be assessed (Falloon et al., 2020).

Proponents of STEM education outline its potential to prepare students for life in the 21st century, with English (2020, p.47) arguing that educators can "ill afford to ignore the rapid growth in innovation emanating from advances in the STEM fields". STEM education is thought to improve motivation and engagement in STEM subjects, in turn promoting STEM career interest (Ryu et al., 2019; Mohr-Schroeder et al., 2014). Reynante et al. (2020, p.796) recognise STEM as an "opportunity to challenge the notion of settled and siloed knowledge", supporting students in recognising connections between the disciplines and their relevance in the real world. As STEM education is centred around real-world problems, it is associated with enhancing problem-solving and reasoning skills. STEM tasks can encourage higher order critical thinking and problem-solving skills (Stohlmann et al., 2012; Kelley & Knowles, 2016) by engaging students in open-ended questions that allow for multiple solutions. Through STEM pedagogies and practices such as inquiry-based learning, project-based learning and the engineering design process, students can use iterative test data to improve and refine their design solutions (Moore et al., 2014; Bryan et al., 2015). They are encouraged to justify their scientific claims and design decisions with evidence and reasoning (Brown et al., 2011; Siverling et al., 2019), thereby developing important 21st century skills (such as critical thinking, communication, collaboration and creativity, information retrieval and evaluation, innovation) that are in increasing demand in today's society (Beswick & Fraser, 2019; Maass et al., 2019; Stehle & Peters-Burton, 2019; Bybee, 2013).

Yet, as a burgeoning field of study, STEM education faces many challenges and unanswered questions. Notwithstanding the affective gains evident in the literature, research on the effectiveness of STEM education in developing students' content knowledge remains limited, with little (and inconclusive) evidence on student outcomes, particularly from a long-term perspective (Goos, 2022; Maass et al., 2019; English, 2016; Fitzallen, 2015; Honey et al., 2014). Related to this, another challenge presents around the *assessment* of integrated STEM. There is a paucity of research into possible approaches for assessing integrated knowledge and practices, with little discussion on assessment issues for integrated STEM education (Fang & Hsu, 2019). Therefore, we continue to rely on extant assessment instruments that predate current STEM education initiatives (Roehrig et al., 2021). A recent review by Gao et al. (2020) found that most assessments in the studies analysed focused on the assessment of monodisciplinary learning or transdisciplinary affective domains, with little attention paid to interdisciplinary learning and practices. Assessing integrated learning is challenging, particularly given the lack of clarity around what precisely integrated learning is. Key learning processes and practices need to be identified and evaluated, and assessment resources and tools need to be developed, pointing to the need for classroom based, longitudinal research (Gao et al., 2020). As the construct of integrated STEM broadens, questions have also been raised around the development of disciplinary knowledge and the "epistemic viability of the STEM construct" (Tytler, 2020, p. 22). As Lehrer (2016) cautions us on the danger of moving towards a STEM "epistemic stew", the lack of clarity around integration and the role of each discipline with STEM further complicates the field.

2.3 Integrated curriculum and STEM integration

There is growing conviction that classroom practices should reflect the cross-disciplinary nature of STEM and that, consequently, STEM disciplines should not be taught in isolation (O'Dwyer et al., 2023; STEM Task Force, 2014). However, there remains a dearth of research examining the perceptions and implementation of integrated STEM in regular school settings (Fang & Fan, 2023). As a growing pedagogical construct with many differing needs for implementation (Siverling et al., 2019), many curricular models of integrated STEM are presented in the literature (Bybee, 2013). While attempts to make connections between the subject areas (by drawing knowledge from several disciplines around a central theme) have been evident since the early 1990s, Ryu et al. (2019) argue that more recent conceptualisations of STEM education "transcend disciplinary boundaries in order to advance students' STEM literacy, twenty-first century skills, and capability to understand and address STEM–related global issues" (p. 495).

The world's grand challenges have spurred calls for an integrated approach to STEM education (Nadelson & Seifert, 2017; Owens & Sadler, 2020). Like most real-world problems, today's most pressing issues (such as energy solutions and climate change) cannot be neatly categorised by subject area. They are messy and complex and require applying and synthesising multiple STEM disciplines (Nadelson & Seifert, 2017). Presenting real-world problems in the classroom offers children the opportunity to learn and apply STEM disciplinary ideas and practices in context, rather than learning "abstract and fragmented bits and pieces of knowledge and then have to assimilate them at a later time" (Ryu et al., 2019, pp. 295-496).

Researchers have long questioned the value of strictly siloed disciplinary approaches at the school level and in academic fields. D'Ambrosio (2015) uses the "epistemological cage" metaphor to describe knowledge systems. He writes;

> Traditional knowledge is like a birdcage. Birds living in the cage are fed by what is in the cage, they fly only in the space of the cage, they see and feel only what the wires of the cage allow. The birds in the cage communicate among themselves in a language proper to those that live in the cage, they breed and procreate, they repeat themselves. They can not see the color the cage is painted outside. A similar situation may happen with specialized scholars. The scholars in the cage develop their own jargon and adhere to rigorous methodological and ontological standards. To overcome academic sameness is a big challenge...Being inside our ivory tower, what can we say? We are inside this ivory tower, and we are very comfortable there. But we cannot really say much because we don't see the world as well enough either. We have to go out, but that is not so easy" (pp. 23-24)

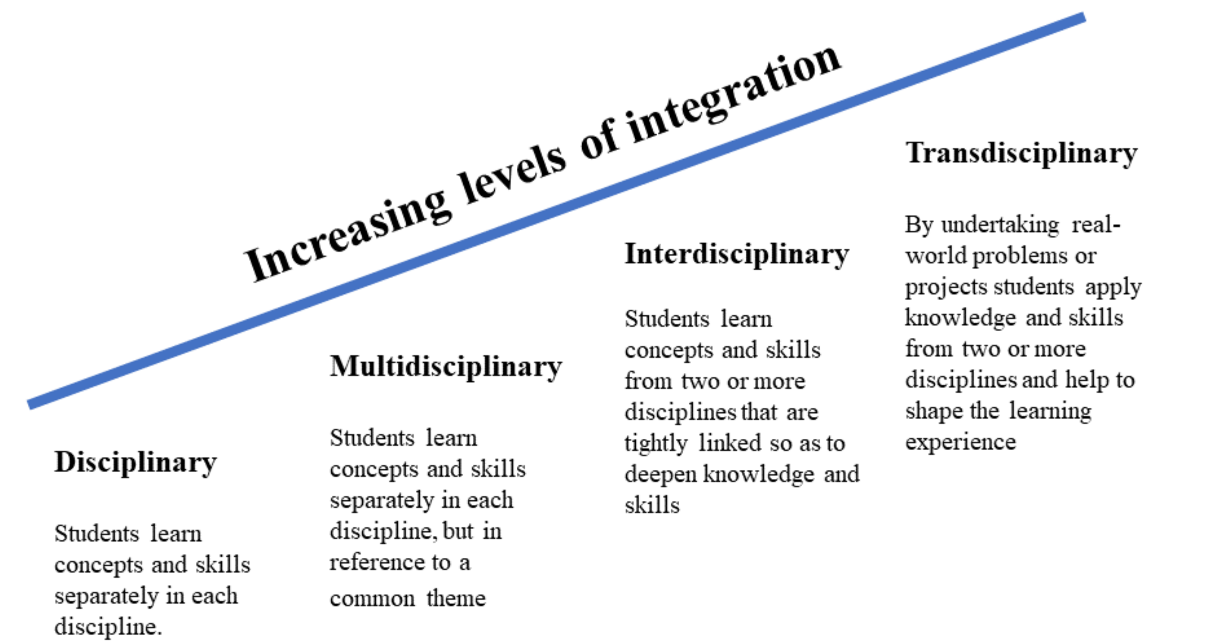
If traditional knowledge is a 'birdcage', then STEM education may offer a door to freedom, by compelling us to take a 'worldly perspective' (Rennie et al., 2020) and utilise connections between the disciplines. Although STEM education is increasingly equated with integrated approaches that span disciplinary boundaries, the degree of this boundary crossing varies (English, 2016; Leung, 2020; Li, 2014). Indeed, in a recent systematic review of conceptual frameworks for integrated STEM education, Moore et al. (2020) found that while researchers held congruent views on several key themes, they held significantly different views on the degree to which the disciplines should be integrated. The many different perspectives reflect perhaps Kennedy and Odell's (2014) view that STEM education has evolved into a meta-discipline, "an integrated effort that removes the traditional barriers between these subjects, and instead focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies" (p. 246).

Curriculum integration is an ambiguous term, with no single conceptualisation capturing the many different ways it can occur (Burke & Lehane, 2023). Indeed, curriculum integration is not a new concept, and educational researchers have grappled with this equivocal term long before the acronym 'STEM' was coined. Many models of integration are offered in the literature. Integration has been presented as a continuum of approaches. Jacobs (1989) offers a *Continuum of Options for Content Design*, moving from very separate *disciplinary-based* and *Parallel Disciplines* designs, through *Multi-disciplinary* and *Interdisciplinary* options, before presenting the *Integrated Day* (a full-day programme focusing on children's questions and interests arising from problems in their world) and *Complete Programme* design (in which children "create the curriculum out of their day-to-day lives" empowering them with "a sense of independence and self-direction"(p.18)). Fogarty (1991) later presents a 10-model continuum, outlining increasing levels of integration from *Cellular* (singular subject focus) to *Immersed* and *Networked* approaches (in which an individual or experts from across disciplines integrate information across disciplines to explore a common topic or concept).

Conversations about STEM integration are rooted in such broader discussions on curriculum integration (Roehrig et al., 2012). Vasquez et al. (2013) offer a simplified model of STEM integration (see Figure 2.1). They present a continuum of STEM approaches to curriculum integration, with each of the four ways of organising the curriculum depicting an increasing level of integration. They begin with a *disciplinary* approach in which students learn concepts and skills separately in each discipline. The subsequent model of integration is termed *multidisciplinary*, whereby concepts and skills are presented in separate disciplines but are centred around a common theme. The third approach is *interdisciplinary*, allowing the student to learn concepts and skills from two or more disciplines. In interdisciplinary integration, the disciplines are tightly linked in an effort to deepen knowledge and skills. The final approach offered by Vasquez and colleagues is *transdisciplinary.* In transdisciplinary integration, real world problems provide the students an authentic opportunity to shape their learning experiences, by addressing issues of interest to them and applying skills and knowledge from two or more disciplines.

Figure 2.1

Vasquez et al.'s (2013) continuum of STEM approaches to curriculum integration



Moore et al. (2021) offer three forms of STEM integration that generally occur in the classroom: content, context and application/tool integration. Activities that utilise *content integration* have multiple STEM disciplinary learning objectives (and perhaps learning objectives from other disciplines, such as the Arts or social sciences). During *context* *integration*, on the other hand, the learning focuses on one (or more) content areas while drawing the context from another discipline. *Application/tool integration,* meanwhile, refers to the use of an application or tool from one discipline to teach another discipline. English (2016, S8) offers her *STEM integration matrix* as a tool for "analysing and categorising the content and context of integrated activities". This matrix notes the nature and extent of disciplinary content integration (*primary, supporting or absent*) as well as the nature and extent of context integration (disciplinary context(s) and/or background context(s)). English's (2017) sample STEM integration matrix is outlined in Table 2.2 below. Her contribution offers a means of identifying "broadly the balance of disciplinary content coverage and the range of problem contexts employed across a suite of STEM problems" (p. S8), thereby providing teachers with a tool to aid STEM planning and evaluation.

Table 2.2

Sample STEM integration matrix (from English 2017)

Content	Science	Technology	Engineering	Mathematics	(Arts)
Primary			✓	✓	
Supporting	✓				
Context					
Disciplinary		✓	✓		
Background	Personal	Societal	Occupational	Historical	Other
		✓		✓	

Indeed, it must also be noted that English's (2017) and Moore et al.'s (2021) possible inclusion of the arts represents the growing STEAM movement (Science, Technology, Engineering, *Art*, and Mathematics). As identified in our recent systematic literature review on effective interventions for addressing STEM and the arts (Leavy et al., 2022, see Appendix A), the inclusion of the arts in STEM is seen as a valuable means of enhancing 21st century skills and making STEM more accessible to previously marginalised groups in STEM, by exploiting culturally relevant pedagogies and attributing value to a range of cultural capitals. However, such viewpoints often position the arts as being integrated *into* STEM "in the service of elevating STEM learning" (Leavy et al., 2022, p. 8). For meaningful integration of the *A* in STEAM, it is vital that both the arts and STEM are co-equal and viewed as making mutually beneficial contributions to teaching and learning. In many of the studies reviewed, the *A* in STE*A*M was superficial, there to support the communication of STEM learning, with little to no attention given to the development of learning outcomes in the arts. Such examples offer further evidence on the challenges of *meaningful* integration in the field, highlighting the possibility of merely paying lip service to 'included' disciplines within integrated STEM or STEAM tasks.

Other models of integration advocate for the use of real-world context. The *Authentic Integration of Mathematics and Science* model (Treacy & O'Donoghue, 2014; Treacy, 2021) offers a blueprint for creating transdisciplinary lessons. These rich tasks are rooted in relatable contexts, provide for structured, focused inquiry and dialogue, and require synthesising prior knowledge and skills in mathematics and science. Other scholars position engineering as the glue that holds integrated STEM together (Thornburg, 2009, Tank et al., 2018). Engineering design-based STEM integration (Siverling et al., 2019; Guzey et al., 2016) uses engineering to drive the learning of the four STEM disciplines. Also referred to as design-based learning (English, 2020; 2019), this approach involves students learning STEM disciplinary content by participating in the engineering design process. Researchers have also reported on the implicit inclusion of disciplinary learning during engineering tasks, in which students apply prior mathematics, science and technology knowledge without being explicitly asked to by the teacher. This prompted Larkin and Lowrie (2023) to add further to Vasquez et al.'s (2013) continuum of integration approaches to STEM education. They position the term *Quasidisciplinary* at the lower end of the continuum, likening it to the use of methodologies (such as engineering design approach) or non-STEM-specific teaching approaches (such as play-based learning) to teach STEM, without identifying any specific disciplines.

Despite the lack of consensus concerning the specific details of STEM integration, we continue to witness the drive of the global STEM agenda. Bussey and colleagues (2020) contend that developing a “grand, unifying theory across STEM disciplines is both unlikely and of questionable value” (p. 60). Bybee (2013) challenges the appropriateness of a single definition, a view supported by Martín-Páez et al. (2019), who believe it necessary to “delimit the term to avoid the terminological amalgam” (p. 803). Breiner and colleagues (2012) suggest that although a shared conceptualisation could provide clarity, an operational definition of STEM could be counterproductive, given the various initiatives and stakeholders involved in STEM education. They argue that a one-size-fits-all definition could force compartmentalisation and lead to the exclusion of valuable groups that could enhance the field of STEM education. The variation in the degree of discipline integration will inevitably persist (Moore et al., 2020). However, the continuums and models of Vasquez et al. (2013), Moore et al. (2021), English (2017) and others support researchers and practitioners in moving the field towards more consistent and agreed-upon language, presenting ways to think about the different types of STEM integration, in turn aiding both research and practice (Moore et al., 2020).

Of course, that is not to say that interdisciplinary learning should be children's only exposure to the STEM disciplines. This position was laid out in the early literature on curriculum integration, with researchers such as Beane (1995) proclaiming that:

> In the thoughtful pursuit of authentic curriculum integration, the disciplines of knowledge are not the enemy. Instead they are a useful and necessary ally... If we are to broaden and deepen understandings about ourselves and our world, we must come to know ‘stuff’, and to do that we must be skilled in ways of knowing and understanding. As it turns out, the disciplines of knowledge include much (but not all) of what we know about ourselves and our world and about ways of making and communicating meaning. Thus authentic curriculum integration, involving as it does the search for self- and social meaning, must take the disciplines of knowledge seriously” (pp. 616-617).

The literature on integrated STEM education strongly advocates for a balance between disciplinary and integrated knowledge and does not generally advocate for total integration (Rennie et al., 2020; English, 2017; Pearson, 2017). High quality STEM provision values the contribution of the individual disciplines, specific disciplinary conventions and ways of knowing, highlighting the balance and interplay between integrated and disciplinary knowledge as critical to student learning in STEM contexts (Rennie et al., 2020). Pearson (2017) advises STEM educators on the necessity to attend to the learning goals and learning progressions of individual disciplines, reminding us that students will face considerable challenges in connecting across disciplines if they have limited understanding of the relevant disciplinary concepts and ideas. Indeed, he cautions that more integration is not necessarily better, and although there are many benefits to integrated approaches, a strategic approach that "accounts for the potential trade-offs in cognition and learning" is advised (Pearson, 2017, p. 225).

While integrated STEM may increase, what Reynante et al. (2020) refer to as, students' *epistemic fluency* (that is, the ability to recognise and employ different ways of knowing with ease), it has also been argued that these crosscutting connections force us to bridge gaps between disciplines that are indeed closely related, but simultaneously fundamentally different in nature (Couso & Simarro, 2020; Erduran, 2020; Tytler et al., 2020). Couso and Simarro (2020) challenge the assumption that transdisciplinary integration is best, suggesting that complete integration rarely happens in real school settings. Their suggestion is supported by a recent review by Larkin and Lowie (2023), which found that only 8% of the studies analysed on STEM education in early and primary years involved higher levels of integration (*interdisciplinary* or *transdisciplinary*). As Couso and Simarro (2020) argue, engineering and science objectives often presume the lead, while other disciplines (namely mathematics) are reduced to a service role. Focusing on mathematics, for example, as a tool for problem solving rather than a legitimate way of thinking about those problems, results in what they term "an epistemic malpractice that could communicate a poor view of the nature of each of the STEM disciplines" (Couso & Simarro, 2020, p. 25). English (2017) also urges caution, suggesting that total integration could limit students' learning of core disciplinary knowledge and skills. Offering an alternative view, she and colleagues position integrated STEM as a valuable opportunity to consolidate and extend learning in disciplinary units (English, 2017; King & English, 2016). Similarly, Nadelson and Seifert (2017) state that not all STEM teaching should be integrated, promoting a mixture of foundational disciplinary STEM knowledge instead with integrated project-based STEM.

2.4 STEM Frameworks

Many frameworks have been offered in an attempt to make sense of the messiness of STEM and provide a vision for high quality STEM education in research and practice (Blackly & Howell, 2019; Butler et al., 2020; Falloon et al., 2020; Guzey et al., 2016; Jackson et al., 2021; Moore et al., 2014; Simarro & Couso, 2021; Thibaut et al., 2018). For example, Moore et al. (2021) offer their STEM Roadmap, a seven-point framework for STEM integration. They state that effective integrated STEM education should begin with a motivating and engaging context, include engineering design challenges of relevant technologies to enhance problem-solving abilities, creativity and higher-order thinking skills, provide children with an opportunity to learn from failure, incorporate mathematics and science learning objectives (or indeed broader disciplinary areas such as language and the arts), be taught in a child-centred manner, emphasise teamwork and communication, and prioritise integration within a STEM unit. Meanwhile, Roehrig et al. (2021) describe seven similar central characteristics of integrated STEM. They further emphasise the centrality of *real-world problems* and include “exposure to details about STEM careers” (p. 5).

Others, such as Kelley and Knowles (2016) and Tan et al. (2019), offer metaphors to paint a picture of their conceptual frameworks for STEM. Kelley and Knowles (2016) present STEM education as “a block and tackle of four pulleys to lift a load, in this case situated STEM learning” (p. 3). The four pulleys of science, technology, engineering and mathematics are connected by a rope of “community of practice”, illustrating how the system must “work in harmony to ensure the integrity of the entire system” (p. 4). Tan et al. (2019) turn to a music analogy, describing their framework as the STEM Quartet. The STEM Quartet positions problem-solving as the overarching process, with complex real-world problems at its core, a focus on the connections between the disciplines, and the four disciplinary domains themselves. For Tan and colleagues, the four disciplines, much like a quartet of musicians, must work together to produce a harmonious sound. However, one discipline takes the lead at a time, while others provide support. The frameworks described here are by no means an exhaustive list. However, they provide an example of how researchers are attempting to conceptualise the field in terms of research and practice. By guiding the teacher practices one would expect to observe within an integrated STEM lesson, such frameworks may also contribute to developing appropriate observation protocols and other assessment tools (Roehrig et al. 2021).

2.5 STEM literacy

Given the challenge of defining STEM education, researchers have suggested a focus shift towards the *shared goals and outcomes* of STEM education (Honey et al., 2014; Breiner et al., 2012). Arguably, the main goal of STEM education is to contribute to a STEM-literate society (Falloon et al., 2020; Honey et al., 2014; Owens & Sadler, 2020; Pearson, 2017). As Zollman (2012, p. 12) proclaims,

> We are in the STEM generation whose comprehensive purpose is to resolve (1) societal needs for new technological and scientific advances; (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, knowledgeable citizen.

While initial policy drives for STEM literacy sought the promotion of STEM graduates to feed the STEM pipeline (as outlined in Chapter 1), recent efforts reflect broader societal goals. There is growing consensus that *all* citizens, irrespective of their career choice, need to be STEM literate (Zollman, 2012; Mohr-Schroeder et al., 2020).

Unlike the inconsistent conceptions of STEM education and STEM integration, there is general agreement on what it means to be ‘STEM literate’, with literature referring to the knowledge, skills and dispositions needed to productively engage in STEM-related study and practice (Falloon et al., 2020). While all literacies derive from the foundations of traditional literacies (reading, writing, speaking and listening), a much broader definition of literacy is required for today’s globalised and digital world (Meyers et al., 2013). Although Bybee (2010) might be credited with spotlighting the term *STEM literacy*, the “groundwork to uncovering the layers of literacy within and across STEM disciplines has been laid by stakeholders throughout the 20th and 21st centuries” (Cavalcanti & Mohr-Schroeder, 2019, p. 3). Individual disciplinary literacies have long been discussed in their relevant fields.

Scientific literacy: The focus of scientific literacy has shifted over the years, from an early emphasis on memorising scientific concepts and laws, to a more transformative vision for social participation and emancipation (Valladares, 2021). Scientific literacy is the knowledge and understanding of, and ability to use scientific concepts and processes, to make decisions and act as a reflective citizen, by engaging in reasoned discourse to interpret evidence and explain phenomena scientifically (OECD, 2018). Yacoubian (2018) outlines four components associated with scientific literacy: knowing what counts as science and differentiating that from non-science; knowledge required for engaging in science-related social issues; awareness of the risks and benefits of science; and the ability to think critically about science.

Technological literacy: Accelerated technology development has led to profound societal changes. This has spurred the evolution of *technological literacy* to "both understand our new world and how to live a meaningful existence in it" (Avsec & Jamšek, 2016, p. 44). Technologically literacy is the knowledge and skills needed to use, manage and evaluate technology (Dinçer, 2018). Central to this is the capacity to use, understand and evaluate technology and technological principles and strategies, to innovate, make decisions and solve problems (National Assessment Governing Boards, 2010; International Society for Technology in Education, 2000; as cited in Zollman 2012). The International Technology Education Association (2007) also adds that "a technologically literate person understands, in increasingly sophisticated ways that evolve over time, what technology is, how it is created, and how it shapes society, and in turn is shaped by society" (p. 9).

Engineering literacy: Engineering literacy on the other hand, has not been globally defined (Jackson et al., 2021). However, the Accreditation Board for Engineering and Technology (2010) describe it as the application of mathematical and scientific knowledge, to develop ways to utilise economically the materials and forces of nature for the benefit of humankind (Owens & Sadler, 2020; Zollman, 2012). Owens and Sadler (2020) suggest that such a definition is problematic, as it stresses technological solutions to all problems while ignoring the need for social responsibility and environmentally sustainable engineering solutions. Notwithstanding the difficulties of defining engineering literacy, the recognition of its importance at primary level has been reflected in recent international curriculum development.

A recent audit of primary curricula by the NCCA's STEM development group (NCCA, 2023d) found that Scotland and New Zealand curricula, for example, refer to *engineering*, *graphics*, and *designing* under the area of technologies, while Welsh curriculum notes the importance of *design thinking* and *engineering* to support technical and creative ways to meet society's needs. Notably, Ontario presents the engineering design process as a key theme under their curriculum topic *STEM Investigation and Communication Skill* (NCCA, 2023d).

Mathematical literacy: Referred to by the NCTM (2000) as the ability to read, listen, think creatively, and communicate about problem situations, mathematical representations and solutions in an effort to deepen an understanding of mathematics (cited in Zollman, 2012), mathematical literacy is inherently concerned with the ability to use mathematics outside the mathematics classroom (Kaiser & Willander, 2005). In their Programme for International Student Assessment (PISA), the OECD (2024, p. 55) use it as a measure of performance, describing it as the ability to

> formulate, employ and interpret mathematics in a variety of context to describe, predict and explain phenomena... A mathematically literate student recognises the role that mathematics plays in the world in order to make well-founded judgements and decisions needed by constructive, engaged and reflective citizens.

Mathematical literacy, therefore, calls for the "'literate learning of mathematics' as well as 'mathematical literacy' as a life-related competence" (Venkat, 2014, p. 163). Such aspirations demand a move away from traditional mathematics curriculum and classroom approaches that ignore the "critical issues threatening the survival of civilisation" (D'Ambosio, 2015, p. 21). Instead, D'Ambosio (2015) argues that schools must be a space "not only for instruction, but primarily for socializing and for criticizing what is observed and felt in everyday life", in order to stimulate creativity and new ways of thinking (p.24). D'Ambosio's (1999, 2015) concepts of *Literacy* and *Matheracy*, and Steen's (1999; 2002) and Goos et al.'s (2019) quantitative *literacy* and *numeracy* highlight the necessity of complex reasoning and communication skills in our data and technology-driven world. Such conceptualisations of mathematical literacy also underscore the centrality of *statistical literacy* in today's society, which Gal (2002) defines as:

> people's ability to interpret and critically evaluate statistical information, data-related arguments … to discuss or communicate their reactions to such statistical information, such as their understanding of the meaning of the information, their opinions about the implications of this information, or their concerns regarding the acceptability of given conclusions. These capabilities and behaviors do not stand on their own but are founded on several different knowledge bases and dispositions. (pp. 2-3)

STEM literacy: STEM literacy should be considered an integrated literacy, not limited to the siloed perspectives (Zollman, 2012). By examining how disciplinary literacy is conceptualised in science, technology, engineering and mathematics, we can see some obvious similarities. Being literate in each of the disciplines involves more than merely developing content knowledge and skills; it extends to the ability to utilise these in practice. Each is concerned with problem-solving in some way. Each is deeply grounded in real world applications, both in terms of industry and economy, and global and active citizenship. There is an emphasis on decision-making, critical thinking and critical judgements. From an integrated perspective, STEM literacy is applying concepts and skills from the four disciplines to solve problems that cannot be solved using a single discipline (Bybee, 2010; Jackson et al., 2021). Techakosit and Nilsook (2018) offer six elements of STEM literacy, namely: the ability to identify STEM problems, the ability to seek new knowledge, the application of STEM concepts, the ability to solve problems using STEM, the ability to communicate the information using STEM, and the ability to make decisions based on STEM.

Zollman (2012) reminds us that we must also remain mindful of the *affective* elements of STEM literacy, such as motivation, self-confidence, beliefs and attitudes, which he associates with developing a STEM *identity*. Teachers support this STEM identity work by setting up engaging and collaborative classroom environments that provide opportunities for students to operationalise their STEM capabilities to progress towards desired goals. STEM literacy, therefore, can be viewed as "a vehicle through which to develop the 21st century learning skills... while honing rich disciplinary content learning" (Mohr-Schroeder et al., 2020, p. 36). However, as Cavalcanti and Mohr-Schroeder (2019) caution, the definition of STEM literacy must remain dynamic to reflect society's ever-evolving technological demands. Mohr-

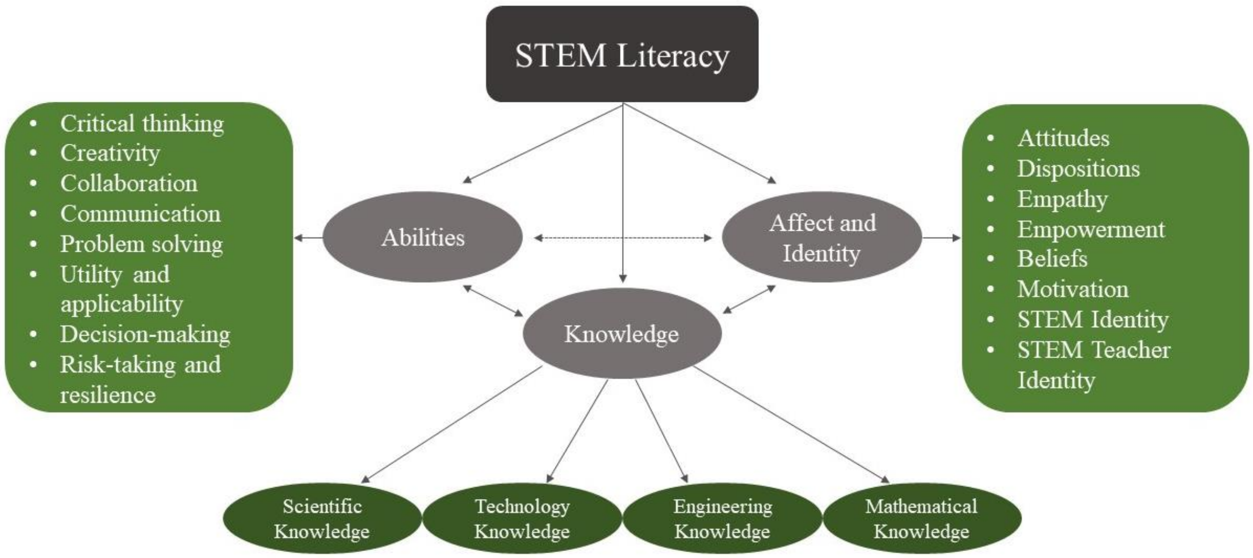
Schroeder et al. (2020, p. 33) offer a comprehensive definition of STEM literacy, that is both equitable and outcomes-oriented, and is respectful of the individual strengths that each discipline offers, while positioning integrated STEM at its core:

> STEM literacy is the dynamic process and ability to apply, question, collaborate, appreciate, engage, persist, and understand the utility of STEM concepts and skills to provide solutions for STEM-related personal, societal, and global challenges that cannot be solved using a single discipline.

Given the promotion of STEM literacy development as a critical goal of STEM education, Jackson et al. (2021) point to the need for more clarity on how educators can provide meaningful learning experiences to empower their learners. Central to this, Huang et al. (2023) argue, is the importance of teachers' own STEM literacy in mediating students' learning. Describing teachers as "catalysts" of students' learning, they argue that teacher preparation for STEM education affects their STEM teaching, directly or indirectly, and can largely determine the success of STEM initiatives (p. 4). Huang and colleagues (2023) offer a framework of STEM literacy that proposes that STEM literacy comprises three aspects- knowledge, abilities and attitude. Knowledge refers to the synthesis of the four disciplines; Ability relates to applying STEM concepts and skills to address STEM problems; and Attitudes is concerned with positive orientations towards STEM. In alignment with Zollman's (2012) position, however, it could be argued that more affective constructs (self-confidence, motivations, beliefs etc.) and indeed STEM identity could be effectively incorporated into this framework. Therefore, this study draws on Mohr-Schroeder et al.'s (2020) equity-based definition of STEM literacy that promotes the utilisation of interdisciplinary STEM to solve real-world challenges, while framing PSTs' STEM literacy as the development of STEM knowledge, abilities and affect (see Figure 2.2).

Figure 2.2

A framework for STEM literacy (adapted from Huang et al., 2023; Zollman, 2012; Jackson et al., 2021; and Falloon et al., 2020)



2.6 The Role of Mathematics

As noted previously, one of integrated STEM's main challenges is maintaining a disciplinary balance. Science has long been associated as the central discipline within STEM education, with many reports and publications using the terms 'STEM' and 'science' interchangeably or equating the role of STEM education with the development of broad-based scientific literacy (English, 2016; Marginson et al., 2013). While engineering was certainly the neglected discipline for a time (English, 2016), particularly at the primary level, a rise in research on engineering practices has elevated its role, and engineering practices are now a central characteristic of most STEM frameworks (Moore et al., 2021; Roehrig et al., 2021; Guzey et al., 2016). However, growing evidence suggests that the underrepresentation of mathematics in STEM education is a cause for concern.

Although mathematics is a core discipline in curricula internationally and is often portrayed as the 'underpinning' discipline in STEM (Maass et al., 2019), research on interdisciplinary approaches to mathematics highlights its tendency to be used as an *auxiliary* discipline (Just & Siller, 2022), playing a service role to the other disciplines within integrated STEM (Baldinger et al., 2020; Frykholm & Glasson, 2005; Tytler et al., 2019; Walker, 2017). Doig and Williams (2019) refer to the "tendency for mathematics to disappear from attention in interdisciplinary problem solving and integrated studies… to be black-boxed or treated as a tool" (p. 300). Indeed, Fitzallen (2015) suggests that positioning mathematics as the 'underpinning discipline' sets it up in a supporting role in an integrated context. This leads to a devaluing of the discipline, in which teachers view mathematics as a support for teaching science and engineering within integrated STEM curricula (Forde et al., 2023; Ring et al., 2017; Ring-Whalen et al., 2018). In their exploration of mathematics in post-primary STEM classrooms, Just and Siller (2022) found that science educators viewed mathematics as "a minor matter and a means to an end" (p. 15). This view, they argue, could be perpetuated by teachers, who pass an auxiliary view of mathematics to their students. When mathematics is positioned as a tool for other disciplines, the value of mathematics (compared to the other disciplines) declines, and the mathematical cognitive demand diminishes, making it "less visible to the learners and less powerful than these other disciplines" (Doig & Williams 2019, p. 300).

Reducing mathematics to a service tool is problematic. It fails to support the educational experiences espoused by the mathematics education community (Frykholm & Glasson, 2005) and promotes procedural fluency over conceptual understanding (Baldinger et al., 2020). Gravemeijer et al. (2017) note that technological developments have changed the mathematical competencies needed in today's world. Much of the service role tasks involve work that "can be performed by computers and are performed by computers in the world outside school" (p. S107). Instead, they argue the need to develop "competencies that complement computer capabilities" (p. S106) and advocate for the advancement of mathematical reasoning. A recent study by Forde et al. (2023) investigated the presence of mathematics and levels of cognitive demand required from mathematical tasks in integrated STEM units. Using 2,030 sets of their STEM Observation Protocol (STEM-OP) scores, generated from video-recorded classroom observations of 106 teachers in the United States, they compared the scores of observations which included mathematical content and those that did not. They found that including mathematics content in integrated STEM lessons leads to higher STEM-OP scores (that is, higher degrees of STEM integration as measured by the protocol). However, their findings suggest that, when present, the mathematical tasks were of low cognitive demand (Level 1 and Level 2 of Smith and Stein's (1998) and Matsumura et al.'s (2006) levels of cognitive demand). Their work stresses the need for more research examining the implementation of mathematically high cognitively demanding tasks within integrated STEM and for further guidance for teachers to support and extend students' mathematical learning within interdisciplinary tasks.

Other researchers have noted the challenges teachers face in designing and orchestrating the authentic integration of mathematics within STEM activities in the classroom. Walker (2017) suggests that many of the topics explored in integrated STEM lessons provide a challenge from the beginning, as although there is undoubtedly mathematics involved, the difficulty is in finding relatable grade-appropriate mathematics content that aligns with both curriculum and the chosen topic. Just and Siller (2022) also found that mathematical concepts remain hidden in the tasks, but noted the possibilities for rich mathematics learning if the units were "slightly transformed" (p. 15). Indeed, this need for transformation has been evidenced for over a decade when Shaughnessy (2013) reminded us that unless we involve significant mathematics for students and shine a light on the mathematics involved in the task, the "M in STEM will remain silent" (p. 324). Making the mathematics more explicit in integrated STEM tasks by foregrounding mathematical content, proficiencies and literacies is a firmly held position of many, including Baldinger et al. (2020) and English (2016). Baldinger et al. (2020) highlight the importance of identifying central mathematics learning outcomes in integrated STEM tasks, in order to promote the rich mathematics practices we expect in the classroom and "allow mathematics to fully voice its disciplinary power" (p. 71).

Mathematics educators and STEM educators alike are reaching consensus on the need to offer opportunities for the authentic integration of mathematics that positions mathematics as integral to STEM and highlights the vital role of mathematics in our lives. Stohlmann (2018) offers the slightly adapted acronym of 'integrated steM', which "integrates mathematics explicitly through content integration with at least one of the three other disciplines of STEM either through content or context integration" (p. 311). In integrated steM, the focus remains on mathematics while being supported and enhanced by the other disciplines. Stohlmann's findings highlight the benefit of using real-world problems, with multiple entry points and the provision of support for children to develop mathematical understanding through pre-and post-STEM activities. Stohlmann (2018) also advocates for three pedagogical practices to implement integrated steM: engineering design challenges, mathematical modelling, and open-ended or games-based mathematics integrated with technology, arguing that open-ended problem solving is required to prepare children better for their current and future lives. Baldinger et al.'s (2020) review of practices at post-primary level also connected the value of real-world tasks to interdisciplinary mathematics engagement, as they required a genuine need to solve mathematical problems beyond routine procedure. It has also been suggested that carefully choosing tasks that relate to students' lives compel critical thinking and conceptual understanding (Bakker et al., 2014).

Given the increasing need to deal with uncertainty and risk, and reason with complex data in our world, Stohlmann (2018) also noted the potential of integrated steM education to promote and enhance statistics education, a view also held by English (2015), Fitzallen and Watson (2020) and Makar et al. (2023). School statistics has long been taught as an isolated subject (Rossman & Chance, 1999) and has been criticised for using 'toy data sets' that fail to address issues of social or personal relevance (Ridgway & Ridgway, 2019). This has resulted in recent calls for the use of real-world data sets that stimulate interest and promote social awareness and active citizenship (Makar et al., 2023; Weiland, 2017; Zapata-Cardona, 2023). Integrated STEM, therefore, could be viewed as a vehicle to drive authentic statistical investigations. Furthermore, as Watson et al. (2020) argue, by serving as "the methodology for analysing the data arising naturally in STEM problem-solving contexts", statistics can potentially provide an integrating "thread" (p. 112).

Designing and implementing authentic interdisciplinary mathematics experiences is challenging work, and we need to consider how teacher education might build on the work in separate disciplines to support specific integrated practices (Baldinger et al., 2020). The mere inclusion of mathematics in a STEM task does not equate the activity to interdisciplinary mathematics. Describing interdisciplinary mathematics as “a very broach church” (Doig & Williams, 2019, p. 301), these authors call for the construction of a unifying but broad definition of interdisciplinary mathematics. Without such guidance, they argue, interdisciplinary mathematics education “may suffer the fate of other educational waves of enthusiasm and become a name for virtually anything that is different from the disciplinary tradition” (p. 301). Teachers have reportedly struggled to incorporate meaningful interdisciplinary mathematics in ways that challenge and extend mathematical thinking (Tytler et al., 2019). In fact, teachers have identified mathematics as the most challenging discipline to integrate (Arnone & Hanuscin, 2018). Given the recent changes to our curriculum landscape in Ireland (NCCA, 2023a; 2023c; 2024), we need to prepare tomorrow’s teachers for the challenges of interdisciplinary mathematics. As Tytler, Anderson and Williams (2023) note, “Balancing disciplinary with interdisciplinary learning depends on the imagination and thoroughness of planners of STEM projects who are dedicated to integrating mathematics into projects in ways that engage students” (p. 1312).

2.7 Teaching integrated STEM

The growing field of STEM education research points to the enthusiasm for integrated approaches. Integrated STEM has been linked to the enhancement of learners’ 21st century skills, and learner motivation and interest in STEM subjects (Cotabish et al., 2013; Han et al., 2023; Moore, 2014; Nadelson & Seifert, 2017). However, research suggests that while teachers see the connections between the disciplines (Wang et al., 2020; Wang et al., 2011), many struggle with the enactment of integration (Breiner et al., 2012; Estapa & Tank, 2017). Drawing on similar observations from Timms et al. (2018) and Zollman (2012), Falloon and colleagues (2020) contend that teachers have been “charged with the responsibility of implementing STEM curriculum” yet “struggle to grasp what STEM education ‘looks like’, how it should be planned, why and how they should revise historical teaching methods, and what and how student outcome should be assessed and reported” (p. 371). The shift away from traditional teacher-led approaches may challenge teachers’ “repertoire of classroom practices” while shifting the power towards student-centred approaches may be ‘unsettling’ for both teachers and students (Way et al., 2022, p.2).

It should not be surprising that teachers feel unprepared to teach in integrated ways (Dare et al., 2018; Shernoff et al., 2017). The literature has cited many reasons, including a lack of administrative support and limited interdisciplinary understandings (Couso & Simarro, 2020; Ryu et al., 2019). Given the recent rise of STEM education, few teachers have been exposed to integrated approaches as learners during their time at school, and teachers report being unable to imagine what such approaches look like in the classroom (Shernoff et al., 2017). They were also unlikely to have experienced integrated learning during ITE, given that teacher education programmes have traditionally focused on developing skills and knowledge in the individual disciplines (Huang et al., 2022; Lo, 2021; Zhang & Zhu, 2022).

A commonly cited challenge emerging from studies in the post-primary sector raises concerns around teachers' capabilities and expertise in the 'other' STEM disciplines (Ní Ríordáin et al., 2016) and indeed the pedagogical challenges they face in relation to supporting students in integrated lessons (Honey et al., 2014). As generalist teachers, however, primary school teachers have been exposed to a broad range of pedagogical approaches and methodologies during ITE (Scogin et al., 2023). This experience, coupled with a relatively flexible curriculum and timetable, places primary school teachers in a unique position to design and facilitate integrated STEM education in their classrooms (Hourigan et al., 2022). However, as non-specialists, many primary teachers reportedly lack the necessary background knowledge and confidence to enact integrated STEM in the classroom (Nadelson et al., 2013).

As Kelley and Knowles (2016) contend, "making crosscutting STEM connections is complex and requires that teachers teach STEM content in deliberate ways so that students understand how STEM knowledge is applied to real-world concepts" (p. 3). This is particularly challenging when such crosscutting connections are often implicit within our curricula. High quality STEM teacher preparation is therefore critical (Ryu et al., 2019; Stohlmann et al., 2012). There is a need to develop teacher's subject content and pedagogical content knowledge and self-efficacy in the STEM disciplines (Honey et al., 2014). However, merely developing content knowledge and conceptualisations of integrated STEM will not suffice. Research points to the need to build teacher beliefs, knowledge related to the importance of integrated STEM, a developing vision of what integrated STEM instruction looks like in practice, and a strong STEM teacher identity to enhance successful implementation (Estapa & Tank, 2017; Galanti & Holincheck, 2022; Roehrig et al., 2012).

Teacher educators, therefore, are faced with the challenge of designing and providing ITE programmes that prepare our PSTs to embrace the changing landscape of integrated STEM education (Corlu et al., 2014; Ryu et al., 2019). Kelley and Knowles (2016, p. 10) suggest that the first "key to preparing STEM educators" is to ground their conceptual understanding of integrated STEM education by examining fundamental learning theories, pedagogical approaches and developing an awareness of current STEM education initiatives. They also stress the importance of offering a strong conceptual framework for the integration of STEM, and teaching through an integrated STEM approach to build confidence. A detailed discussion of the characteristics of effective integrated STEM teacher education is presented in Chapter 4.

2.8 Conclusion

This chapter presents a critical synthesis of the literature pertinent to this dissertation. It outlines the affordances of integrated STEM education that have led to the global STEM movement, while highlighting the accompanying challenges that impede its effective implementation in the classroom. Current efforts to make sense of this contested term are presented through a discussion of the many STEM frameworks that strive to provide a vision for high quality STEM education in research and practice. This chapter provides an overview of STEM literacy, one of the overarching goals of STEM education, discussing the skills, knowledge and affective constructs that contribute to the development of a STEM literate society. The underrepresented role of mathematics in integrated STEM is examined and the challenge of incorporating meaningful interdisciplinary mathematics is considered. This chapter points to the challenges integrated STEM education presents, as a nascent field, to PSTs and in-service teachers alike. Given that many teachers have not experienced integrated STEM as learners, they are unlikely to have the necessary skills and dispositions to implement integrated STEM in the classroom, leading to calls for integrated STEM education during ITE.

This chapter begins a discussion on these important areas of literature. However, each paper presented in this dissertation continues the discussion as relevant to its particular study.

The following chapter, Chapter 3, details this dissertation's research design, and provides an overview and rationale for the approaches taken in the individual papers.

Chapter 3: Methodology

3.1 Introduction

This study presents an action inquiry into the development of integrated STEM teachers by examining preservice primary teachers' (PSTs) evolving understandings of integrated STEM and their emerging STEM teacher identities while concomitantly identifying characteristics of effective learning experiences that contribute to developing STEM-literate PSTs. This chapter provides an overview of the dissertation's research design. The five papers that comprise the succeeding chapters each report on an individual study with unique research questions. This chapter presents an outline and rationale for the approaches and methods used across the five chapters. Further details on each study's specific design and approaches used are discussed in Chapters 4-8.

3.2 Participants

The research participants in this dissertation are primary PSTs. Participants were undertaking a mathematics specialism as part of their undergraduate ITE programme. This purposeful sampling strategy was chosen to best explain the phenomenon studied and provide an understanding of the research problem (Creswell, 2007; Mertler, 2019). Coordinating a mathematics specialism module provided the opportunity to introduce a new integrated STEM intervention to a convenience sample of PSTs. As these PSTs had elected to join this specialism, they had expressed their interest in the area. While this could be viewed as biasing the sample and decreasing the generalisability of the findings, the purposeful sampling of participants sought to select *information-rich cases* (Patton, 2002).

The individual papers within this dissertation report on two separate groups of participants. Chapters 4, 5 and 8 report findings from an intervention with *Cohort 1*. In Chapters 4 and 5, *Cohort* 1 (n=30) was in Year 3 of a Bachelor of Education programme at Mary Immaculate College, Limerick (Spring 2022). Chapter 8 returns to this group of participants (n=27) one year later, in the final weeks of Year 4 (Spring 2023). Chapters 6 and 7 report the findings of a second intervention, involving a different, but comparable group of participants. *Cohort 2* (n=28) was in Year 3 of their Bachelor of Education programme (Spring 2023) at the same institution. This stratified purposeful sample facilitated comparison between the subgroups (Creswell, 2007).

Chapters 5 and 6 also include children as participants in the respective studies. In Chapter 5, 25 fifth class children (aged 10-11) engaged in five STEM workshops facilitated by the PSTs in *Cohort 1*. Chapter 6 reports data from 62 sixth-class children (aged 11-12), who engaged in the research lessons with PSTs in *Cohort 2*. The children attended an economically disadvantaged, inner-city school. The school, which was identified through an existing School/University partnership, has 426 children enrolled, many of whom are newcomers from 46 different countries. While such learners are known by a variety of names in policy and indeed in literature, such as "English Language Learners, English Speakers of Other Languages (ESOL) learners, English as foreign language speakers, English as second language learner, English Learners (or ELs), Limited English Proficient (LEP) students, non-native English speakers, language-minority students, and/or bilingual students" (Sharma & Sharma, 2023, p.822), the term 'Emerging Bilingual' is used in this dissertation (particularly relating to Chapter 6) to describe these learners. 'Emerging Bilingual learners' was chosen as a non-deficit term, which acknowledges strengths that these learners bring, thus maintaining a language-as-resource outlook. While acknowledging that some of these learners may well be multilingual learners, following discussions with the classroom teacher and an expert in the field, a decision was made to use the term Emerging *Bilingual* learners. All lessons took place in the children's school environment.

3.3 Research design

Action research designs are systematic inquiries that gather data to subsequently improve teaching practices, how students learn, or the ways particular settings operate (Creswell, 2014). While Reason and Bradbury (2006) contend that there is no short answer to the question 'What is action research?', they suggest that it seeks to "bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people" (p. 1). It has been argued that action research can be applied in almost any setting "where a problem involving people, tasks and procedures needs a solution, or where some change of feature results in a more desirable outcome", thus embracing problem posing and problem solving (Cohen et al., 2018, p. 440). Improvement and involvement are, therefore, at the core of action research (Robson & McCartan, 2016). As outlined in Chapter 1, this dissertation is framed as action inquiry describing my ongoing and empirically based attempt to improve the design of a STEM teacher education module (Tripp, 2005).

Action research has been integrated into ITE programmes across disciplinary areas, offering "new insights about practical pedagogical experiences through critical interpretation of practice" (Manfra, 2019, p. 167). However, despite the benefits of action research highlighted in the literature, it has been argued that ITE programmes do not pay enough attention to such approaches (Aras, 2021; Black, 2021; Willegems et al., 2017). As a STEM teacher educator, I wanted to inform my practice, by identifying the types of learning experiences that supported the development of my students' STEM literacy and STEM teacher identity. An action research approach supported my dual role as teacher-researcher. As McKernan (1991) states;

> Action research, as a teacher-researcher movement, is at once an ideology which instructs us that practitioners can be producers as well as consumers of curriculum inquiry; it is a practice in which no distinction is made between the practice being researched and the process of researching it. That is, teaching is not one activity and inquiring into it another. The ultimate aim of inquiry is understanding; and understanding is the basis of action for improvement. (p. 3)

In line with this view of action research, this study aimed to produce practical knowledge and create new forms of understanding about STEM teacher education at ITE, since "action without reflection and understanding is blind, just as theory without action is meaningless" (Reason & Bradbury, 2006, p. 2).

3.3.1 Research paradigm

This dissertation is underpinned by pragmatism. By rejecting the dualisms of objectivism and subjectivism, and positivism and interpretivist paradigms (Biesta, 2010), pragmatism permits the researcher to "abandon these dichotomies" and adopt the "optimal philosophical position and methodology for the research question under consideration" (Cantley, 2022). Described as a new paradigm and philosophical system (Morgan, 2014), pragmatism is rooted in the work of Dewey and his emphasis on human experience (Biesta, 2010; Hammond, 2013; Morgan, 2014). Pragmatism views knowledge as generated through the combination of action and reflection, therefore knowledge from the pragmatist perspective is “always about the relationships between action and consequences, never about a world ‘out there’” (Biesta, 2010, p.25). Given the emphasis on human experience, advocates of pragmatism view reality and knowledge as being socially constructed (Cantley, 2022). Pragmatism’s view of knowledge as “generated in action and reflection on action in order to address particular problems” (Hammond, 2013, p.607) provides an underpinning for action research. Indeed Hammond (2013) suggests that pragmatism provides an epistemological basis for action research, which has been criticised for being “too easily understood as a series of steps… rather than as a perspective on the generation of new knowledge” (p.613).

Pragmatism also rejects the methodological binaries of qualitative and quantitative research, and has been strongly associated with mixed methods research (Cohen et al., 2018). Foster (2024) recently advocated for *methodological pragmatism* as a “compatibilist framework” that “liberates researchers in education to conduct the most rigorous research possible by drawing on any methods from any tradition that will further their research goals” (p.4). Similarly, the range of embedded questions across this dissertation’s studies demanded a responsive methodological approach.

The qualitative approach used in this study was chosen to explore and understand the meaning participants ascribed to STEM education and their STEM teaching and learning experiences (Creswell & Creswell, 2018). It sought to use words as data to gather rich, thick descriptions that get to the complex inner experiences of participants and determine how these meanings are formed (Braun & Clarke, 2013; Corbin & Strauss, 2008; Geertz, 1973; Miles et al., 2020). Acknowledging the many reasons to do qualitative research, Corbin & Strauss (2008, p. 16) argue that,

> the most important is the desire to step beyond what is known and enter into the world of participants, to see the world from their perspective and in doing so make discoveries that will contribute to the development of empirical knowledge.

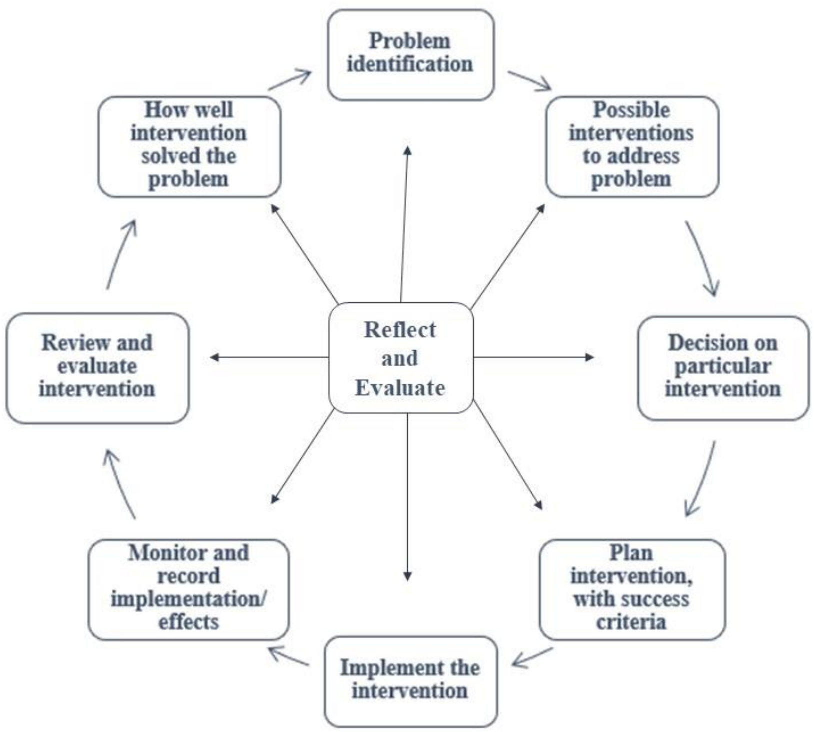
However, the research question to be answered should dictate the methodological approach used to conduct the research (Corbin & Strauss, 2008; Creswell & Guetterman, 2021). The questions driving chapters 4-6 and chapter 8 necessitated predominantly qualitative approaches to support inquiry. However, chapter 7 examines the influence of an integrated STEM intervention on PSTs' attitudes towards statistics. As the research problem was neither exclusively qualitative nor quantitative (Cohen et al., 2018), one way of looking at the problem would not do it justice (Creswell & Plano Clarke, 2011). Consequently, this chapter takes a mixed methods approach, drawing on quantitative and qualitative data and data analysis. The quantitative *Survey of Attitudes Towards Statistics* (SATS-36) scale was used to measure PSTs' attitudes towards statistics at the start and end of the elective. Written reflections were also used to generate qualitative data that provided insight into PSTs' *perceived* changes in attitudes and the *nature* of this change. The mixed method approach taken to this study provided a richer, broader, and deeper understanding of the PSTs' attitudes and experiences that a single approach could not have yielded (Cohen et al., 2018; Creswell & Plano Clark, 2011), in turn expanding and strengthening the study's conclusions (Schoonenboom & Johnson, 2017).

3.3.2 Taking a wide lens: Action research in module design

As Capobianco (2022) argues, the form of inquiry and action research you choose must be "compatible with the educational values of your workplace or educational situation and, ultimately, yield a natural desire to change and improve that situation while constructing new knowledge and understanding of a unique kind" (p.142). The overall study adopted a broad view of action inquiry, in which colleagues and I (the researcher/teacher educators) were iterating teaching and research actions in an ITE classroom setting. This research was exploratory in nature and sought to gain insight into effective teaching and learning experiences in the development of integrated STEM teachers. We aimed to be responsive in our teaching by capitalising on successes and redesigning to address shortcomings of the previous iteration. Drawing from the literature on action research, this dissertation presents two action research cycles, following Cohen et al.'s (2018) eight-step process of action research (see Figure 3.1).

Figure 3.1

Eight-step framework for action research (from Cohen et al., 2018).



3.3.2.1 Intervention 1.

The initial intervention involved participants from *Cohort 1*. The design of *Intervention 1* was informed by literature on STEM teacher education programmes. Four principles of effective STEM teacher education were identified from the literature. These principles relate to providing opportunities to experience integrated STEM as learners, opportunities to design and plan STEM tasks and lessons, to promote collaboration and reflection, and to engage PSTs in theory and literature on STEM. Given the successful ties that previous elective modules had to field practice (Hourigan & Leavy, 2019; Leavy & Hourigan, 2016, 2018), and the strong working relationship built with a local school through a School/University partnership (Hamilton et al., 2021; Leavy & Hourigan, 2022), a fifth principle relating to field practice was included in the design. Success criteria and assessment measures (e.g. pre-/post-intervention tools etc.) were piloted and incorporated into the module design. This intervention (detailed in sections, 3.3.3.1 and 4.7.2) was implemented and monitored during Spring 2022. Findings revealed many strengths of the module as outlined in

Chapters 4, 5 and 8. It became evident during the module, however, that while rich integrated STEM learning and teaching were being achieved, evident gaps in the module were emerging. A key finding from the data pertaining to *Intervention 1* related to the issue of maintaining a disciplinary balance in integrated STEM, with the challenge of authentically integrating mathematics being of main concern. This led to deep reflection and discussion amongst the teacher educators and further analysis of the data ensued to identify reasons for this neglect of mathematics within integrated STEM, part of which is reported in Chapter 5.

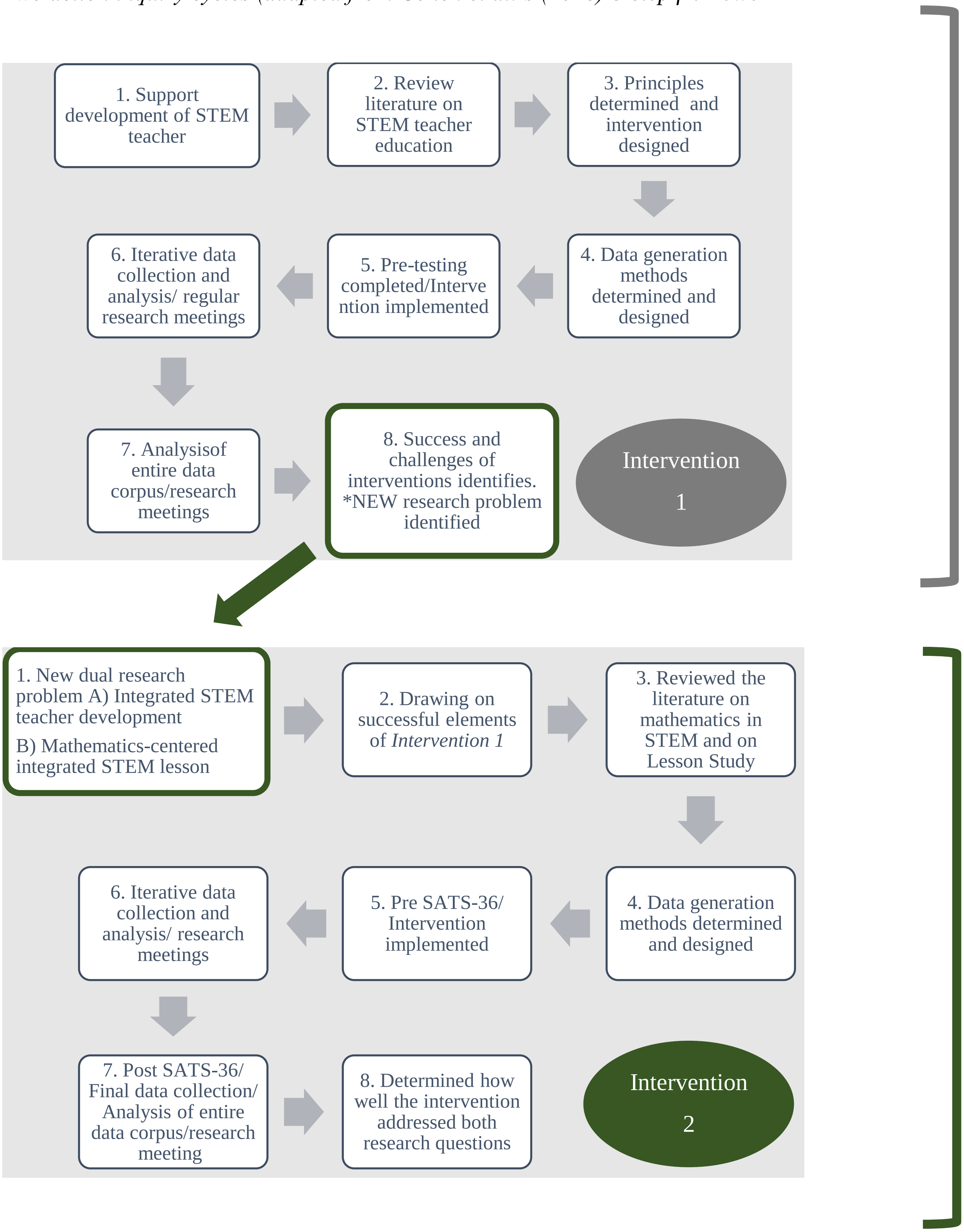
As noted in Cohen et al. (2018), action research is formative, and the problem, aims, and methodology are subject to change during the process. Indeed, Kemmis and McTaggart (2000) point out that in action research

> The stages overlap, and initial plans quickly become obsolete in the light of new learning from experience... The criterion of success is not whether participants have followed the steps faithfully, but whether they have strong and authentic sense of... the situations in which they practice (p.595, cited in Simms, 2013, p.2).

While this dissertation had initially planned to only research and report on *Cohort 1,* a significant finding from *Intervention 1* steered the overall research in a new direction (see Figure 3.2). While the focus remained on integrated STEM, the second iteration of this specialism module needed to attend to the difficulties presented by *Cohort 1* in meaningfully integrating mathematics into STEM tasks.

Figure 3.2

Two action inquiry cycles (adapted from Cohen et al.'s (2018) 8-step framework



3.3.2.2 Intervention 2.

Returning to the literature on mathematics in STEM education, we sought to redesign the module for the following year (*Cohort 2*, Spring 2023). This redesign (*Intervention* 2) desired to incorporate successful features of *Intervention 1*, such as collaborative experiences, reflection, and STEM field practice. Concomitantly, it aimed to address the new research problem identified, which was: *to maintain a focus on mathematics within STEM when supporting the development of integrated STEM teachers* (see Figure 3.2). The literature pointed to Lesson Study as an appropriate guiding framework to achieve our aims, and statistics was nominated as the mathematics strand to drive integration. *Intervention 2* (outlined in 3.3.3.2) underwent the same monitoring and review process as *Intervention 1* in an effort to identify how well the intervention addressed the problem (Cohen et al., 2018).

3.3.3 Taking a narrow lens to the collaborative inquiries within each module

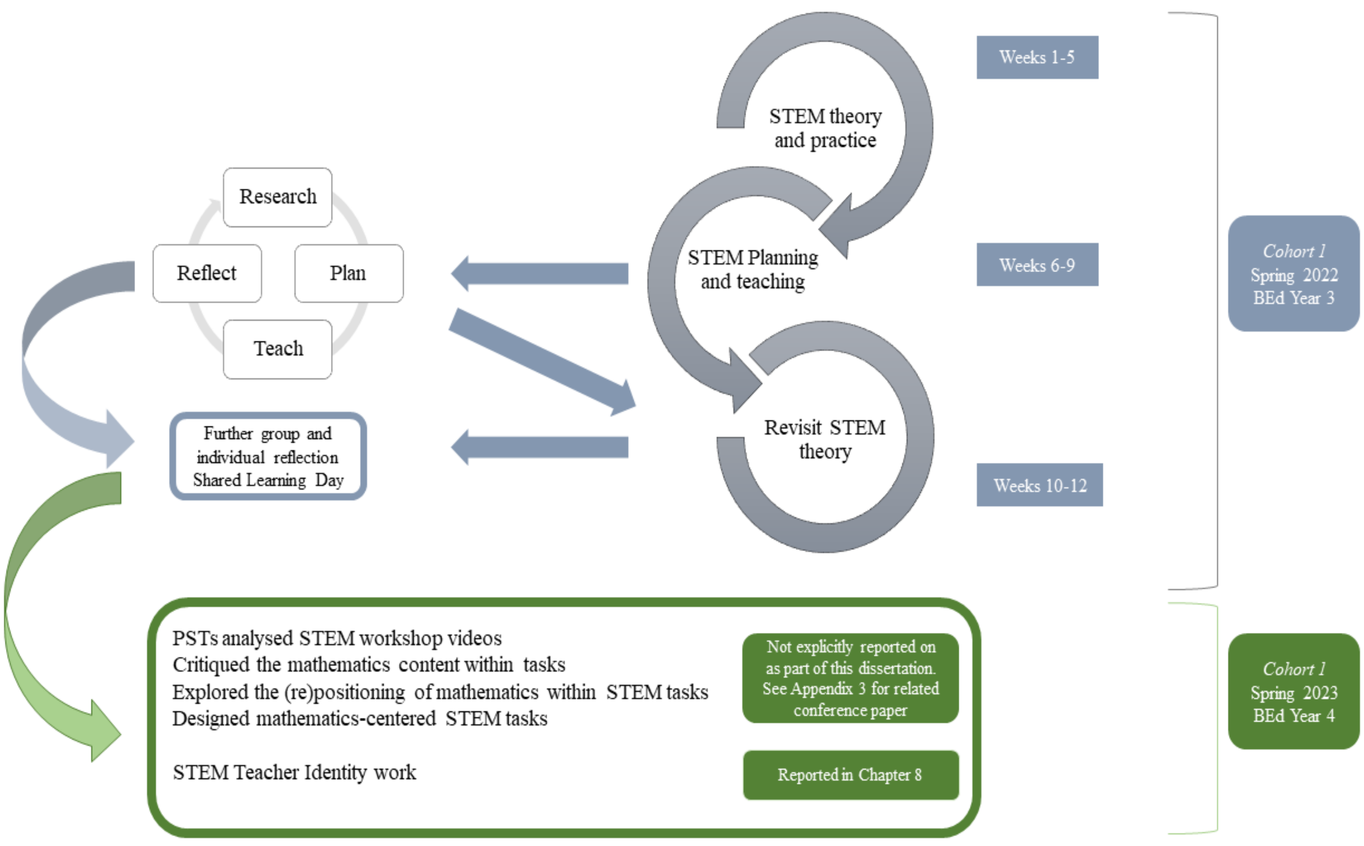
Kemmis (2009) contends that teachers' practices, their understanding of these practices and the conditions in which they practice are incessantly bound together in a turbulent bond. He argues that while "each shapes the other in an endless dance in which each asserts itself, attempting to take the lead, and each reacts to the others", action research can serve as "a kind of music to this dance- a more or less systematic, more or less disciplined process that animates and urges change in practices, understandings and the conditions of practice" (p. 463). While action research frames the overall research aim to design and redesign effective learning experiences for primary PSTs, the two interventions at the heart of this dissertation present collaborative action approaches to engage PSTs in a critical inquiry into their own STEM practices, their understanding of these practices and the conditions in which they practice.

3.3.3.1 Cohort 1: Collaborative inquiry into integrated STEM in action.

For changes in practices to be not only initiated but sustained, the literature points to the importance of linking reflection, collaboration and inquiry (Loughran, 2010). *Cohort 1* engaged in a form of collaborative inquiry (see Figure 3.3). Firstly, they worked together as they explored and made sense of STEM education as STEM learners. They then collaboratively planned and facilitated five STEM education workshops in a local school with a pre-existing School/ University partnership. PSTs observed children's actions and STEM learning, noting children's decision-making, recording the use of disciplinary knowledge, 21st century skills, alongside challenges and obstacles when engaging with the tasks. They subsequently engaged in collaborative reflection with their peer group and teacher educators. All participants, PSTs and teacher educators, shared their observations and what they had noticed, supporting and challenging each other to think deeply and critically about the experiences. PSTs engaged in further prompted reflection exercises, and the participants planned for future modifications of the tasks in light of their shared observations and findings.

Figure 3.3

STEM education experiences for Cohort 1 (Intervention 1 in grey)



Note: Intervention 1 is illustrated above in grey. The section in green illustrates a follow up intervention with *Cohort 1* in Year 4, to address their concerns about the role of mathematics in integrated STEM. This intervention is not reported as part of this dissertation. However, an overview is given here (and in Chapter 8) to provide insight into the range of their experiences in the context of their emerging STEM teacher identity.

Action research has been described as a meta-practice (Kemmis, 2009; Kemmis & Grootenboer, 2008), a practice-changing practice. Kemmis (2009) refers to our "prefigured" notions of *what education means* (shaped by pre-existing ideas in educational discourse, "thinking" and "saying" that orient and justify practices), *how education is done* (shaped by the materials and resources available to us) and how people *relate* to each other in educational settings (shaped by previously established patterns of social relationships and power). However, he argues that each new experience or "episode of a practice" makes possible new understandings, and that as such "the sayings and doings and relatings that compose practices are restlessly made and re-made in and through practice" (p. 466). The influence of the inquiry on the PSTs' own practice is further explored in Chapter 8, as they reflect on the many experiences and "episodes" that have contributed to their emerging STEM teacher identity, highlighting the STEM intervention as a significant turning point.

3.3.3.2 Cohort 2: Lesson study as collaborative inquiry.

Intervention 2 was guided by a specific collaborative inquiry framework, Japanese Lesson Study. Lewis et al. (2009) describe Lesson Study as "a system for building and sharing practitioner knowledge that involves teachers in learning from colleagues as they research, plan, teach, observe and discuss a classroom lesson" (p. 2). Lesson Study is an embedded practice in Japan, being viewed as part of the job (Stigler & Hiebert, 1999) or as Fujii (2016) puts it, "like air, part of everyday school life" (p. 411). Despite having a rich history in Japan, spanning over a century (Ding et al., 2023), English-language accounts did not appear until the late 1990s (Lewis & Takahashi, 2013). Global attention was drawn to Lesson Study following the Third International Mathematics and Science Study (TIMSS), which highlighted Japan's high student achievement. Of particular influence was the publication of Stigler and Hiebert's (1999) *The Teaching Gap,* which offered a comparison of U.S. and Japanese reform efforts, making links between Lesson Study and Japan's successful educational landscape. Many potential benefits of Lesson Study have been highlighted in the literature, including the development of pedagogical skills, content mastery and discipline-specific teaching practices; the evolution of teacher beliefs; the promotion of teacher-learning communities; the improvement of student learning outcomes; and the strengthening of connections between research and practice (Ding et al., 2023; Huang & Shimizu, 2016; Lewis et al., 2019; Ní Shúilleabháin, 2022). Lesson Study can also facilitate curriculum reform and implementation (Lewis & Takahashi, 2013; Stigler & Hiebert, 1999).

While primarily associated with the professional development of in-service teachers, studies at the ITE level have grown steadily. By rooting teacher learning in the classroom, Lesson Study can bridge the *theory to practice* divide, responding to the common criticism of ITE internationally (Hourigan & Leavy, 2019; Larssen et al., 2018). Pérez Granados et al. (2024) refer to how Lesson Study can "show them [the PSTs] the value of theory in their profession and how it helped when making decisions and solving problems that arose in practice" (p. 16). Lesson study has also been associated with the development of PSTs' important noticing and reflection skills, and the ability to critically analyse and evaluate research lessons (Hourigan & Leavy, 2019; Leavy & Hourigan, 2016). Acknowledging the challenge of developing teacher noticing skills amongst PSTs, Guner & Akyuz (2020) found that the structure of Lesson Study contributed to PSTs' noticing of students' mathematical thinking. They suggest that investigating the mathematics involved, anticipating students' thinking, working collaboratively with peers, making observations in authentic classrooms and engaging in post-teach conversations about these observations, fostered the desired noticing skills. Hourigan & Leavy (2019) also credit the intentional features of the model for such reported gains, suggesting that attention to noticing was initiated during the planning phase through a structured lesson note, which required PSTs to predict student responses and identify subsequent teacher reactions.

Lesson Study had been found to support the development of mathematical knowledge, specialised content knowledge and pedagogical content knowledge during ITE (Leavy, 2010; Leavy & Hourigan, 2016; Leavy & Hourigan, 2018; Lewis, 2019; Ní Shuilleabháin & Meehan, 2018), as well as the supporting the development of positive teachers' beliefs, values and dispositions (Péraz Gómez et al., 2024; Soto et al., 2015). Therefore, Lesson Study has potential to contribute to transformational learning. As Cajkler and Wood (2016) contend, Lesson Study "focused on the improvement of pedagogy, not just the 'performative' (Ball, 2003) training of a prospective teacher to meet a list of standards" (p. 94), supporting the notion of the "continually learning teacher" (p. 95), thus developing an inquiry stance and facilitating PSTs' transition into teaching.

Although the extent to which Lesson Study is considered a form of action research has been contested, they are undoubtedly closely related (Hanfstingl et al., 2019). Lesson Study has been conceptualised as a tool for instructional improvement (Lewis et al., 2006), a form of professional development (Fujii, 2016) and a professional learning approach (Lewis, 2009). However, Takahashi & McDougal (2016) remind us of the importance of maintaining a clear research focus, something which they argue appears to have been "lost in translation" as practitioners apply *jugyou kenkyuu* (Japanese Lesson Study) in their own contexts (p. 514). Therefore, Lesson Study can be positioned as "a process in line with action research: action for change and research for understanding" (Pérez Granados et al., 2024, p. 8). Other researchers have positioned Lesson Study as a category of action research, describing it as a "far-eastern example of action research" (Posch, 2019, p. 496), a form of action research originating in Japan (Austin, 2017) and a "highly specified form of classroom action research focusing on the development of teacher practice knowledge" (Dudley, 2011, p. 2). Indeed, Lewis and colleagues (2009) argue that Lesson Study's inquiry cycle is consistent with Noffke's (1997) three-pronged description of action research, which seeks to improve teachers' knowledge and effectiveness (the *personal*) by collaboratively building knowledge and theory (the *professional*), thus supporting goal development and the teaching culture (the *political*).

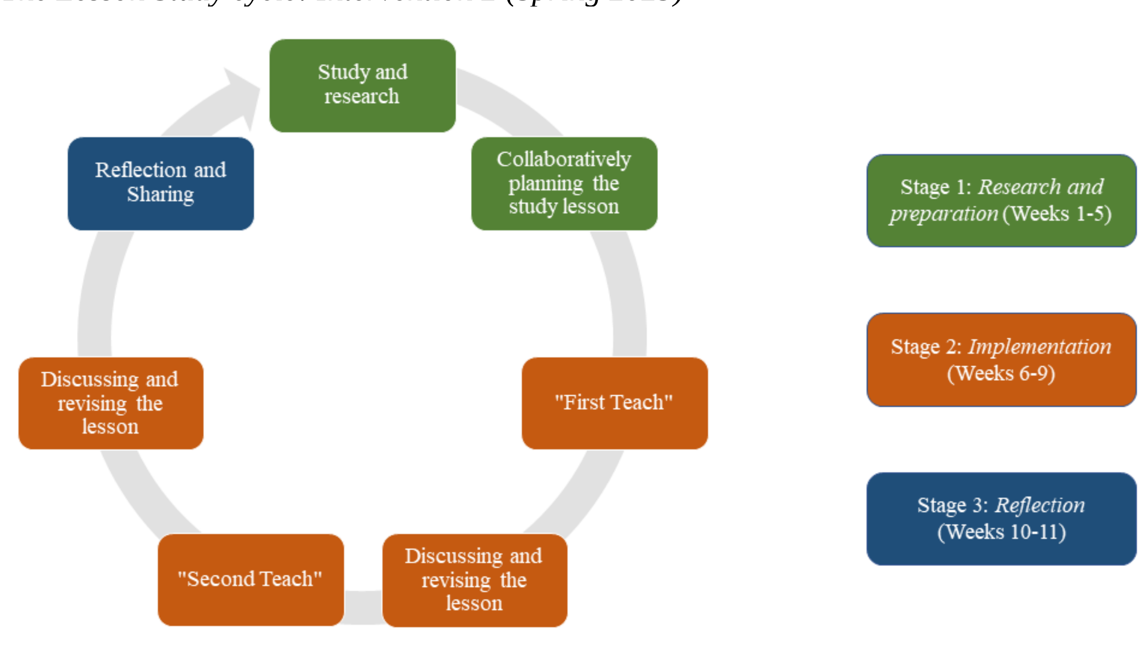
As Ní Shuilleabháin (2022) proposes, Lesson Study can be viewed "as layered activity where teachers research their own practice and the researcher(s) working with them can focus on a same or separate research question" (p. 129). This dissertation examines both layers. Chapter 6 reports on the researchers' and PSTs' shared research question, examining children's statistical reasoning in an integrated STEM context. Chapter 7, on the other hand, centers on the PSTs as study participants, examining their attitudes towards statistics following the Lesson Study cycle. Lesson Study guided the PSTs through three distinct stages (Figure 3.4). Stage 1 was the *Research and Preparation stage.* It introduced the PSTs to Lesson Study and engaged them in key readings on the process. Participants (Cohort 2) were introduced to the global issue of colony collapse disorder and engaged in literature to deepen their understanding of pollinators and the role of data science for active citizenship. An expert on the honeybee was also invited to give a guest lecture on the area. PSTs engaged in further reading to deepen their knowledge of statistics education (PSTs had just completed a core statistics education module the previous semester) and inclusive strategies to support Emerging Bilingual learners in the classroom. Reading materials are detailed in Chapter 6. PSTs formed five Lesson Study groups (5-6 members in each group), and each group designed one of a series of 5 consecutive lessons (outlined in Chapters 6 and 7).

Stage 2 was the *implementation stage*. Each group delivered their lesson across five consecutive days to one 6th class in a local school. Each lesson was taught by a PST and observed by the other Lesson Study group members and the teacher educators (researchers). A post-lesson meeting followed each lesson. This debriefing session (detailed in 3.4.6) provided an opportunity for reflection and feedback. PSTs then redesigned their lesson in light of their observations and discussions on *Teach 1*, and subsequently taught the revised lesson to a comparable 6th class in the same school.

In Stage 3, the *reflection stage*, PSTs shared a summary and analysis of their research lesson in a group presentation for their peers, reporting on their observations and learning about the key aims of their Lesson Study.

Figure 3.4

The Lesson Study cycle: Intervention 2 (Spring 2023)



3.4 Data generation measures

A range of data generation methods were used across the studies that make up this dissertation. Table 3.1 outlines the characteristics of the individual studies conducted.

Table 3.1

Characteristics of studies conducted

Chapter	Participants	Year	Sample size	Data generation methods
4	*Cohort 1*	Spring 2022	30 PSTs	Pre-/Post qualitative survey Pre-/Post STEM task analysis Participant journals
5	*Cohort 1*	Spring 2022	30 PSTs 25 children	Post-teaching focus groups Participant journals and written reflections Field notes Video footage of STEM lessons Group presentations
6	*Cohort 2*	Spring 2023	28 PSTs 62 children	Lesson plans and feedback Lesson resources Samples of children's work Classroom observations Classroom audio recordings Field notes Post-teaching focus groups Written reflections Group presentations
7	*Cohort 2*	Spring 2023	28 PSTs	Pre-/Post SATS-36 Written reflections Group presentations
8	*Cohort 1*	Spring 2023	5 PSTs	STEM Story-lines Graph annotations Video narratives Prompted reflections Semi-structured interviews

3.4.1 Qualitative STEM Survey

The pre-and post-intervention surveys (*Cohort 1, Intervention 1*, Chapter 4) were administered in weeks 1 and 11, respectively. The pre-intervention survey consisted of a 13-item questionnaire. The survey items were informed by Hourigan et al.'s (2022) study with in-service teachers. The survey began by collecting demographic information on the participants, while the remaining items focused on their current perspectives on STEM and STEM education: how related they perceived the disciplines to be, how they would teach STEM in the classroom, the perceived benefits of STEM for children, challenges that exist and concerns they had, and how confident they would be to teach STEM. The items exploring discipline-relatedness and confidence levels asked participants to give a ranking from 1 (*not at all*) to 10 (*extremely)* and explain their choice. All other items required open responses. The post-intervention survey had one extra item, which asked participants to advise other PSTs on how to design and teach a good STEM lesson (see Appendix D). The majority of participants completed both pre- and post-intervention surveys during class time. A *Microsoft Forms* version of the pre-survey was emailed to three participants absent during Week 1.

As Cohen et al. (2018) argue, all elements of the research design, including methodologies and instruments to collect and generate data, are deliberately chosen for their *fitness for purpose*. Mindful of the "trade-off between the potential breadth and depth of the information that can be gathered" (Prendergast & O'Meara, 2022, p. 127), this survey, or questionnaire, was chosen as a quick and efficient approach to gathering data from all participants at the same point, prior to and post engaging in the intervention. This survey was qualitative in nature, as it was deemed to be well suited to research on experiences, understandings, perspectives and practice-type questions (Braun & Clark, 2013). Given the small sample size, open responses allowed for more in-depth information to be gathered. All data were typed and compiled in Microsoft Excel, to aid analysis and intercoder comparisons.

3.4.2 Task analysis

The STEM task analysis activity (*Cohort 1, Intervention 1*, Chapter 4) was completed pre- and post-intervention in an effort to identify changes in PSTs' understanding of STEM education, development of their STEM knowledge, and changes in their ability to recognise opportunities for STEM education in practice. Participants were presented with a STEM task outline and asked to complete a task analysis document. The task outline (see Figure 3.5) and analysis template (see Appendix E) were identical in weeks 1 and 11. The task chosen was an adapted version of an integrated mathematics and science activity from Science Foundation Ireland's (SFI) *Discovery Primary Science and Maths* programme (SFI n.d). This particular task was chosen as it was deemed a high-quality, integrated task but lacked key elements of published STEM frameworks, such as being embedded in a real-life context or engaging the students in design thinking (see Chapter 2, section 2.4) The analysis template required the participants to review and critique the task as detailed in Chapter 4. They were also asked to provide at least one modification that could be made to enhance the task and justify their reasoning. In doing so, this activity facilitated the comparison of their STEM knowledge-in-action following exposure to the intervention, by identifying how they could apply what they learned to a pedagogical situation. In measuring the quality of the task enhancement (that is, what was deemed a 'good' STEM task), I drew on the characteristics of high-quality STEM education (such as the use of real-world contexts and development of 21st century competencies) as identified from the available literature and published STEM frameworks (detailed in 2.4 and 5.3.2).

Figure 3.5

STEM task outline for task analysis activity (Intervention 1)

3.4.3 Video recordings of lessons

Each of the five STEM workshops in *Intervention 1* was video recorded and digitized (and became a data source for Chapter 5). Video was chosen as it can "provide us with opportunities to thoroughly consider the complexity typical of social practices" (Blikstad-Balas, 2017, p. 511). Video offered three distinctive features, as identified by Jewitt (2012). Firstly, video provided data through a real-time sequential medium. Secondly, video data produced a fine-grained multimodal record, which thirdly, were durable, malleable, and shareable. Obtaining video footage of each of the five STEM workshops allowed the researchers to reexamine classroom practices and interactions more closely. It also afforded the PSTs an opportunity to review their own lessons and interactions, and make further observations on children's STEM learning. It also made it possible for PSTs to view and analyse their peers' STEM lessons, allowing key moments to become a shared unit of analysis.

3.4.4 STEM Story-lines

STEM story-lines (*Cohort 1*, Chapter 8) provided a graphical account of PSTs' experiences of science, mathematics, engineering and science education to support them in their STEM teacher identity development. Beijaard et al. (1999), who were the first to use the story-line method in the field of teaching and teacher education, suggest that the approach "fits into the narrative research tradition because of its emphasis on teachers' stories, i.e., the way teachers make sense of experiences and events they encounter in their own teaching practice (cf. Connelly & Clandinin, 1990)" (Beijaard et al., 1999, p. 47). Such visual methods also allow for a novel and creative form of expression (Packard & Conway, 2006). The graph template and accompanying narrative elicitation methods were devised by adapting previous studies from Bobis et al. (2021), Conway (2001) and Beijaard et al. (1999). These three studies, detailed in Chapter 8, each took a unique approach to identity graphing/story-lines to meet the needs of their participants and research questions (see Figures 3.6-3.8). The STEM story-line templates in Chapter 8 (Figure 3.9) leaned on Conway's (2001) use of 'comfort' levels on the *y axis.* Participants were asked to visually represent their comfort levels (from low to high) reflecting the degree of enjoyment, dislike, confidence or anxiety associated with each discipline throughout their experiences. Bobis et al.’s (2021) use of key events and experiences across time informed the *x axis* (Figure 3.6) with the addition of Conway’s “The Future?” (Figure 3.7) which encouraged participants in this study to consider their future-oriented reflections, i.e. where they envisage their comfort levels being in the future.

Figure 3.6
Example identity graph from Bobis et al.’s (2021)

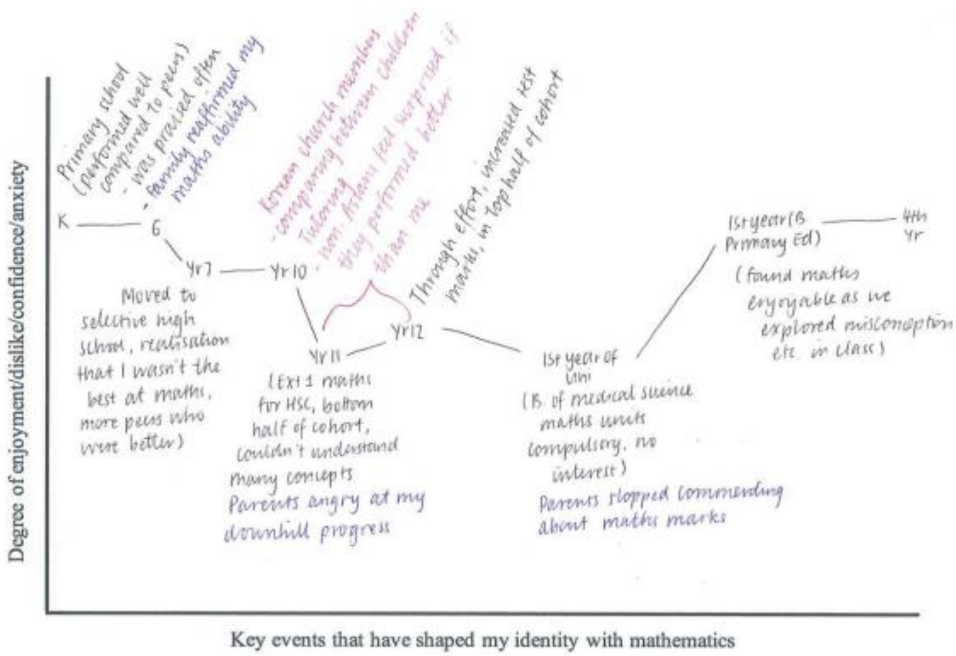


Figure 3.7

Conway's (2001) Contours of the intern year activity

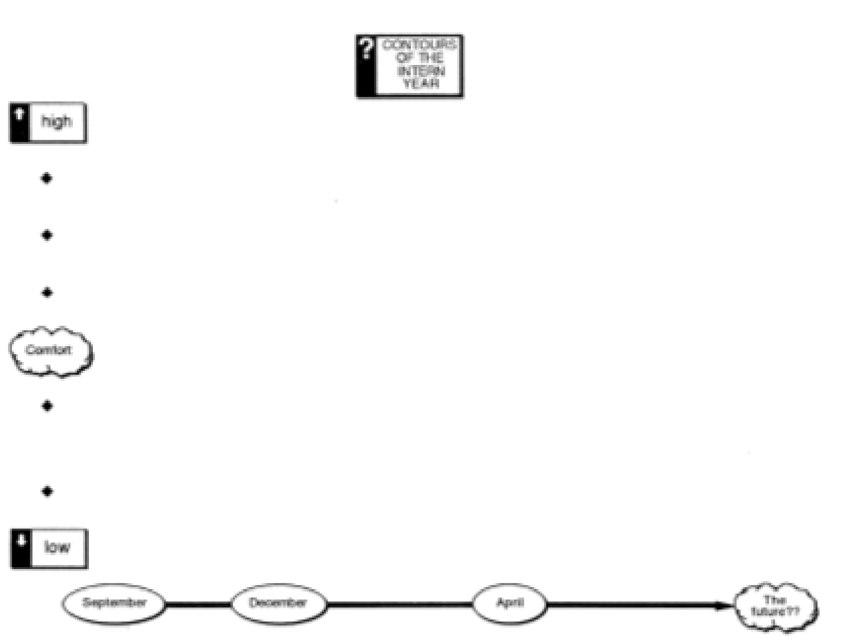


Figure 3.8

Bejaard et al.'s (1999) Illustration of Two Teachers' Story Lines Concerning Their Professional Motivation

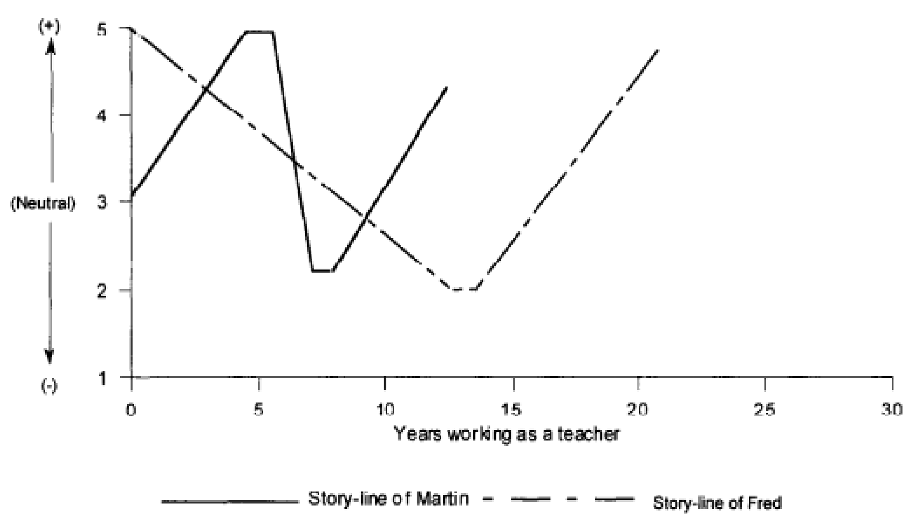
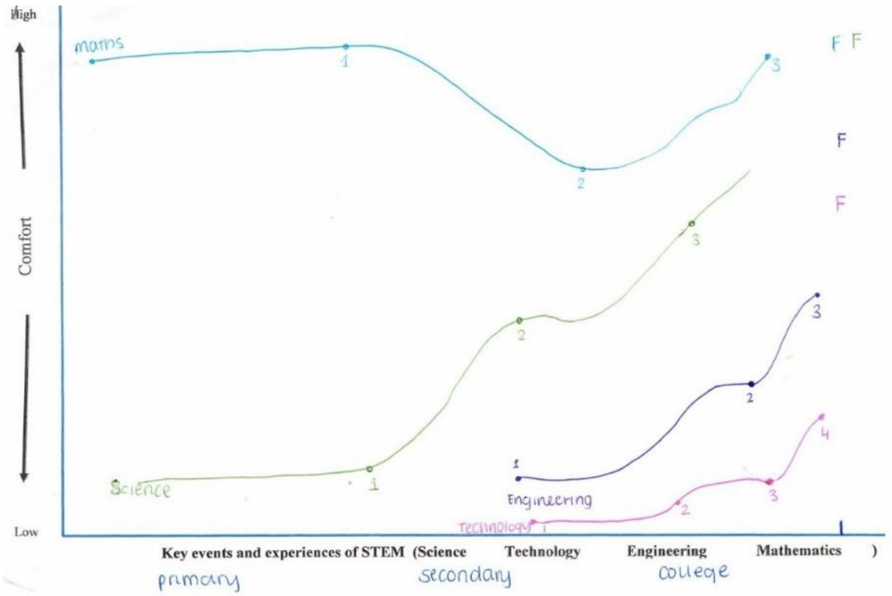


Figure 3.9
Completed STEM story-line (Participant 2)



It has been noted that inviting participants to construct images *and* annotate their meaning results in relatively high input, thus leading to new insights for the researcher (Packard & Conway, 2006). Once the story-lines were drawn, participants were asked to identify key moments (high points, low points, turning points) on their graph. Given the *'busyness'* of the STEM story-lines, with four individual lines on one graph, participants were asked to mark timestamps that were important to them with a number, codeword or symbol on the graph, and then write a short corresponding narrative describing the event on a separate page (see sample of completed annotations sheet in Appendix F). All 27 PSTs in the class completed these story-line activities. Due to time constraints, it was not feasible to interview all 27 participants. However, in an effort to capture a fuller picture of their STEM stories, the PSTs recorded a short, three-minute video narrative that guided the viewer through their STEM story-lines, reflecting on and describing key events. They also completed a related prompted reflection, which required the participants to consider how the experiences noted in the graph have shaped them as a teacher, and to describe their future as a STEM teacher. The entire class data were used to identify a purposeful sample of information-rich cases that were subsequently invited to attend interviews.

3.4.5 Interviews

Qualitative interviews were used to further explore the emerging STEM teacher identity of the five participants identified during the STEM story-line activity above (*Cohort 1*, Chapter 8). Kvale (1996) reminds us that the *inter-view* is an interchange of views on a topic of mutual interest, offering the image of the interviewer as a *traveller*, who journeys with the interviewee into unknown territory, thus co-constructing knowledge (Cohen et al., 2018). Interviews were the chosen methods of data collection in this instance as they provide “rich and detailed data about individual experiences and perspectives” by offering the flexibility to ask unplanned questions and probe participant thinking (Braun & Clarke, 2013, p. 80).

Interviews were semi structured, in that they used the STEM-story lines and an interview schedule to guide the process, but were open to being “substantially modified based on the flow of the interview” and asked additional unplanned questions as a follow up to participants comments (Robson & McCartan, 2016, p.285). While Banks (2018, p. 76) refers to the method of photo-elicitation which can put the interviewee at ease and awaken memories, where “the awkwardness that an interviewee may feel from being put on the spot and questioned by the interviewer can be lessened by the presence of a photograph to discuss... ”, similarly, the use of the previously drawn STEM story-line graphs as an introduction to the interview were used to make the participants feel at ease. Using the STEM story-line, they were enabled to retell their stories, and as highlighted in Chapter 8, unearth forgotten memories and unrealised experiences. The interview schedule was also informed by Galanti and Holincheck’s (2022) framework for STEM teacher identity (with questions relating to participants’ motivation, self-image and self-efficacy for teaching STEM) and Lutovac’s (2020) and Lutovac and Kaasila’s (2014) work with PSTs on future oriented identity (with questions such as *How has that experience shaped you as a teacher?*, and *How do you see your future as an integrated STEM teacher?*). Interviews lasted approximately 34 minutes. All interviews were digitally audio-recorded and transcribed for analysis.

3.4.6 Focus groups

Across both *Intervention 1 and 2*, focus groups were the chosen method to support de-briefing as they provided an opportunity for collaborative reflection on a shared experience. Focus groups allowed for rich data generation, due to what Mertler (2019) describes as “people’s tendency to feed off others’ comments” (p. 175). The focus group took place immediately after the STEM workshops with *Cohort 1* (Chapter 5) and following the Lesson Study *Teach 1* and *Teach 2* with *Cohort 2* (Chapter 6). Each focus group consisted of the 5-6 PSTs in the individual workshop/lesson study group and 3 teacher educators. These de-briefing conversations reflected on the students' learning, based on the PSTs' and teacher educators' observations of the implemented classroom practice (Shimizu & Kang, 2022). As Kager et al. (2022) argue, it is the students' responses to the planned activities that are scrutinised in the post-teach discussions, and not individual teachers' skills. Therefore, the conversations were rooted in a culture of collaboration and shared responsibility. Post-teaching sessions began by discussing the workshop/lesson and sharing observational data collected (i.e. observations of children's learning and thinking, observations they were surprised by etc.).

Discussions then led to what we learned about the workshop/lesson's main aim (children engagement in design tasks; children's conceptual understanding of measures of central tendency; children's understanding of relationships between variables etc.), the challenges experienced, and our key takeaways from the lesson. Final discussions centered around possible adaptions and modifications that could be made to the workshop/lesson considering their observations of children's learning. Discussions were digitally recorded and transcribed for analysis.

3.4.7 Group presentations

Each group of PSTs in *Interventions 1* and *2* (n=10 groups, Chapters 4, 5, 6 and 7) presented a summary of their workshop/lesson, key observations from the classroom, and final activity modifications (for a hypothetical re-teach) to their peers and teacher educators. PSTs included photographs from the classroom, workshop/lesson artefacts and samples of children's work, and shared their learning and key take-aways from the experience (STEM workshops/ Lesson Study). Each presentation lasted approximately 25 minutes, with 5 minutes assigned for questions and discussions at the end.

3.4.8 Reflective prompts and participant journals

Participants generated data through a variety of elicited documents (Charmaz, 2014). Participating PSTs in *Cohort 1* kept a participant journal (Chapters 4 and 5), each receiving an identical notebook on the first day which they labelled with their unique identifier code, thus encouraging frank discussion and honest reflection. PSTs used this journal at each stage of the 12-week intervention and were encouraged to use it freely to record their thoughts and questions. Guidelines for prompted reflections and exit slips ranged from detailed to minimal instructions. The use of the journal was selected in this instance to support the tracking of PSTs' evolving understandings across the 12 weeks.

Participants in *Cohort 2* were required to complete written reflections at various stages during their intervention (Chapters 6 and 7). PSTs were asked to write a reflective critique of their experiences at the end of the Lesson Study cycle, offering a space for substantial individual reflection. Prompts guided them to reflect on their understanding of teaching and learning in STEM education, insights into children's statistical thinking about the statistical concepts taught, what they observed and learned about Emerging Bilingual learners, and what they understood about the statistical concepts they taught, and how they should be taught.

3.4.9 Lesson plans and classroom observations

Lesson plan drafts, their annotated feedback, and final lesson notes were also collected (*Cohort 2,* Chapter 6). PSTs used a specific lesson note outline to plan their Lesson Study research lessons. These plans, adapted from Ertle et al. (2001), required the PSTs to consider not just the steps involved in the lesson but also possible student responses and reactions to these lesson activities and subsequent teacher responses (see Figure 3.10). Furthermore, it compelled PSTs to describe the goal of each section of the lesson, and to provide a detailed description of how they would determine the achievement of such goals in the classroom, thereby formulating an observation protocol. PSTs made written notes during the lesson as they observed their peers teaching and recorded small group discussions at their table during whole class activities.

Figure 3.10

Excerpt from Ertle et al.'s (2001) Example Descriptions for Study Lesson Plans

Steps of the lesson: learning activities and key questions (and time allocation)	Student activities/ expected student reactions or responses	Teacher's response to student reactions / Things to remember	Goals and Method(s) of evaluation
This column is usually laid out in order by the parts of the lesson (e.g., launch, investigation, congress, extension/applications, etc.), and also includes the allocation of time for each of these parts. *This column should also include a description of key questions or activities that are intended to move the lesson from one point to another.*	*This column describes what students will be doing during the lesson, and their anticipated reactions or responses to questions/problems you will present.*	*This column describes things that you want to remember to do/not to do within the lesson as well as other reminders to yourself.* *Also, as you have anticipated student responses and reactions (previous column), this column provides a place where you can think through how you might use those responses and reactions in synthesizing a true learning experience within your classroom.*	*This column describes the goals that are being focused upon during each part of the lesson, and for each activity/problem.* *It should also include a concrete description of how you will determine that you have achieved each of these goals.*

Guiding questions			
How should this lesson progress? (How much time should I spend?)	*What do I expect of my students? How will they respond?*	*Is there anything specific I want to remember to do? Any reminders for my students?*	*What should I look for to know that my goal(s) have been achieved?*

3.4.10 Field notes and researcher diary

Capobianco (2022) highlights the importance of the researcher's notebook when engaging in action research, as a place for "recording and containing ideas, insights, and reflections" (p. 143) and "develop the habit of mind of becoming a reflective practitioner" (p. 147). Across both *Intervention 1 and 2,* my field notes also included researcher observations on children's thinking and reasoning, along with PST interactions during classroom practice. These observational notes were recorded in the field, at times accompanied by theoretical notes (my thoughts on those observations and events). More detailed memos (Charmaz, 2014; Corbin & Strauss, 2008) were written at home. These memos, Charmaz (2014) argues, "catch your thoughts, capture the comparisons and connections you make, and crystallize questions and directions for you to pursue" (p. 162). Keeping field notes, and a researcher diary, recorded and tracked the analytical insights that developed during data collection (Patton, 2002).

3.4.11 Survey of Attitudes Towards Statistics (SATS-36)

The pre and post versions of the survey were administered at the beginning and end of *Intervention 2* to measure changes (or not) in PSTs' attitudes towards statistics (Chapter 7). The Survey of Attitudes towards Statistics (SATS-36) (Schau, 2003) consists of 36 items measuring six attitude components, namely *Affect* (students' feelings concerning statistics), *Cognitive Competence* (students' attitudes about their intellectual knowledge and skills when applied to statistics), *Value* (students' attitudes about the usefulness, relevance, and worth of statistics in personal and professional life), *Difficulty* (students' attitudes about the difficulty of statistics as a subject), *Interest* (students' level of individual interest in statistics), and *Effort* (amount of work a student expends to learn statistics). The literature provides extensive support for the multidimensionality of the SATS-28 and SATS-36 constructs and confirms the reliability and validity of the scales (e.g., Coetzee & Van Der Merwe, 2010; Persson et al., 2019; Vanhoof et al., 2011). Indeed, in their review of fifteen scales commonly used to measure attitudes towards statistics, Nolan et al. (2012) concluded that the SATS-36 demonstrated the strongest levels of construct validity and internal consistency. The scale has been used extensively in ITE to examine the impact of course design features on the attitudes of PSTs towards statistics.

3.5 Data Analysis

Given each chapter's range of data and research questions (Chapters 4-8), a responsive analytical style was chosen for each. A grounded approach to data analysis was adopted in Chapters 4 and 6, in an effort to derive themes that were "grounded in a close inspection of qualitative data gathered from concrete, local settings" (Braun & Clarke, 2013, p. 184) and grounded in the views of the participants of the study (Creswell & Creswell, 2018). It should be noted from the outset that Chapters 4 and 6 took a grounded *approach* which Braun & Clarke (2013) refer to as 'GT-lite'. However, Corbin and Strauss (2008) argue that regardless of whether the researcher aims to build theory or otherwise, any qualitative researcher can use many of their procedures. Chapters 4 and 6 drew on multiple stages of data collection, with collection and analysis being conducted simultaneously in an iterative process (Charmaz, 2014), thus helping me to define, explicate, and conceptualise what was happening in the data (Charmaz, 2017). The approach encouraged me to think analytically throughout the research process, which supported reflection and action throughout the inquiry, and highlighted further opportunities for data collection (e.g. new written reflection prompts for PSTs). Focused coding followed initial coding, allowing for the synthesis, analysis and conceptualisation of larger segments of data (Charmaz, 2014). The constant comparative method was utilised to compare data to data, and data to emerging concepts (Creswell & Guetterman, 2021; Engler, 2022) and to support the identification of themes and differences within and across each participant's data corpus (Boeije, 2002; Charmaz, 2014; Ryan & Bernard, 2003).

Data in Chapter 5 underwent two separate rounds of coding. The first pass through the data used inductive coding to generate themes. One of these themes *Rich STEM lessons, with an emphasis on engineering and 21st century skills; but where's the mathematics?*, subsequently became the focus for the second pass through the data guided by a deductive analytic framework. This reanalysis of the data aimed to gain retrospective insight into *why* mathematics appeared to have been neglected in these lessons, by identifying factors that contributed to, or inhibited, a focus on mathematics within the integrated STEM workshops.

The mixed methods approach in Chapter 7 also demanded mixed analyses. The data from the SATS-36 was statistically analysed. To measure the internal reliability of each component of the SATS-36, Cronbach alpha values were calculated for each component of both pre- and post-surveys. For each of the 6 components (Affect, Cognitive Competence, Value, Difficulty, Interest and Effort), a component value was calculated for each participant by summing each item score within that component and subsequently calculating the mean of these items. Descriptive data analysis was completed to determine PSTs' attitudes to statistics across components. Subsequently, in order to gauge the impact of participation in the elective on participants' attitudes to statistics, the pre and post surveys were matched using unique identifiers used across the study. Descriptive and inferential analyses were completed to examine the nature of changes in participants' attitudes across the elective course. Given the lack of normality within distributions, the Wilcoxon signed-rank test was used as a non-parametric alternative to the t-test, to determine whether changes in PSTs' attitudes within the respective SATS-36 components were statistically significant. Further insight into PSTs' *perceived* changes in attitude was sought through qualitative means. The related qualitative data generated through written reflections was then thematically analysed, to provide the rich, thick descriptions needed to reveal the complexity and contradictions of PSTs' stories of their experiences, and to locate the meanings they place on events (Miles et al., 2020; Braun & Clarke, 2013).

To begin the examination of participants' emerging STEM teacher identity, Chapter 8 adopted a narrative approach. Given the various *storied* accounts (graphic, video, written reflections, interview transcripts) shared by the PSTs, initial exploration used the individual as the unit of analysis, drawing together "elements from multiple stories to construct an overarching narrative" (Braun & Clarke, 2013, p.333). Once a sense of each participant's emplotted story (Lutovac & Kaasila, 2019) was constructed, Reflective Thematic Analysis (Braun & Clarke, 2021; 2022) was utilised to identify patterns across the five participants' data and generate themes. This required familiarising myself with the data, systematically coding and categorizing the data, organising these codes into broader themes or patterns that captured key STEM-teacher identity components, all the while reflecting on my own biases and interpretations throughout the process of analysis.

3.6 Ethical considerations

I received approval from the Mary Immaculate Research Ethics Committee (MIREC) to engage in this research. Approval under MIREC number A19-051 was received in January 2022. All ethical guidelines were adhered to during the course of the research. Ethical considerations were strictly put in place prior to commencing the research. Participants were given an information sheet detailing the study's aims and what their participation involved. It highlighted their rights to anonymity and how that would be protected. It reassured the participants that their involvement was voluntary and reminded them of their right to withdraw from the research at any time without reason or repercussion. The information letter also explained how the data would be used and disseminated, and outlined what would happen to the data on completion of the research. Once participants had time to consider this letter, informed consent was obtained (See Appendix G for sample documents). In relation to Chapters 4, 5 and 6, the school children were given a child-friendly information and assent form, while their parents and guardians were also provided with an information and consent form. It was explained to children that the research aspect was voluntary, and they were assured that they could still partake in the classroom activities regardless of their participation in the study.

Given that I was both researcher and teacher educator, further considerations existed in terms of sampling and gaining informed consent ethically. Ferguson et al. (2004) argues that a fiduciary relationship exists between the university student and the teacher/researcher. This relationship is central to the education of students and the learning situations that are created for them. I had a dual role and responsibility, something which Ferguson et al. (2004) refer to as ‘double agency’. They state that this violates the fiduciary relationship. However, it is also acknowledged that faculty research involving students is necessary, as teacher educator researchers also have a commitment to develop pedagogical knowledge about their discipline, ultimately leading to improved learning experiences for their students. Sampling students that I teach was therefore not just convenient, it was necessary to evaluate learning experiences that positively influence their development as STEM teachers. Therefore, to minimise perceived coercion, a gatekeeper (Creswell, 2014) was involved in all stages of recruiting and gaining informed consent.

As Leentjens and Levenson (2013) state, “voluntary participation is only truly voluntary if not participating has no consequences for the student…a requirement to participate affects the basic fiduciary relationship (p. 396). Therefore, there was no incentive or disincentive for participation. Many of the data collection methods were intrinsic elements of the modules’ learning experience. Participants were guaranteed the same learning experiences irrespective of their involvement in the research. No extra effort or time was required as a participant. Participants were made aware of their right to exit the study at any point, without question or repercussion. Students were reminded of this throughout the research project.

As Iphofen (2009) suggests, the researcher’s task is to “convey [the participant’s] experience authentically and in a way that might be useful for the purposes of explanation, policy-making or practice” (p. 139). It is important to view knowledge development as a collaborative, interactive process between the researcher and the participant (Olukotun 2021; O’Keeffe 2022). This researcher-participant dynamic refutes the notion of a traditional researcher-participant dichotomy and helps ameliorate power differentials (Olukotun 2021). Placing both the researcher and participants within the context of the research, Lather (2006) argues, disrupts these traditional ‘subjective /objective’ binaries. The participants’ valued perspectives and their contribution to the research were repeatedly communicated throughout the process. Approaches to data collection and analysis attempted to promote this, by presenting the participant’s voice to the reader through vignettes and images of their data, in an effort to allow the audience to construct their own meaning from the data.

3.7 Validity and reliability

Other measures undertaken to ensure the validity and reliability of the research are detailed in each paper’s methodology section across Chapters 4-8. These include the use of investigator triangulation (Onwuegbuzie & Leech, 2006), in which multiple reseachers collected and analysed the data, engaging in regular research meetings to ensure intercoder reliability, as well as the presentation of code tables to highlight the robust nature of the analysis. Other forms of triangulation added to the validity of the findings by corroborating evidence from multiple methods of data collection from different individuals (Creswell & Guetterman, 2021). This level of triangulation was made possible by prolonged engagement in the field, which allowed the gathering of significant and varied data and to “obtain an adequate representation of the ‘voice’ under study” (Onwuegbuzie & Leech, 2006). The longitudinal nature of the data collection, and the multiple data collection points across this time allowed for more than a mere snapshot of pre- and post- data, but revealed the ebb and flow of PSTs’ changes of understandings across the intervention.

Meticulous record keeping allowed for the construction of a detailed audit trail (Cohen et al., 2018). This also included a researcher journal, which as noted previously, afforded the space to record observations and detailed memos, thus supporting reflexivity as I turned the researcher lens back on myself. My positionality statement in Chapter 1 also acknowledges my subjectivity from the outset of this dissertation. As Braun and Clarke (2022, p.13) contend, however, reflexivity “isn’t all naval-gazing” drawing on Wilkinson’s (1988) work to highlight how reflexivity can be *personal* (that is how my values shape the research and knowledge produced), *functional* (how the methods and design shape the research and knowledge produced), and *disciplinary reflexivity* (how academic disciplines shape knowledge production). External auditing (Creswell & Guetterman, 2021) or expert review (Cohen et al.,

2018) was utilised before, during and after the research. A department colleague with expertise in the field (in addition to my supervisor) reviewed my research design, assessing the appropriateness of data generation tools prior to commencing data collection, and provided critique during the process to ensure that the findings were grounded in data, themes were appropriate etc. I also contacted researchers with particular expertise in the methodological approaches used, for example the story-line method adapted in Chapter 8 (Conway, 2001) and the SATS-36 instrument used in Chapter 7 (Schau, 2003). As previously detailed in this chapter (section 3.4.11), the SATS-36 instrument was chosen for its strong psychometric properties, with a review from Nolan et al. (2012) determining that it demonstrates the strongest construct validity and internal consistency of the fifteen most commonly used scales.

3.8 Conclusion

This chapter has provided an overview of the research design and briefly outlined the methods and approaches used to generate and analyse the data. The chapters that follow will provide more detail on the individual studies and approaches used. The upcoming chapters present five research articles that have been prepared for publication in peer-reviewed books and journals. This begins with Chapter 4, which provides and overview of *Intervention 1* and reports the evolving STEM understandings of the PSTs in *Cohort 1*.

Chapter 4: *Reciprocal interplays in becoming STEM learners and teachers*: preservice teachers' evolving understandings of integrated STEM education

Chapter 4. Reciprocal interplays in becoming STEM learners and teachers: preservice teachers' evolving understandings of integrated STEM education

Preamble

The following article reports on an integration STEM education intervention with *Cohort 1*. The module design was informed by the literature. Qualitative pre and post intervention data and participant research journals revealed the PSTs' evolving understandings of integrated STEM education and identified the key characteristics of the intervention that PSTs associated with these changes. This article has been peer-reviewed and accepted for publication in the *International Journal of Mathematical Education in Science and Technology*

The full citation for this journal is as follows:

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Statement of authorship;

I hereby declare that I, Michelle Fitzpatrick, am the principal author of this article. The following statements outline my contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis and interpretation of data for the work; AND

• Drafting of work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

See Appendix H for Signed Statement of Authorship

See Appendix I for signed letter from Dr. Colin Foster (Editor-in-Chief at IJMEST) confirming the status of this article

4.1 Abstract

Integrated STEM education has the potential to develop important skills, competencies and dispositions needed in the 21st century. Children's foundational knowledge is shaped in the early years and primary teachers have therefore been recognized as the gatekeepers to STEM education. Many teachers, however, feel unprepared to teach integrated STEM. This study responds to the call for more evidence on the types of learning experiences needed to prepare STEM-literate preservice teachers. Using pre-/post intervention data from surveys and STEM task analysis documents, as well reflective journal entries, we report on 30 preservice teachers' initial understandings of integrated STEM education and explore their evolution across a 12-week intervention, discussing key learning experiences that reportedly led to these changes. The findings suggest that preservice teachers had deeper, more critical understandings of STEM education as a result of the intervention and began to develop a pedagogical toolkit to support STEM learning in the classroom. These developments can be attributed to the powerful interplay that existed between participants' experiences as STEM learners in coursework and as STEM teachers during field practice. In an effort, however, to address low initial confidence in engineering, we inadvertently tipped the scales of disciplinary balance, at the expense of mathematics.

Keywords: Integrated STEM, preservice primary teachers, initial teacher education, mathematics education

4.2 Introduction

The field of Science, Technology, Engineering and Mathematics (STEM) continues to attract much attention. International policy documents have long advocated the need for STEM literate citizens and, to that end, have highlighted the importance of quality STEM education provision across the sectors. Economic competitiveness has been the driving force to maintaining the 'STEM pipeline', with international bodies calling for more STEM graduates with in-demand skillsets, necessary for current and emerging job roles (World Economic

Forum, 2020). However, the opportunities for STEM education to address socio-scientific issues, issues of social justice and sustainable development are receiving increased attention. There is a recognized need to support the development of well-informed, critical citizens to tackle global and local societal issues that affect our daily lives and prepare all our young people for the 21st century challenges they will face (Kurup & Li, 2022; Maas et al., 2019).

While the push for advancing STEM agendas is evident globally, STEM education itself is an embryonic field of research (English, 2016; Goos, 2022a). Uncertainty remains around how STEM education is conceptualized, and what Tytler (2020) calls "the epistemic viability of the STEM construct" (p.22). Despite the ongoing advocation for STEM education in research and policy, reports on student performance have been inconsistent, and it has been argued that strong evidence to support the effectiveness of STEM education on student outcomes is still needed (Goos, 2022b; English, 2016; Honey et al., 2014; Maass et al., 2019). This discrepancy could, in part, be attributed to teacher preparedness (Nadelson et al., 2013; Ryu et al., 2019) and the paucity of research on teachers and teaching in STEM (Li & Anderson, 2020; Margot & Kettler, 2019). While there appears to be interest in and enthusiasm for interdisciplinary approaches (Hamilton et al., 2021; Hourigan et al., 2022; Shernoff et al., 2017), integrated STEM presents many challenges in the classroom which can lead to a resistance towards implementation (Radloff & Guzey, 2017). These challenges are well documented (Dare et al., 2018; Kim & Bolger, 2017; Lesseig et al., 2016; Margot & Kettler, 2019; Nadelson & Seifert, 2017; Nesmith & Cooper, 2019; O'Dwyer et al., 2023; Radloff & Guzey, 2016) with common barriers relating to: teachers' own disciplinary and pedagogical content knowledge; structural challenges within schools and systems, such as integrating established curricula and time for collaboration and planning; and the range of integrated STEM conceptions held by teachers.

Given the challenges that are presented to teachers it is crucial that they are provided with quality, evidence-based teacher education programs that prepare them to implement integrated STEM in the classroom. This study reports on the implementation of an integrated STEM education course and reports on teachers changing understandings of STEM education.

4.3 Integrated STEM education

STEM education is a broad, ambiguous term, that may simply refer to one of the four distinct disciplines (Sanders, 2009). However, there appears to be an increasing focus on interdisciplinary and integrated approaches (English, 2017; Honey et al., 2014; Kloser et al., 2018) that present the disciplines in "a more honest or realistic fashion" rather than creating "artificial divides" that are not generally present in real life scenarios (Glancy & Moore, 2013, p.4). Although spanning disciplinary boundaries is a key feature of integrated STEM (Leung, 2020; Li, 2014), the extent of this boundary crossing varies (English, 2016). In a recent integrative literature review of conceptual frameworks and definitions, Moore et al. (2020*)* found that although common characteristics exist among conceptualizations of STEM integration (such as the importance of basing STEM lessons on real world problems and promoting cross disciplinary shared practices, skills and concepts) there were variations in how these features of STEM education were reflected in each study's definition and the degree to which they were emphasized. These many definitions of STEM education are problematic (English, 2016; Moore et al., 2020). However, Breiner and colleagues (2012) argue that not only would a common conceptualization of STEM be difficult to achieve, a one size fits all approach is likely to be counterproductive given the various initiatives and stakeholders across the globe. Instead, it is suggested that the focus be placed on shared outcomes of STEM education (Breiner et al., 2012; Honey et al., 2014). There is consensus around the belief that integrated STEM education has the potential to develop important skills, competencies and dispositions needed both personally and professionally (Falloon et al., 2020; Leavy et al., 2023). Developing these STEM literacies, as Mohr- Schroeder et al. (2020) argue, is not an option, as every child, regardless of future career choice, needs to leave school as "an informed consumer and decision-maker in our ever-increasing information and data-rich society" (p.35).

4.4 Primary teachers and STEM education

Children's foundational knowledge of STEM is shaped in primary school, preparing them for active participation in the future (Kurup et al., 2019; Nadelson et al., 2013). Primary teachers, therefore, have been recognized as the gatekeepers to the STEM education pipeline (Cotabish et al., 2013; O'Dwyer et al., 2023). Successful STEM integration in the classroom, however, is dependent on teacher knowledge and their confidence in using STEM pedagogies and approaches (Henriques et al., 2020). As generalists, primary teachers are inevitably exposed to a broad range of pedagogical approaches and methodologies during initial teacher education (Scogin et al., 2023). With a relatively flexible curriculum and timetable, primary school teachers are in a unique position to use their experiences of pedagogical approaches in different domains, to design and facilitate integrated STEM education in their classrooms (Hourigan et al., 2022). However, as non-specialists, many lack the necessary background knowledge, confidence and efficacy to implement integrated STEM in the classroom (Nadelson et al., 2013). There is evidence to suggest that without strong knowledge of beliefs and understandings related to integrated STEM, the likelihood of teachers using it effectively (if at all) in the classroom is low (Ring et al., 2017; Stohlmann et al., 2012).

4.5 STEM teacher education

While research calls for teachers to "cultivate their STEM thinking", STEM teacher development is generally under-researched (Rinke et al., 2016, p.300). Early findings from Zhang and Zhu's (2022) review on STEM preservice teacher (PST) education support this call, indicating that the research frontier of PST education focuses more on PST training of single subjects, rather than the integration and interdisciplinary nature of STEM. Given the growing emphasis on STEM in primary schools, Corp et al. (2020) highlight their concern about the lack of published research regarding primary teacher STEM preparation. Their systematic review of the literature found no published data on the type of content or pedagogy courses needed to help primary teachers teach STEM effectively and call for more evidence on what is being done, and more research into what is effective in preparing STEM-literate PSTs. The literature on STEM teacher education can be divided into four distinct, but overlapping, foci examining the professional development of in-service and preservice teachers at both primary and post-primary level. The majority of research on STEM teacher development focuses on practicing teachers, with little research on the effective preparation of preservice STEM teachers (Rinke et al., 2016) particularly at primary level.

Traditional professional development (PD) programmes for preservice and in-service teachers have focused on developing skills and knowledge in the individual disciplines (Huang et al., 2022; Lo, 2021). PSTs are rarely provided with opportunities to develop pedagogical approaches to integrated STEM, with engineering content being particularly uncommon (Guzey et al., 2020). Such practices need to be reimagined, as teachers feel unprepared to teach in integrated ways (Dare et al., 2018; Shernoff et al., 2017). Shernoff et al. (2017) found that the expert STEM teachers and administrators in their study believed that teacher education is "wholly inadequate and would need to be considerably rethought and revamped, for integrated STEM to flourish in school" (p.13). They advised that, while effective in developing disciplinary content and pedagogical knowledge, pre-service programmes should be redesigned to cultivate integrated approaches more explicitly. To achieve this, they recommend the inclusion of coursework on theoretical foundations of interdisciplinary approaches to STEM and student-centred STEM pedagogies. While exploration of STEM paradigms is implicitly suggested in most studies, others explicitly refer to the need for teacher educators to provide teachers and PSTs with opportunities to engage with peer-reviewed research on best practice in STEM (Çiftçi et al., 2022; Johnson et al., 2021a; Nadelson, 2013), and engagement with integrated STEM frameworks (Ring et al., 2017)

Teachers in Shernoff et al.'s (2017) study identified their inability to imagine what an integrated STEM lesson *looks like* as their biggest obstacle. They recommend that PSTs are exposed to modelling of STEM lessons and classroom observations as well as mentoring from experienced STEM teachers. Participants in their study also suggested that STEM PD should incorporate STEM approaches, to enable the teachers to experience STEM from the perspective of the learner. Giving teachers the opportunity to engage in rich STEM experiences as a learner is a common consideration in STEM professional development design across the sectors. This has involved the 'experts' acting as role models (Pimthong & Williams, 2021; O'Dwyer et al., 2023), often including inter-faculty collaboration and team teaching (Bartels et al., 2019; Berisha & Vula 2021; Johnson et al., 2021a; Murphy & Mancini- Samuelson, 2012). As many preservice teachers have not seen or taught a STEM lesson before (Bartels et al., 2019), engaging in these in-class tasks is seen as a way of modelling the lesson structure and pedagogical approaches expected for effective STEM education. In their examination of teachers' implementation of engineering design challenges, Lesseig et al. (2016) also found that engaging practicing teachers in STEM tasks as part of a PD model familiarized participants with the goals, content and processes involved and demonstrated links to curriculum standards. It also modelled ambitious instructional practices while providing teachers with tangible experiences and examples that they could bring to the classroom.

Effective modelling of authentic integrated STEM tasks has been found to increase PSTs' STEM competence and confidence (Johnson et al., 2021a; Murphy & Mancini-Samuelson, 2012), with similar findings reported in studies examining the professional development of practicing teachers. O'Dwyer et al. (2023) found that engaging primary teachers in integrated STEM tasks during PD workshops improved teacher-efficacy. Drawing on Bandura's (1977) sources of efficacy as an analytic lens, the authors report that these experiences supported *performance accomplishment* (by attending to areas of uncertainty and showcasing the value of STEM), *emotional arousal* (by engaging in positive, enjoyable STEM activities), *vicarious experiences* (by observing the PD facilitator modelling best practices, giving them first-hand experience of the approaches they would subsequently implement in their own classrooms), and *verbal persuasion* (through the encouragement and support of the PD facilitator).

With particular emphasis on elementary engineering, Nesmith & Cooper (2019) also found that incorporating integrated STEM tasks in their PD programme for in-service teachers contributed to engineering self-efficacy amongst participants and the incorporation of engineering activities in their classrooms. Indeed, a specific focus on engineering practices is evident across the literature. Guzey et al. (2014) advise that the goal of STEM is not "the addition of engineering practices but the integration of engineering practices" (p.139). In response, many PD and initial teacher education (ITE) programmes have centred around engineering practices (DiFrancesca et al., 2014; Karisan, 2019; Lesseig et al., 2016). Given that teachers are inclined to "teach what they were taught" (Nadelson, 2013, p. 158), new concepts and practices, such as engineering, need to be explicitly addressed during ITE, so that PSTs may embrace new approaches in their future practice.

Lesson plan design and development and the modification of tasks is a central feature in many teacher education programmes (Hass et al., 2021; Kim & Bolger, 2017; Nowikowski, 2017; Pimthong & Williams, 2021; Rinke et al., 2016; Ryu et al., 2019). Designing lesson plans has had a positive influence on PSTs attitudes towards integrated approaches (Kim &

Bolger, 2017). Although initially a response to distance learning and examination during the COVID-19 pandemic closures, Haas et al. (2021) found promising results for their primary PSTs, noting innovative teaching approaches and an acceptance to teach STEAM as a result of designing outdoor trails using educational technologies. Ryu et al. (2019) further suggest that initial teacher education programmes need to explicitly support PSTs in critically choosing, analyzing and modifying existing curricular online materials and consider how they could use them appropriately in the classroom.

While actively engaging in STEM tasks is a prominent feature of STEM teacher education programmes, the centrality of collaboration and reflection is woven throughout. Particular studies have framed their research model around collaborative or reflective practices. For Akaygun and Aslan-Tutak (2020), working on STEM tasks together encouraged PSTs to respect and learn from each other, and reflect on the interdependence of the individual STEM disciplines. Radloff and Guzey's (2017) study suggests that video analysis and reflection resulted in more informed and focused conceptualizations of STEM education. Through reflection, PSTs were enabled to internalize and consider how they could facilitate integrated STEM in their future teaching. It has also been recommended that PSTs be given opportunities to reflect on their past STEM experiences, to help them "actively self- regulate their ideas of STEM integration" (Ryu et al., 2019, p. 509). Blackley et al. (2017) used a *reflective identity formation model* to frame their pilot programme. The model was rooted in an activity-based, "learning-by-doing approach", and incorporated a series of reflections to support the PSTs in considering how the programme's activities improved their content and pedagogical knowledge and skills; how their beliefs had been challenged; and how they might modify their practices in the future (pp.33-34). It has been noted that while reflective practices are an important component of teaching generally, they are of acute importance when teachers are required to engage in new curriculum with little or no prior experiences (Ryu et al., 2019).

4.6 Focus of this study

This study responds to the call for more research into identifying the effective characteristics of course experiences that contribute to producing STEM-literate PSTs (Corp et al., 2020). It examines PSTs' initial understandings of integrated STEM education and the evolution of understandings across a 12-week STEM education intervention. This study was motivated by three research questions.

Research question 1: What do pre-service primary teachers understand by integrated STEM education?

Research question 2: How do STEM understandings change across a 12-week STEM education intervention?

Research question 3: What do preservice primary teachers report as key learning activities in their development as integrated STEM teachers?

4.7 Methods

4.7.1 Participants

Participants were 30 preservice primary teachers undertaking a STEM education elective module as part of a mathematics education specialism. All participants were in the final semester of their 3rd year in a 4-year concurrent Bachelor of Education degree program in an Irish university. Of the 30 participants, 9 identified as male, and 21 as female. They had completed all required mathematics, science, and information and communication technologies (ICT) modules over the previous 5 semesters (mathematics modules n=5; science modules n=2; ICT modules n=2). In the previous semester, 28 participants completed a mathematics education elective exploring *Scratch* as an educational resource to support the learning of mathematical concepts. As part of that elective, they were also introduced to STEM education via a 6-hour online, asynchronous unit of work. Participation in the research was voluntary. All ethical considerations were adhered to, with approval being obtained from the institute's Research Ethics Committee.

4.7.2 Module overview

This intervention comprised of a 12-week, 6 credit module focusing on integrated STEM (see Table 4.1). Three STEM teacher educators worked with 30 PSTs, meeting twice weekly for a total of 3 hours per week. Two guest lecturers with expertise in technology and STEM task design also contributed to the module. The module design was informed by the available literature on effective integrated STEM interventions in both professional development and initial teacher education. The key principles identified in the literature and used to frame this intervention are:

Principle 1: to engage in theory of STEM education, including integration, STEM pedagogies and frameworks

Principle 2: to engage in STEM activities as a learner (particularly engineering design challenges)

Principle 3: to support the design and planning of STEM tasks and lessons

Principle 4: to promote collaboration and reflection

A long-standing School-University Partnership with a local school, has meant that this particular specialism module has traditionally incorporated field placement. Given these pre-existing structures, we decided to incorporate field practice into our intervention design.

Principle 5: to engage in STEM teaching field practice

Another consideration when designing this intervention was to ensure a balance of individual disciplines across the module. Given that the PSTs had engaged in discrete modules in mathematics, science and digital technologies over the previous 5 semesters, this module sought to draw on past learning experiences while focusing on integrative approaches. As the PSTs had no prior formal experience in engineering education (and limited exposure to technology education), an emphasis was placed on the *T* and *E* of STEM. This 12-week intervention can be divided into three phases as outlined below (see Figure 4.1).

Table 4.1

Activities and data collection associated with the 12-week module

Week	Activities	Principle/ discipline focus*	Data collection
Week 1 *Introduction* *AR in Mathematics*	Module introduction Collect baseline data '*What does STEM mean to me?'* – Whole class activity Team- building challenge: *Paper cup tower challenge* Augmented Reality in Mathematical Problem Solving	**M, TP2, P4**	Pre-intervention survey Pre-intervention task evaluation Pre-intervention concept maps
Week 2 *What is integrated STEM?*	History and nature of STEM Integrated STEM/Integration across the curriculum STEM and children's literature STEM Challenge: *Build a parachute to help Jack escape the Giant* STEM statement sort	**S,E** **P1, P2, P4**	Participant Journals Statement sorting responses
Week 3 *Perspectives on STEM*	Perspectives on STEM education/ Role of STEM education STEM in the Irish context STEM Challenge: *Garden design challenge* STEM Literacies: Rainbow carousel activity exploring disciplinary/STEM literacies	**S,T,E,M,** **P1, P2, P4**	Participant Journals Rainbow Carousel posters
Week 4 *STEM Pedagogies* *Technology*	Inquiry-based learning/ Problem Based learning/ 5 'E's What makes a lesson a STEM lesson? Group activity: *Planning a budget holiday for a family of 4* The 'T' in STEM (nature of technology, impact, categories of technology, emerging technologies)	**E, T, M** **P1, P2, P4**	Participant journals
Week 5 *Engineering design* *STEM skills*	Engineering design process21st century skills Engineering design challenge*: Spaghetti and marshmallow tower challenge*	**E** **P1, P2, P3, P4**	Participant journals Reflections on task Researcher observations Task evaluation sheets
Week 6 *STEM in Action*	Introduction to group tasks (class divided into 5 groups of 6. Each group was given an outline of a STEM task to develop) Tasks evaluated using Guzey et al.'s (2016) framework STEM observation (observed video footage of authentic STEM classroom activity, and completed observation protocol) Engaged in STEM lesson (PSTs designed and built a mathematics game using electrical circuits)	**S, E,** **P1, P2, P3, P4**	Observation protocol Participant journals Photographs of STEM task

	In class preparation for group STEM teach		
Week 7 *Supporting the STEM learner* *STEM Talk Moves* *Lesson preparation*	Promoting and supporting STEM Talk Open questioning/ Higher order thinking skills Groups shared draft lesson with whole class- Feedback offered Final in-class preparation for STEM Teach	**P1, P3, P4**	Participant journals Record of planned questions
Weeks 8 and 9 *Groups teach their lesson in a local school*	5 STEM lessons were taught over 5 days to a 5th class (10-11 year olds) in a local school. Each group taught 1 STEM lesson.	**P5, P4**	Lesson artifacts Video record of the lessons Individual participant reflections Post lesson focus group/ transcripts Researcher notes
Week 10 *The Big Thinkers* *Maintaining the 'M' in STEM*	Exploring STEM Frameworks/ STEM lesson design essentials (Roehrig et al. (2021); Jolly (2016); Johnson et al. (2021); Vasquez et al. (2013); Cianca (2020)) Evaluating their own lesson using a published framework Exploring the role of Mathematics in STEM (re)Consider opportunities for meaningful Mathematics integration in their own STEM lessons	**M** **P1, P3, P4**	Feedback on group discussions Participant Journals
Week 11 *Fostering Curiosity and Discourse in STEM* Data collection	Accessing quality STEM resources Generating curiosity and discourse in the classroom (using photographs, videos, data representations, investigations, testable questions) Collect post- intervention data	**P2, P3, P4**	Participant journals Post-intervention survey Post-intervention Task evaluation Post-intervention Concept Map Concept map comparison analysis
Week 12 *Group Presentations*	Groups present a summary of, and their reflections on, their STEM teaching experience in weeks 8/9.	**P4**	Groups' PowerPoint presentations Presentation transcripts Researcher observations
Week 15			Final individual reflections Each PST submitted a virtual poster of STEM Task as part of the module assessment

Note. S= science; T= technology; E= engineering, and M= mathematics

P1= Principle 1; P2= Principle 2; P3= Principle 3; P4= Principle 4; P5= Principle 5

4.7.2.1 Phase one: Weeks 1 -5

The initial 5 weeks of the module focused on the theory of STEM education, giving the PSTs insight into perspectives on STEM education, integrated STEM and STEM literacy. It introduced STEM approaches and pedagogies, such as student-centred, inquiry-based learning, problem-based learning, and examined characteristics of a 'STEM lesson'. PSTs engaged with the literature on STEM education, through peer-reviewed articles, book chapters and practitioner papers. A key consideration at this phase was to provide the PSTs with ample opportunities to engage in STEM activities as learners. PSTs were introduced to the engineering design process (EDP) through a range of tasks (see Table 4.1). This allowed the PSTs to engage in STEM experiences from the learner's perspective. The importance of this principle became increasingly obvious as PST reported in reflective diaries and elsewhere that they had little exposure to many of the approaches used and had very different experiences in the disciplinary areas in school.

4.7.2.2 Phase two: Weeks 6-9

In week 6, participants were randomly divided into 5 groups, with 6 members in each. Each group was introduced to the STEM task that they would develop and teach in week 8/9. As this was the first time the PSTs had designed and taught a STEM lesson, an outline of the task was offered as a support. The five tasks presented to the PSTs were designed by one of the STEM educators (SE) on the module.

The design of these tasks was informed by an extensive review of the literature, in which the SE identified key features of integrated STEM tasks from the published frameworks (Fitzpatrick et al., in press). Seven key features of high-quality STEM education were identified, including: problem-solving design and approaches, disciplinary knowledge and connections across the disciplines, engineering design and practices, the appropriate use of technology, situating learning in a real-world context, the emphasis of student-centred pedagogies and the development of 21st century skills and competencies (Blackley & Howell, 2019; Butler et al., 2020; Jackson et al., 2021; Johnson et al., 2021b; Kelley & Knowles, 2016; Quigley et al., 2017; Shahali et al., 2016; Simarro & Couso, 2021; Tan et al., 2019; Thibaut et al., 2018; Yata et al., 2020). Five tasks were designed to incorporate these seven characteristics (See Table 4.2).

Table 4.2

Five STEM tasks

STEM task	Task outline
Harmless can holder	Design a holder for carrying a six-pack of cans that is harmless. The one that is currently used on packaging is made of plastic.
Build a bridge	Design and build a bridge that spans a gap of 50cm between two tables.
Seismic Shake-up	Design a model of a tower that could survive an earthquake.
Kicking machine	Design a kicking machine that can 'kick' a table tennis ball into a paper cup over a defined distance.
Build a rollercoaster	Design the roller coaster with the best turn/loop that safely delivers the marble into the paper cup.

The PSTs evaluated their task outline using Guzey et al.'s framework (2016) and, with this as a guide, planned a STEM lesson for a 5th class (age 10-11 years) in a local school. The PSTs developed an introduction to their task which established a driving context and rationale for the lesson. They sourced photographs, videos, and other resources to support this context. Each group decided on suitable design challenge criteria and parameters and gathered materials needed for their lessons. The SEs worked closely with the PSTs, offering feedback and advice, as necessary. PSTs collaborated online and met in person outside of designated class times to plan the lesson structure and organize resources and materials.

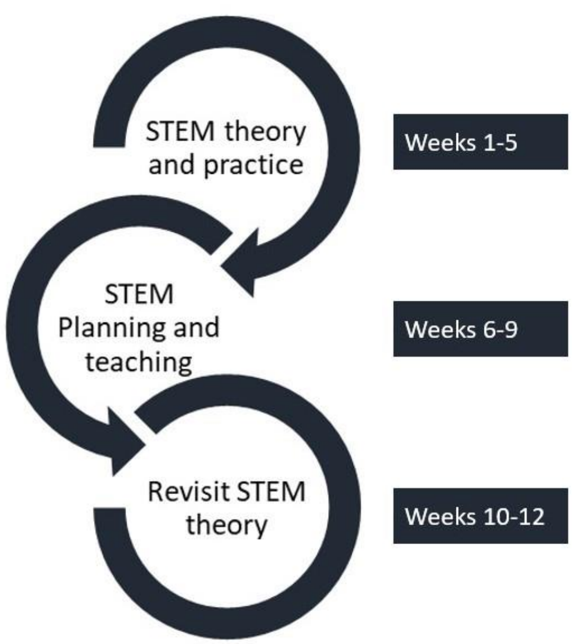
During weeks 6 and 7 in-class activities focused on preparing for the field practice. PSTs engaged in a video observation activity and completed an observation schedule. They explored the role of the teacher in promoting STEM discourse in the classroom and drafted some questions and prompts for their own lessons. Each group outlined their planned lesson to their peers and offered each other feedback before final preparations were made. Each group then taught their STEM lesson, over five days of intensive STEM workshops in a local school, during weeks eight and nine. The five lessons, each delivered to the same 5th class (age 10-11), were video recorded. The lessons were non- sequential, and each had a specific focus (see

Table 4.2). Following each lesson, the group met with the SEs to debrief and reflect on the lesson.

4.7.2.3 Phase three: Weeks 10-12

The final three weeks offered PSTs the opportunity to reflect on their field experience while revisiting and advancing their knowledge on the theory of STEM education. They examined some published STEM frameworks, using them as a lens in which to evaluate the STEM lesson they had taught. They revisited the positioning of mathematics within their STEM tasks and explored opportunities for making stronger links with the discipline. Video footage of the STEM lessons taught was made available to the participants for review. The PSTs engaged in further group reflection and prepared a presentation to share their findings. On the final week, each group provided a 30-minute in-class presentation, based on their STEM teaching experience. They shared the task and an overview of the lesson with their peers, provided samples of the children's work, offered their reflections and critiques on the process, and suggested changes they would make if teaching this lesson again.

Figure 4.1
The module's three phased cycle



4.7.3 Data collection

A number of data collection tools were used as part of a larger study, such as concept maps, post teaching focus groups and video footage (see Table 4.1). This paper, however, reports specifically on the data collected through pre-/post- intervention surveys, pre-/ post-intervention task analysis documents, and participants' journals and reflections.

The pre-and post-intervention surveys were administered in weeks 1 and 11 respectively. The pre- intervention survey consisted of a 13-item questionnaire. Items 1-4 collected demographic information on the participants. The remaining items explored their current perspectives on STEM and STEM education: how related they perceive the disciplines to be, how they would teach STEM in the classroom, the perceived benefits of STEM for children, challenges that exist and concerns they have, and how confident they would be to teach STEM. The items exploring discipline relatedness and confidence levels asked participants to give a ranking from 1 (*not at all*) to 10 (*extremely)* and explain their choice. All other items required open responses. The post-intervention survey had one extra item, which asked participants to give advice to other PSTs on how to design and teach a good STEM lesson.

The task analysis activity was identical in weeks 1 and 11. Participants were given a task outline (see Table 4.3), and a task analysis document to complete. The task chosen was an adapted version of an integrated mathematics and science activity from Science Foundation Ireland's (SFI) *Discovery Primary Science and Maths* programme (SFI n.d). It was chosen by the researchers as it was deemed a high-quality, integrated task but lacked key elements of the published STEM frameworks, such as being embedded in a real- life context or engaging the students in engineering design. When reviewing the task, the participants were asked if they thought this was a STEM task, to rate it as a STEM task (ranking 1-10), and to explain their responses. Participants were then asked what disciplinary areas were targeted in this task, and what potential it had to develop skills and dispositions amongst pupils. Finally, they were asked to provide at least one modification that could be made to enhance the task, and to justify their reasoning.

Table 4.3

Outline of task for analysis activity

Investigating Slopes • Construct a ramp by setting up a half-tube (from a kitchen roll etc.) on the floor with some Lego blocks underneath one end. • Place the toy car at the top of the ramp. • Predict how far the toy car will roll along the ground. Then let it go. • Measure how far the car travels. Repeat a number of times, changing the angle of the slope by adding or taking away Lego blocks. Make a graph of your results. • Explore this on different surfaces (wooden floor, tiles, carpet, outside on the concrete, and the pitch) to see what effect the surface has on the distance the toy car travels.

Participants were encouraged to use a reflective journal throughout the module. They were provided with a notebook and given reflective prompts or exit slips each week. These journal entries offered insight into changes in participants' understandings of STEM across the 12-week module. It also provided a record for the participant to reflect on at the end of the intervention, when they were asked to identify 3 key pieces of learning from the module. Participants were asked to describe the changes (which could relate to changes in their knowledge, understanding, skills or dispositions) and identify experiences or key moments in the module that influenced their learning.

4.7.4 Data analysis

A grounded theory approach was taken in this study. Data collection and analysis was conducted simultaneously in an iterative process (Charmaz, 2014). Analysis began with the pre-intervention data collected through the survey and task analysis activities. All data were coded inductively, allowing the theory to emerge from the data (Strauss & Corbin, 1998). Initial coding was followed by focused coding, which allowed for the synthesis, analysis and conceptualization of larger segments of data (Charmaz, 2014, p. 138). To strengthen the validity of the analysis, codes were independently generated by each author. Both researchers met regularly during the pre-intervention data collection and analysis: to compare codes, discuss tentative categories emerging from the data, and develop analytical memos. A constant comparative method was used to analyze the data, allowing the researchers to compare data to data, and data to emerging concepts (Engler, 2022). The entire data set of pre-intervention surveys were analyzed and items subsequently compared across participants. A similar method was carried out for the task-analysis documents. Data were then analyzed from *within* each participant's pre-intervention data corpus.

Participant journals were analyzed on an ongoing basis. Many of the codes supported the emerging categories from earlier data (such as '*lack of STEM experience as a learner*'), and new codes were identified (such as '*growing confidence in engineering*'). The post-intervention data were analyzed in the same way as the pre-intervention data, and the full data set was then explored. Second round analysis, focusing solely on Research Question 3 was carried out on the data collected through the participant journals, post-intervention surveys and final written reflections.

The constant comparative technique adopted in this study aided the identification of consistencies and differences within and between each participants' data corpus, with the aim of continually refining concepts and theoretically relevant categories (Chun Tie et al., 2019). For core categories to be deemed 'theoretically relevant', and kept beyond the intermediate coding phase, they needed to be evident across the set of participants, and to occur consistently in the range of data collected over the 12-week intervention.

4.8 Results

The findings of this study are presented in three sections, under the heading of each research question.

4.8.1 Research question 1: What do pre-service primary teachers understand by integrated STEM education?

A welcome, and not unexpected, finding from the pre-intervention survey revealed that all participants were familiar with the acronym 'STEM'. Most (87%) referred to 'integrating', 'interconnecting' or 'combining' the disciplines in some way when defining STEM education. While some participants referred only to a link between the disciplines or subjects when describing their understanding of STEM education, over half referred to the relevance of a 'real-life context', 'problem solving' and 'skills' in their definition. It is clear that the PSTs brought prior knowledge of integrated STEM education with them from the previous semester. This was particularly evident from their descriptions of the benefits for children. Participants cited possible benefits of STEM education as 'developing a deeper understanding' of the content and improved problem-solving skills. Some participants referred to various 21st century skills, most notably, creativity and critical thinking skills, while others highlighted the importance of fostering interest in the STEM disciplines amongst young learners.

4.8.1.1 Theory to practice gap: Difficulty applying STEM knowledge

While emerging understandings of integrated STEM education appeared strong, participants displayed difficulties in translating this theory into their perceived practice. Interestingly, even participants that had informed understandings of STEM education from the survey data set, failed to bring those ideas and critique to the task analysis activity. When critiquing the STEM task initially, PSTs focused on the presence of the four disciplines, most notably the subject areas of mathematics and science. This is unsurprising, given that mathematics and science are the only STEM subjects specifically on the national curriculum. While two participants made some suggestions which might enhance this as a STEM task (such as giving the children "more freedom and responsibility in relation to building the ramp and how they measure" (PST5) and offering "choice of materials or allowing them to suggest suitable alternatives" (PST15)), most suggested modifications either advocated for the addition of technology (which was reported as the missing discipline) or adding another/ extending a mathematics or science element. While many of these suggestions had the potential to improve the task in terms of mathematics or science, they fell short of enhancing the task as an integrated STEM activity. The promising survey responses relating to the role of problem solving, creativity and critical thinking were not evident in the task analysis responses, which were, for the most part, focused on disciplinary content only.

4.8.1.2 The Confidence Chasm: Science and Mathematics eclipse Engineering and Technology

Pre-intervention data collected suggests that the PSTs brought a strong knowledge of the primary mathematics and primary science curriculum with them from previous core modules. Participants also expressed confidence in their ability to teach mathematics and science given their experience as learners, and their previous teaching placement experience:

> My elective course is maths education. My specialism is the arts specialism maths. I studied chemistry, physics, accounting, and higher-level maths in the Leaving Cert. I really enjoy and am passionate about STEM subjects. (PST5, pre-survey)

> I have taught science and mathematics previously in the primary setting with no difficulty. (PST6, pre-survey)

Conversely, PSTs reported lower levels of confidence in the areas of engineering and technology. Participants felt unprepared to teach engineering and technology reporting that they "have been less exposed to those elements" (PST3, pre-survey). In fact, over 50% of the participants cited engineering and technology as either a challenge, or their biggest concern about teaching STEM:

> I would feel semi-confident in my ability to teach this [STEM] as I feel I would be able to confidently teach science and maths and would be less confident incorporating the engineering and technology elements. (PST3)

Concerns around engineering were particularly evident. Many participants highlighted that engineering practices were new to them, with many "not having knowledge in engineering" (PST4, pre-survey) as they had "never done engineering before" (PST7, pre-survey). PSTs displayed naïve understandings of engineering education, with nearly all participants identifying the instructed step-by-step construction of the ramp as engineering during the task evaluation activity in week one.

4.8.2 Research question 2: How do STEM understandings change across a 12-week STEM education intervention?

4.8.2.1 Adopting a critical stance towards STEM tasks

Participants displayed increased criticality in the post-task analysis activity. When asked to rate the task as a *STEM task* out of ten, all participants gave a lower rating than they had in the pre-intervention activity. In fact, the pre-intervention median rating of 8 (range 6-10) dropped to a post-intervention median of 6 (range 2-8).

Those most critical of the task felt, that although there was good integration of mathematics and science, the lesson was "quite restrictive as children aren't given opportunities to be creative and use their own ideas" (PST14). It was most criticized for not being rooted in a real-life context, and for being "quite basic" (PST8). Others stated that the task was overly prescriptive "limit[ing] the children to do an exact task" (PST10), hence taking away the possibility for "EDP, redesign or the development of many STEM skills" (PST2). One participant felt it was not a STEM task at all, arguing that there was:

> no explicit connection between two or more STEM topics … [and] no clear engineering design process. It does not incorporate the 21st century skills to be targeted in a STEM lesson. (PST11)

Compared to their lower-order extension suggestions in week one, participants proposed insightful modifications in the post- intervention evaluation that enhanced the STEM-nature of the task. Such modifications included, allowing the children to collaborate on the task in groups; providing a relevant and engaging real life context for the task; and giving the children freedom and choice in relation to materials, ramp design, or indeed on how to approach the task in the first instance. In their justifications for these modifications the PSTs cited the importance that STEM tasks are relevant and engaging, incorporate challenge and problem solving, promote creativity and the engineering design process and develop 21st century skills. While some of the participants still displayed naïve and emerging understandings of STEM, particularly in engineering and technology, all the participants viewed this task more critically, through a STEM lens, in the post-intervention task evaluation, shifting and broadening their focus beyond mathematics and science content.

4.8.2.2 Enriched understandings of STEM learning and a developing toolkit to support them in practice

> At the beginning of this semester, if I was asked to describe what STEM entails, I would have simply explained what the acronym stands for and outlined the content matter within each discipline, rather than the skills that children develop through engaging in STEM. (PST26, final reflection)

While participants had initially focused on STEM as integrated content, an appreciation for the development of broader STEM literacies is evident in the post-intervention data. When asked about their key learning experiences in the module and how they would teach STEM in the primary school classroom, PSTs highlighted the importance of developing student-led, inquiry-based approaches (88%), through a rich and realistic context (72%) which incorporate and promote the development of 21st century skills (96%):

> Before partaking in this module, I would have assumed that the knowledge children would gain in STEM would come through telling them the different procedures to complete a project. However, the opposite is true ... as they learn in an engaging manner where they discover things for themselves. (PST28, final reflection)

> I saw the 21C skills as abstract and did not see the connections from theory to practice. This module led to a realization of how STEM and these skills are connected, as STEM lessons require them to function, and therefore promote and support them. (PST14, final reflection)

Although participants initially struggled to see how they could apply their STEM knowledge in the classroom, post-intervention data suggest that they have developed a stronger toolkit as STEM teachers. PSTs could identify their role in facilitating inquiry-based learning and were familiar with pedagogies and approaches that support children's STEM thinking:

> I now know the significance of asking open-ended questions that will prompt peer-discussion … [and] the importance of not telling the children what to do, but instead motivating them to reflect on their mistakes and use them to inform future thinking... Additionally, sharing their ideas will allow for whole class debates and enable children to gain insight into alternative perspectives held by their peers. (PST20, final reflection)

> I could prompt the children but ultimately not compromise their ideas. (PST22, final reflection)

> I made sense of ways to shift power to the students.... (PST1, final reflection)

When reporting on their growing appreciation for the student-led practices, this often included the acknowledgement that this is challenging as a PST and a skill they are still developing:

> Scaffolding and guiding the children to make discoveries on their learning, without directly telling [them] what to do can often be challenging. (PST26, post- survey)

> The idea of the teacher taking on a facilitator’s role is something that is difficult (as I discovered in my group’s STEM lesson we taught). However, it is essential if the children are to engage with the inquiry-based process and are to communicate effectively with other members of their class, in which they share ideas and eventually mutually agree on which ideas are best to tackle the problem at hand. (PST16, final reflection)

Overall, self-reported confidence ratings increased following the 12- week intervention. When asked how confident they would be to teach STEM in the primary school, an initial median rating of 7 (in a range of 3-9) increased to 8 (range of 6-9). However, participants remained concerned about lesson planning (including pitching the lesson to include and engage all learners), time management, classroom management and curriculum fit.

4.8.2.3 Bridging the chasm; but trading concerns

In the post-intervention data collected nearly 70% of all participants explicitly identified engineering as central to teaching STEM in the classroom, or as a key piece of learning during the module. While some naïve views of engineering prevailed (notably, viewing the step-by-step build of a ramp as engineering in the post-task analysis), the majority of participants show a renewed appreciation for, as well as confidence in, engineering practices:

> Having engaged with the module, I now have a better understanding of engineering in STEM and how it underpins the other three disciplines. The engineering design process allows for the integration of all disciplines together...and facilitates the development of 21st century skills. (PST21, final reflection)

> In week one, I believed that the role of engineering in STEM was simply just to build something. However, I now realize that engineering is much more than this. The Engineering Design Process scaffolds pupils learning and engagement with the task... I will use EDP in undertaking STEM activities in my future teaching. (PST7, final reflection)

Participants growing understanding of engineering was evident across the 12 weeks, as is evident in the data corpus for PST16 (Table 4.4)**.**

Table 4.4.

PST16's evolving understanding of engineering.

Pre-survey: *I feel that in terms of teaching maths and science I would be confident, however, teaching and accurately emphasising technology and engineering could prove to be somewhat difficult.*

Pre-intervention task analysis: *This is a good example of a STEM task as it incorporates aspects from at least 3 of the STEM disciplines, Science, maths and engineering*

Journal (Week 3): *Something I want to know more about is how to improve the incorporation of engineering*

Journal (Week 4): *Engaging in the construction of a tower using marshmallows and spaghetti as a learner was a worthwhile task. Different members of the group offered different perspectives that I didn't think of initially and through taking on their ideas in conjunction with my own, we came up with solutions.... having undertaken the task, I can see how to re-do the task more effectively and what strategies may work when undertaking this task again.*

Final reflection: *After engaging with this planning process (EPD cycle: Ask-Imagine- Plan phases), I definitely started to feel more confident with what the Engineering Design Process entails and how effective it is for use when planning out STEM tasks*

Post intervention task analysis: *Little engineering and technology involvement [in this task].*

Final reflection: *The first key piece of learning that I acquired from the module was a deep understanding of the Engineering Design Process and what this process manifests itself as in the primary school classroom.*

Post Survey: *In order to design and teach a good STEM lesson, meaningful integration of the disciplines is key in my opinion. Children need to clearly see how maths, science, engineering and technology play a role in the lessons, and that these aren't just shoved into the lesson for the sake of saying that 2,3,4 disciplines feature in the lesson.*

PST16's concerns around "meaningful integration" are echoed by many of her peers. While confidence in teaching STEM is reportedly increasing along with pedagogical knowledge for teaching engineering, participants in week 12 appear less certain of their initial confidence in teaching mathematics in STEM. PSTs reported difficulties in recognizing the potential role of mathematics and incorporating age-appropriate mathematical content in their tasks, that could lead to authentic mathematics learning:

> Meaningfully integrating disciplines is far more beneficial to the student than simply throwing together elements of STEM for the sake of it. (PST10, final reflection)
>
> Science and Engineering can be easily incorporated in lessons and maths can too with a bit of thought. (PST7, post- survey)
>
> [A challenge is] meaningful integration, incorporating maths that is age appropriate and not just incidental. (PST21, post survey)

Post teaching reflections in the participant journals highlighted the 'lack of a maths component' in the tasks they developed (PST2, reflective journal). Mathematical content was recognized as being "informal" and a need for "more explicit links to maths" was identified (PST7, reflective journal). Participants suggested that discipline-specific materials and resources could have been used to encourage and prompt more mathematics (PST3 and PST7, reflective journals). As all tasks were focused around the EDP, it appeared that mathematics took, at best, a supporting role. Indeed, two participants made this observation prior to teaching.

> Our lesson is quite engineering focused. I am concerned about integrating the maths aspect and phrasing questions that will draw the desired language out of the children. (PST26, reflective journal)
>
> Concerning the components of STEM in our lesson, I feel as though engineering plays a large role in our activities throughout the lesson. I would like to make an effort to highlight the use of maths as an element of this lesson, focusing on shape and space. (PST25, reflective journal)

Two participants presented a less critical view of integration and were satisfied with the tokenistic inclusion of mathematics which was 'incidental', or more worryingly, 'accidental':

> Teachers should try to incorporate all of the four STEM disciplines, whether they occur explicitly, or just coincidently, with the links of the different disciplines being pointed out to students. (PST5, final reflection)

> I learned that STEM can be a very broad aspect of the primary classroom. It can be incorporated in many ways. It can even be incorporated by accident. In many STEM tasks, there is accidental mathematics, which means the children are doing mathematics without actually doing mathematics. For example, measuring the length of a material to build a bridge. (PST23, final reflection)

However, most participants voiced concern around the difficulty of authentic integration. Indeed, 50% of post-intervention survey responses highlight meaningful integration and/or fitting STEM into the curriculum as a main concern or challenge. The concern of 'curriculum fit' is perhaps unsurprising, given that mathematics and science are the only STEM disciplines on the current national curriculum. It is interesting to note that while PSTs reported post-intervention concerns around integrating mathematics in STEM activities, they appeared to have a heightened awareness of the importance of mathematics in STEM more generally:

> Now I see maths and maths knowledge as crucial in understanding the contents of other subjects like science, music and art. This understanding will allow me to teach and challenge my students to appreciate maths and its integral importance to the world around us. (PST9, final reflection)

4.8.3 Research question 3: What do preservice primary teachers report as key learning activities in their development as integrated STEM teachers?

> At its base level, the meaning of STEM is quite simple to deduce, however, it is only through engaging with STEM education experiences in context that one can begin to comprehend the value, intricacies and importance of STEM. (PST2, final reflection)

On reflection, PSTs identified a range of activities that contributed to changes in their understanding. Participants reported the value of exploring different perspectives of STEM education, exposure to research and published frameworks, examining inquiry-based approaches to learning and watching videos on STEM education. However, three main themes emerged across the data.

4.8.3.1 Learning by doing: Witnessing the joy and challenges of STEM as learners

The benefits of engaging in STEM activities as a learner were heavily cited across the data sources. STEM experiences were novel for the PSTs as most had not engaged in integrated STEM activities themselves in school. In fact, it became clear that participants had little experience of many of the pedagogies and approaches associated with STEM learning. Most described their experiences of mathematics and science education in school, as teacher- and textbook-led, particularly at post-primary level, where the emphasis was on rote learning and exam preparation:

> The majority of learning was demonstrated inquiry where the teacher carried out the majority of the lesson, telling students what to do and how to do it. (PST28)

> Experiments were followed step by step from the textbook and therefore were always successful, with no discovery. (PST4)

> We just worked our way through the workbook... It was quite boring learning this way and unmotivating. (PST25)

Participants reflected on the in-class STEM activities as a source of enjoyment as well as an opportunity to engage in STEM education through the eyes of the learner, allowing them to appreciate the benefits of STEM for children. Central to this were the opportunities to engage in the engineering design process and recognition of the role of key competencies in STEM tasks:

> The process of collaborating with other class members to agree on a design for the tower gave me an invaluable insight into the many ways children could benefit from engaging with this. (PST16, final reflection)

> During in class STEM tasks we realized that in order to successfully participate in a STEM task, it involved collaboration and communication to respond to the task. This highlighted how engineering fosters the development of 21st century skills and prepares children for the real world. (PST21, final reflection)

PSTs also identified challenges in engaging in the tasks themselves. Such challenges included, collaborating and communicating with peers, and dealing with failure and redesign. These experiences allowed the PSTs to gain insight into the challenges their pupils might face in the

STEM classroom, as well as reflect on how they, as teachers, could support the STEM process in the classroom:

> Getting to experience STEM activities first-hand as a learner enabled me to have to work to overcome the same challenges regarding communication and collaboration which children face, and it alerted me to their significance.... I was unaware of the extent of their importance. (PST3, final reflection)

> I have realized you need to build the courage to take the risk and with that, you have to be able to adapt when things go wrong... I vividly remember doing the spaghetti task in the tutorial. Our group was not successful by any means, but we tried to redesign, and it worked out. We had to use our communication skills. (PST29, final reflection)

> It must not be assumed that all students have indirectly acquired these skills already. From my experience, difficulties in working collaboratively with my peers to create the spaghetti structure revealed the importance of scaffolding and implementing contingencies in the classroom to support the acquisition of each skill. (PST11, final reflection)

PSTs also outlined the role of these experiences in modelling STEM pedagogies and preparing them to plan a STEM lesson themselves:

> I found this method of engaging with STEM highly enjoyable and stimulating. I also felt that engaging with STEM tasks ourselves in class helped inform our planning and execution of the group STEM teaching task. (PST19, final reflection)

> I have learned to facilitate this natural curiosity in the EDP by engaging children in guided discovery, something that was modelled to us during our in-class experience. I now know the importance of asking open-ended questions that will prompt peer discussion. (PST20, final reflection)

4.8.3.2 Seeing is believing: Experiencing STEM teaching and learning in an authentic setting

Having the opportunity to teach a STEM lesson in an authentic classroom was credited by 87% of participants as a key activity that developed their understanding of, and/or increased their confidence to teach STEM. The process of “preparing and actually teaching” the STEM lessons in a local school “brought the concepts that had been discussed throughout the module to life” allowing the participants to “see them play out in real life” (PST14, final reflection).

Witnessing the effect the STEM tasks had on the children corroborated their learning to this point, and appeared to validate the benefits of STEM education:

> I saw first-hand the effect of having a relatable problem for the children when teaching our STEM lesson… From the beginning of the lesson the children were engaged because the solution to the problem had meaning to their lives. (PST17, final reflection)

> It was not until I was teaching the STEM task that I fully understood the value of EDP and the benefits of using this approach. (PST7, final reflection)

> At the time of this learning [about the EDP], I felt confused and overwhelmed as there was so many different processes and approaches ... As I witnessed engineering thinking taking place [during the STEM lesson], it enabled me to understand the benefits of the EDP and encouraged me to carry out STEM tasks in my future teaching. (PST1, final reflection)

Field experience afforded the PSTs the opportunity to focus on the child as a STEM learner. They were "blown away by the creativity of the students" (PST24, final reflection) and highlighted the need to have high expectations for all learners who are "more than capable of creating their own solutions to the problem" (PST21, final reflection). One participant was "surprised...that children would learn these skills" at such a young age, presuming that they would begin to develop "these skills later as they progressed through second and third level education" (PST4, final reflection). PSTs appreciated the various skills and contributions each child brought to the group and commented on its inclusive nature. For one participant, seeing a child in his group with little English being:

> transformed from silence to being a massive part of the group, evoked a passion in me towards STEM, something I did not expect to feel upon beginning this module... I feel that STEM is not appreciated enough. (PST12, final reflection)

It also provided the PSTs an opportunity to apply pedagogical knowledge and skills developed during the module in an authentic setting. In particular, it afforded them a safe space to take on new roles as facilitators of inquiry:

> This allowed me to put my knowledge, skills and dispositions to practice in the classroom. (PST1, final reflection)

> [It] can be quite difficult to know how to create the balance between stepping in to help, or observing in order for the students to try to figure it out for themselves. Thankfully we got the chance to practice it as we took part in teaching the children at the school, which gave me insight when it is appropriate to help guide the students, and times where I knew I needed to allow them to discover the solution themselves. (PST9, final reflection)

Having the opportunity to teach a STEM lesson in an authentic classroom was also cited by many PSTs as the reason for their increased self- reported confidence rating, such as those outlined below:

> I feel really confident with teaching STEM... I think teaching in the school was a good 'trial' run and helped to build my confidence. (PST17, post survey)

> After gaining experience teaching STEM during the group teaching I am much more confident in my ability to teach STEM. (PST3, post survey)

While many benefits of this 'trial run' were offered, PSTs also recognized the ongoing nature of STEM teacher development, with one participant stating:

> While I do feel like I have a good knowledge of STEM education, I feel like I would need more time having put this knowledge into practice in order to feel more confident. I feel like being a good STEM educator is a process, within which experience is required to feel fully confident. (PST16, post survey)

4.8.3.3 Essential interactions: Engaging in meaningful collaboration for success in STEM

Opportunities to collaborate and share learning with peers was cited implicitly and explicitly as a key learning activity. It was evident that working in groups was an under-valued experience for the PSTs. Through collaborative in-class tasks, group lesson design and delivery, and opportunities for peer reflection and sharing, PSTs reported a growing comfort in engaging in this type of teamwork, as well as an appreciation for its benefits.

> When beginning this module, I was not keen on engaging in groupwork and did not see the benefits related to this type of work. However, I have seen how working with a group of diverse learners benefits the project being undertaken and leads to a greater understanding being gained. (PST3, final reflection)

> This module enabled me to become more comfortable growing my voice... and become more collaborative with my peers. I am normally not a massive fan of

> group work but as I have engaged in many tasks where we had to collaborate with our peers, my view has changed... This [STEM teaching experience] is the first time I noticed how much I had grown and adopted more effective ways in which to work collaboratively with my peers. (PST9, final reflection)

While the PSTs have undoubtedly engaged in group work and group tasks previously, there appears to be something about the nature of the STEM tasks, and the level of collaboration needed to successfully complete them that resonated with them. PSTs reported that working with peers helped them develop their own 21st century skills and recognize the importance of such skills in STEM education:

> Working with the group on the STEM teaching task has allowed me to improve my communication skills as well as listening skills. (PST30, final reflection)

> Working with a group was a key component of this module. We worked in groups for weekly tasks during tutorials and had to plan a lesson as a group, both instances equipped me with some of the 21st century skills so prominent in STEM. In the creation of the lesson we had to compromise, as all members had both interesting and different perspectives on how to approach our task. (PST22, final reflection)

PSTs also recognized that through shared experiences and shared reflections they could learn from each other. Although not a specific aim of this intervention, the PST's collaborative learning reflected elements of a community of practice. This in turn revealed to them the potential benefits of such work in future, and the possibilities for collaboration in their careers:

> Not only did I learn from my lecturers, but I learned from my own peers whose different personalities and ideas were interesting. (PST18, final reflection)

> Overall, I found this a really positive experience changing my outlook on group work and essentially becoming closer with my peers as a result. It opened my eyes to the importance of collaboration as a teacher, being able to get advice from others if needed and be able to confide in others. (PST9, final reflection)

4.9 Discussion

Growing STEM education policy and the accompanying shift toward integrated curricula, has created an impetus for examining how we prepare our preservice teachers for interdisciplinary approaches. This study contributes to the field by illustrating changes in PSTs' understandings of STEM across a three phased, integrated STEM module, and identifying features of the intervention associated with this development. Overall findings from pre- and post-intervention measures suggest that preservice teachers had richer, more critical understandings of integrated STEM as a result of the intervention. Furthermore, they began to develop a repository of pedagogical skills to support STEM learning in practice.

Similar to the findings of Bartels et al. (2019), although the PSTs in this study were initially familiar with the acronym STEM, they were unsure of how to teach it. They referred to integrating content and could articulate perceived benefits for children. However, PSTs had difficulty in recognizing particular STEM attributes and potential for integrated STEM teaching and learning when analyzing a STEM task. This suggests that although discrete disciplinary modules and a brief introduction to STEM education in a preceding module gave them a good theoretical base, it fell short of leveraging pedagogical understanding or confidence in integrated approaches. As commonly reported in other studies (Kurup et al., 2019; Shernoff, 2017), the PSTs had little to no school experiences of integrated STEM and reported limited exposure to student-led and inquiry-based approaches, particularly at post primary level. Engaging in integrated STEM tasks as a learner afforded the PSTs the opportunity to engage in rich tasks that modelled the ambitious STEM pedagogies and approaches they would be expected to utilize in the classroom (Lesseig et al., 2016), in turn developing their competence and confidence to teach integrated STEM (Johnson et al., 2021a).

It became evident early on in the research that the PSTs had a desire, and indeed a need, for more engineering experiences, echoing prior research that recognizes engineering as the discipline teachers are least confident to teach (Margot & Kettler, 2019). To that end, in-class activities, and the STEM lessons taught, were centered around an engineering design challenge. This allowed for an increased confidence and appreciation for the role of engineering and the EDP in STEM education coupled with a recognition of the role of 21st century skills that the EDP promotes (Nesmith & Cooper, 2019). Similar to the teachers in Dare et al.'s (2021) study, the PSTs also found that engineering presented a 'new' and exciting way for teachers to frame content.

However, by focusing on the engineering design process, other disciplines were pushed to the peripheries. This corroborates the work of others who acknowledge the challenge of maintaining a balance between the disciplines (English, 2016). Other studies also report that meaningfully combining content from multiple disciplines has proven a challenging task and it is important that aspects of each are not lost in the integration process (English, 2016; Walker, 2017). Despite initial confidence in teaching mathematics, the PSTs struggled to identify meaningful opportunities to incorporate grade-appropriate mathematical learning. While this may appear surprising, given that the PSTs were undertaking a mathematics education specialism, it supports previous research that highlights the underrepresentation of mathematics in STEM (Fitzallen, 2015; Martín-Páez et al., 2019). It could be argued that in tailoring the intervention to develop the required engineering knowledge, skills, and dispositions, we (as SEs) tipped the scales of disciplinary balance. Future iterations of this module will need to pay close attention to maintaining the spotlight on mathematics, least the *M* in STEM fall silent (Fitzpatrick et al., in press; Shaughnessy, 2013). Given that practicing teachers have difficulties in finding productive mathematics learning opportunities within STEM tasks (Tytler et al., 2019) we need to explicitly support our future teachers in developing such skills.

Field experience appears to have been a significant turning in the PSTs' STEM development. While some studies have included an element of field practice (Adams at al., 2014; Johnson et al., 2021a) or micro teaching (Çiftçi et al., 2022; Ryu et al., 2019) in their programmes, others have noted the lack of teaching experience as a limitation of their research calling for future studies to include more opportunities for PSTs to teach STEM in authentic classrooms (Bartels et al., 2019; Nowiskowski, 2017; Pimthong & Williams, 2021). Unlike the PSTs in Scogin et al. (2023) who devalued their STEM clinical experience and were uncomfortable with the student-led approach of STEM, 87% of participants in this study attributed positive self-reported changes to field practice. Seeing their STEM learning from college coursework "play out in real life" (PST14, final reflection), and witnessing "first-hand" the effects STEM learning had on children (PST17, final reflection) authenticated the value of integrated STEM for PSTs. This reflects the findings of professional development studies that acknowledge the observation of student engagement and enthusiasm during classroom implementation as key to developing both teacher efficacy and commitment to STEM (Margot & Kettler, 2019; O'Dwyer, 2023). PSTs also reported that teaching in an authentic setting provided a supportive space for them to practice their emerging skills and pedagogies, and assume new roles as facilitators of STEM. Although challenged by these roles, the perceived benefits of STEM for children (such as the development of 21st century skills) appear to outweigh the obstacles. Providing an opportunity for practicum allowed PSTs to make sense of new approaches. As DiFrancesca et al. (2014) argue, it is only while teaching lessons in the classrooms that PSTs "truly grapple with their instructional choices" (p. 57).

Central to this notion of 'grappling' was the role of collaborative engagement and reflection in this study. Ring et al. (2017) found that "teachers' models became more discriminate and complex", accrediting this to the opportunities their participants had to reflect on their own conceptions, share them and discuss them with their peers (p.462). Likewise, participants in this study, developed richer, more comprehensive and critical understandings of STEM education, as a result of individual and group reflection and collaboration. This group work not only aided PSTs in developing more advanced conceptual constructs, it also sowed the seed of collaborative inquiry. By participating in group lesson design and group teaching, as well as shared reflection on that teaching, PSTs identified the opportunities for peer learning, akin to the work of communities of practice (Lave & Wenger, 1991), and recognized opportunities for teacher collaboration in the future. Dubek and Doyle-Jones (2021) report similar findings, with PSTs stating that collaborating with peers and university faculty "enriched their own practice", as well as growing their appreciation of the value of working and learning from each other (p.458). Co-reflection with peers and faculty, led to further meaning-making, and similar to the PSTs in our study, allowed for a social constructivist approach to teaching and learning. In this way PSTs in our study may also have "experienced the importance of reciprocity in learning with and from each other, in a contextualized and dialogic community of practice" (Dubek & Doyle-Jones, 2021, p.460); however, this merits a follow-up study to allow in-depth focus on these possibilities.

4.10 Conclusion

This study supports the call for maintaining disciplinary balance in integrated STEM, and points to the ease in which the scales can be inadvertently tipped. It also contributes to the field by highlighting the reciprocal interdependence of rich STEM learning and authentic field practice in preparing STEM literate PSTs. The former offered novel and tangible STEM learning experiences, exposing the PSTs to the content, skills and pedagogies needed for successful STEM learning. The latter then validated this learning, as they witnessed integrated approaches play out in an authentic setting. It also highlighted the real challenges of integrated STEM in practice, such as classroom management, engaging all learners, meaningful integration and curriculum 'fit'. Furthermore, post-field practice activities, provided the PSTs with opportunities to reflect on these challenges, identify factors that may contribute to them, and collaborate with peers on ways they might redesign the lesson and adapt their teaching in the future. The return to theory following practice, encouraged deep reflection and meaning-making leading to more critical perspectives of STEM education, as evident in their post-intervention task analyses and final reflections. By culminating the intervention in a shared learning day, PSTs were enabled to share their experiences and address the "two- role tension" of being both STEM learner and STEM teacher (Nesmith & Cooper, 2019, p. 496).

4.11 Declarations

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4.12 Chapter conclusion

This chapter responds to the call for more research on the types of learning experiences that contribute to the development of STEM literate PSTs. It contributes to the field by providing empirical evidence on the evolution of PSTs' understandings of integrated STEM across the 12-week intervention, and by identifying the key activities that contributed to this development. It also reveals the powerful interplay that exists in becoming both STEM learners and teachers, and highlights the reciprocal interdependence of lecture room and classroom experiences as PSTs make sense of integrated STEM. However, it also illuminates the challenge of interdisciplinary teaching, with participants noting concern around "authentic integration". Of particular interest is the growing concern PSTs expressed regarding the M in STEM. Uncertainty on how to *meaningfully* integrate mathematics replaced earlier confidences, revealing the difficulty that PSTs had in applying strong disciplinary knowledge to interdisciplinary tasks. The following chapter interrogates this finding further.

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Chapter 5: Mathifying STEM or STEMifying Math? Challenges and possibilities for mathematics learning within integrated STEM contexts

Chapter 5: Mathifying STEM or STEMifying Math? Challenges and possibilities for mathematics learning within integrated STEM contexts

Preamble

Building from a key finding in Chapter 4, this paper focuses on the challenges and possibilities for mathematics within the integrated STEM context. Reporting again on *Intervention 1*, this paper dives deeper into the PSTs' STEM field practice, as they plan, deliver and reflect on a series of five integrated STEM workshops, facilitated in a local classroom. The study reveals a lack of authentic mathematics teaching and learning in these STEM lessons. This paper elaborates on the difficulties experienced by the PSTs in integrating mathematics as identified in the previous chapter. It reanalyses the data to gain retrospective insight into *why* mathematics appears to have been neglected in these lessons, offering subsequent recommendations to promote mathematics within integrated STEM tasks. This paper presents a peer-reviewed book chapter, published in Judy Anderson and Katie Makar's *The Contribution of Mathematics to School STEM Education: Current Understandings.*

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Statement of authorship;

I hereby declare that I, Michelle Fitzpatrick, am the principal author of this article. The following statements outline my contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis and interpretation of data for the work; AND

• Drafting of work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

See Appendix H for Signed Statement of Authorship
See Appendix I for signed letter from Assoc. Prof. Judy Anderson (Co-Editor) confirming the status of this book chapter

5.1 Abstract

Growing recognition of the importance of STEM education has led to an increase in the number of formal and informal STEM programmes. Efforts to evaluate the efficacy and reach of these programmes have not matched the growth in such initiatives and have become a cause for concern. As educational policy and curricular reform in Ireland increasingly advocate an integrated STEM approach, we sought to evaluate the efficacy of five integrated STEM activities designed by a team of mathematics educators and 30 preservice primary teachers as part of a semester-long mathematics specialism. Tasks were implemented across 5 days of intensive STEM workshops with a class of 11-12-year-old students. We report on our analysis of video footage of the children's STEM engagement, alongside focus groups and interviews with the mathematics educators and preservice teachers. Our findings suggest that while STEM tasks were fertile ground for some disciplinary learning (in this case, science and engineering design process) and the development of certain 21st-century skills, they failed to leverage curriculum-appropriate mathematics learning. We recommend that explicit mathematics disciplinary content be considered when planning STEM tasks to maximise the potential for developing children's grade-appropriate mathematical thinking and reasoning. We also present a series of recommendations and practical suggestions to support teachers in foregrounding mathematics when developing or modifying integrated STEM tasks and activities, offering a worked example of one of our case lessons (The Harmless Can Holder) to illustrate our findings throughout.

5.2 Introduction and Background to the Study

Similar to international trends, STEM education has become a focus of the policy discourse in Ireland. Economic imperatives emphasising the role of STEM in enhancing economic growth sparked initial interest in STEM (GOI, 2006), these were soon followed by efforts to enhance technological capacities in schools (GOI, 2009). A national STEM Education Review Group established in 2013 was tasked with reviewing STEM education in the Irish school system. STEM Education became a central theme in education policy (DES, 2017) and the formal introduction of the term ‘STEM education’ soon followed (GOI, 2017a, b). These policy documents advocate for an integrated approach to STEM education and recommend pedagogical approaches and classroom practices that support inquiry and nurture positive dispositions toward STEM. Possibly the most compelling ‘call to action’ is the publication of the *Primary Curriculum Framework* (NCCA, 2023) which introduces the curriculum area ‘Science, Technology, Engineering and Mathematics Education’ thereby requiring an integrated approach to STEM content provision. In parallel to this is the establishment of a STEM Education development group tasked with supporting the development of the curriculum specification for STEM Education. Given these fast-paced advances in STEM Education policy and curricular development, the authors were eager to explore the efficacy of integrated STEM tasks within the primary school setting.

5.3 Review of the Literature

5.3.1 Integrated STEM

There has been an impetus for more integrated approaches to STEM education, motivated by the opportunity to allow students to experience meaningful interaction between the STEM disciplines, often in response to real-world problems, and reflect the natural connections between STEM disciplines (Honey et al., 2014; Breiner et al., 2012;). However, multiple different, and often contrasting conceptions, of integrated STEM exist. Some researchers define STEM as an approach that integrates the disciplines of Science, Technology, Engineering and Mathematics in a manner that authentically reflects the practice of STEM professionals currently working in STEM fields (Sanders, 2009). While others associate STEM education as a means of reforming from traditional didactic-based classrooms to a more constructivist approach encompassing problem solving and inquiry-based learning strategies (Breiner et al., 2012). Some proponents argue that integrated STEM requires the amalgamation of some or all four disciplines in one lesson (Moore et al., 2014) whereas others argue that integration between two or more STEM disciplines is sufficient (Kloser et al., 2018; Sanders, 2009). Efforts to evaluate the degree of integration of STEM have led to the development of frameworks that guide and support STEM integration. For example, Vasquez, Sneider, and Comer (2013) present integrated STEM as a continuum of increasing levels of interconnection among STEM disciplines. Other frameworks have been developed to identify characteristics for quality STEM approaches such as Moore et al.'s (2014) six major tenets for quality K-12 STEM education and Guzey et al.'s (2016) nine components for the evaluation of STEM integration curriculum. While the range of different interpretations of integrated STEM are problematic (English, 2016), the literature highlights some common key features of high-quality STEM education.

5.3.2 Characteristics of High-quality STEM Education

A comprehensive review of the literature identifies seven key characteristics of high-quality STEM education common across many studies and frameworks: problem-solving design and approaches, engineering design and practices, the appropriate use of technology, the use of real-world contexts to situate learning, interdisciplinary knowledge and connections across STEM disciplines, the emphasis of pupil centred pedagogies and the development of 21st century skills and key competencies.

A common focus of integrated STEM education is to provide students with opportunities to apply mathematics and science understandings when approaching and *solving problems*. Problems used to contextualize STEM learning for students should incorporate *engineering design and practices*, frequently posed as an engineering design problem or challenge through the specific needs of a client (Sadler et al., 2000; Moore et al., 2014). Such tasks can encourage higher order critical thinking and problem-solving skills (Stohlmann et al., 2012; Kelley & Knowles, 2016), by engaging students in a problem-solving process involving open-ended questions that allow for multiple solutions. Students are thereby given the opportunity to use iterative test data to improve and refine their design solutions (Moore et al., 2014; Bryan et al., 2015) and justify for themselves scientific claims and design decisions with evidence and reasoning (Brown et al., 2011; Siverling et al., 2019). The appropriate *use and application of technology* is another key characteristic of integrated STEM education. Given the importance of modelling STEM careers as viable options (Herschbach, 2011; English, 2016; Kelley & Knowles, 2016) and engaging students in authentic engineering and scientific practices, it is particularly advantageous to integrate technology within STEM as that of the tools and practices utilised by STEM professionals (Ellis et al., 2020) wherein "technology enables the emergence of new scientific knowledge and assists in the design process" (Shahali et al., 2016, p. 6), technologies such as prototypes and products when they solve problems.

Engaging students in *real-world contexts* and problems is a key characteristic in the literature on integrated STEM (Stohlmann et al., 2012; Bybee, 2013; Moore et al., 2014; Kelley & Knowles, 2016; Shahali et al., 2016; Blackley & Howell, 2019). Tasks that have a familiar or real-life context are more meaningful and relevant for students and are shown to enhance student engagement, as they can draw on their everyday experiences to solve these types of tasks and are therefore more personally motivated to persevere with them (Moll et al., 1992; Blackley & Howell, 2019). Learning experiences that engage students in authentic, real-world design challenges have been shown to foster the development and application of disciplinary knowledge and core skills across and between the combined STEM disciplines (Sanders, 2009; Breiner et al., 2012; Moore et al., 2014; Kelley & Knowles, 2016; Thibaut et al., 2018; Butler et al., 2020).

The importance of *disciplinary and interdisciplinary knowledge* being made explicit to students is also emphasized (Moll et al., 1992; Herschbach, 2011; Moore et al., 2014; English, 2016; Kelley & Knowles, 2016). There is evidence that learning is enhanced through integrative instruction (Sanders, 2009), as a cross-disciplinary approach allows students to transfer knowledge learned in one area and apply it to a different context which builds their understanding and expertise. Engineering design can, therefore, become the real-world, situated context and platform for STEM learning as it involves a process that can act as a powerful link between science, technology and mathematics (Moore et al., 2014; Kelley & Knowles, 2016). Acknowledgement of the critical role played by *pupil centred pedagogies* underpins the majority of STEM frameworks. Advocated pedagogies align with many universally recommended theories of teaching and learning and emphasise an amalgam of constructivist approaches that combine sociocultural perspectives. One recommended approach, and there are many more, that appears in the integrated STEM education literature is inquiry-based learning. Inquiry "motivates STEM learners to engage in problem stating and solving activities, which require planning, synthesis, and evaluation skills using relevant domain-specific content knowledge" (Duschl & Bismack, 2016, p.12).

Promoted pedagogies foster the development of *key competencies or 21st century skills* (Sanders, 2009; Breiner et al., 2012; Dare et al., 2021). Such skills are generally considered innovation and learning skills that emphasise the four C's, which according to Jackson et al. (2021) are essential skills to live a productive life in the 21st century and consist of critical thinking, creativity, collaboration and communication. When integrated STEM education is used with groups of learners, a robust environment for social interaction is provided, which is critical to the learning process (Sanders, 2009). Consequently, teamwork and communication are identified as significant components of these integrated STEM environments (Moore et al. 2014; Kelley and Knowles, 2016; Dare et al., 2021) where students are expected to work cooperatively and collaboratively within small groups to co-construct design solutions to real-world problems. In implementing this environment of social construction, students hone their communication, teamwork and critical thinking skills as they work with their peers towards a common goal and learn to communicate their thought processes in new ways. Collaboration focuses on sharing and contrasting ideas with other individuals engaged in a similar task with a similar aim (Blumenfeld et al. 2006). While such reflective classroom discourse environments are encouraged, Dare et al. (2021) advise, that given the ill-structured nature of real-world problems, students need to negotiate their understanding and decision-making. Doing so, they contend, requires a high level of pedagogical facilitation and support to ensure that all students' voices are equitably heard (Dare et al. 2021).

5.3.3 Challenges of integrated approaches to STEM education: The role of mathematics

A major challenge of integrated approaches to STEM education is determining 'what' should be included. Of major consideration is which STEM disciplines should be integrated and in what ways. Attention to the traditional concerns of supporting scientific and mathematical literacy has broadened to consideration of ways to link these literacies to technology, engineering, design thinking, and computational thinking. Alongside this is an increasing recognition of the importance of developing 21st-century skills and attributes such as creative thinking, communicative, collaborative and problem-solving skills in addition to promoting the development of positive dispositions toward STEM. As these conceptualisations of STEM education broaden, there is the danger of moving towards a STEM "epistemic stew" (Lehrer, 2016). This leads to the significant challenge of maintaining a balance between different disciplines (English, 2016) alongside consideration of how to develop disciplinary knowledge and practices in tandem with incorporating integrated approaches to addressing real-world problems (Anderson et al., 2020).

A review of research by Anderson, English, Fitzallen & Symons (2020) provides valuable insights into integrated STEM learning particularly in relation to mathematics. Their review highlights the limited use of technology with mathematics emphasising tool use “rather than an integrated, essential component of an activity” (p. 38). With regard to science and mathematics integration, Anderson et al. (2020), alongside English (2016, 2017) refer to the dominance of science in many STEM programmes and highlight how the contribution of mathematics is frequently overlooked. Despite what the authors refer to as the limited attention to engineering in Australian primary schools, they report on the diversity of integrated STEM approaches being carried out by Australian mathematics educators, many of which position engineering design in the primary years and point to the importance of careful planning and the development of habits of mind to ensure focus on desired STEM concepts.

Others have also pointed to the underrepresentation of mathematics relative to other disciplines (Fitzallen, 2015; Martín-Páez et al., 2019) cautioning that, unless given significant attention, “the M is STEM is silent” (Shaughnessy, 2013, p. 324). Despite being generally accepted as the underpinning discipline in STEM (Maass et al., 2019), mathematics is often reduced to a service role in STEM tasks with little opportunity for fostering new mathematical insights (Tytler et al., 2019). Recently, Forde and colleagues (2023) examined video footage of over 2000 integrated STEM lessons. While their findings suggest that teachers’ inclusion of mathematics in their lessons was related to increased cognitive engagement and depth of content integration, only 31% of the integrated STEM lessons observed included mathematical content. Indeed, they found that while there was, on many occasions, intent to include mathematical activity in the lesson, this intent was not always realised during implementation. Furthermore, they noted that the majority of tasks which included mathematics reported low levels of cognitive demand, failing to engage the students in understanding and exploring the nature of mathematical concepts, procedures and relationships.

There is, however, evidence of affective mathematical gains from integrated STEM. Lee et al. (2019) found that the 9th graders in their STEM Project-Based Learning intervention, demonstrated significantly greater affective mathematics engagement in terms of mathematical self-acknowledgement and value as compared to the non-STEM Project- Based Learning students. While Lee et al.'s (2019) study indicates the positive impact of highly situated and integrated instruction on affective mathematical engagement, more research is needed to investigate the impact of STEM on mathematical outcomes (Becker and Parks, 2011). Indeed, a review of integrated STEM curricula in the US (Honey et al., 2014, p. 3) revealed that, compared to science, while there was evidence of improvement in dispositions towards mathematics there was "less evidence of a positive impact on mathematics outcomes". Several reasons have been posited to account for such poor mathematical outcomes including the challenges for teachers in finding productive mathematics learning opportunities within STEM tasks (Tytler et al., 2019).

There is a diversity of interpretations of integrated STEM education and a corresponding lack of evidence-based research identifying the characteristics of high-quality programmes and pedagogies to support STEM learning. What is becoming more apparent is the lack of "clear advice for schools and school systems about STEM curriculum and pedagogy" (Anderson, 2020, p.217) and a lack of conceptual clarity around what refer to as STEM ontologies and epistemologies (Chesky & Wolfmeyer, 2015). Even if identification of high-quality programmes is successful, there remains the challenge of supporting pre-service and in-service teachers to develop the knowledge and skills necessary to implement integrated STEM in classrooms (Anderson et al., 2020; Tytler et al., 2019). Furthermore, when considering the role of mathematics within integrated STEM, Anderson et al. (2020) refer to the need, not only to decide if mathematics should be foundational or incidental in integrated STEM education, they also highlight "the need to support teachers to know the difference between the two approaches and thus design learning activities accordingly" (p. 50). This study represents an effort to gain insights into opportunities and challenges for designing and implementing a series of integrated STEM tasks within the Irish educational system.

5.4 Methodology

5.4.1 Study Setting and Participants

The researchers were mathematics educators in the Department of STEM Education within a College of Initial Teacher Education in Ireland. The college certifies undergraduate (4-year degree) and postgraduate (2-year degree) students to teach children ages 4-12 in primary schools. STEM content is traditionally taught as discrete disciplinary areas within the school and college levels in Ireland; however, recent years have seen a shift to designing integrated STEM content across both settings.

Participants were 30 preservice teachers (PSTs) enrolled in a STEM education specialism module which met 3-hours per week for a duration of 12 weeks. They were in the third year of their initial teacher education programme and had completed 5 mathematics education modules, 2 science modules and 2 ICT modules. In the previous semester, they had been introduced to STEM education via a 6-hour online, asynchronous unit of work. PSTs were provided with input into the history and development of STEM education, models of integrated STEM, STEM task design and provided with opportunities to engage in collaborative STEM activities. Following these experiences, they contributed to the design and development of STEM tasks (see below) and engaged in the implementation of these STEM activities in local primary school. A class of 5th grade children, and their teachers, in a local school also participated in the study. Participation in the research was voluntary and ethical approval was received from the institute's Research Ethics Committee.

5.4.2 Task design and development

Prior to the semester, five STEM tasks were selected and modified by the researchers based on a review of the literature and similar tasks. All tasks had the potential to incorporate the seven key characteristics identified in the review of literature. The tasks were: Harmless Can Holder, Weight-bearing Bridge, Earthquake Tower, Kicking-machine and Build a Rollercoaster (see Table 5.1).

Table 5.1

Initial task outlines

STEM Challenge 1: *Harmless Can Holder* Design a holder for carrying a six-pack of cans that is harmless. The one that is currently used on packaging is made of plastic. Design an environmentally friendly holder to easily allow a person carry six full cans.
STEM Challenge 2: *Weight-bearing Bridge* Children engineer a bridge in groups. They must design and build a bridge that spans a gap of 50cm between two tables. Children will test their model bridges with weights.
STEM Challenge 3: *Earthquake Tower* Design a model of a tower that could survive an 'earthquake' (the shake table).
STEM Challenge 4: *Kicking-machine* The children must design a kicking machine that can 'kick' a table tennis ball into a paper cup over a defined distance.
STEM Challenge 5: *Build a Rollercoaster* Build a roller coaster from a limited amount of materials. Which group can design the roller coaster with the best turn/loop that safely delivers the marble into the paper cup.

During four of the in-college preparatory sessions PSTs were organised into five groups and each group was assigned one of the STEM tasks. The group completed the task themselves and this experience provided further input into the lesson design with a view to its implementation within a primary classroom. Each group designed an introduction to the task. These introductions consisted of a driving context that provided a rationale for the task, alongside the selection of images, videos and other resources to support the task context. Materials were also identified, and task criteria and parameters were established. The PSTs completed a session on developing STEM talk moves to promote classroom discourse, and prepared a set of prompts and questions for their lesson based on expected student responses. PSTs were also supported in completing a STEM observation protocol while watching some STEM video footage, in an effort to develop their noticing skills. This work was overseen by the researchers.

5.4.3 Task Implementation

Tasks were implemented across five days with each task taking approximately 90 minutes. Each group of preservice teachers visited the school on an assigned day and implemented the task with a group of primary children. The children were in 5^{th} grade (10-11 years old) and had no prior experience of integrated STEM education. Task implementation took place in the school recreational/sports hall as this provided adequate space for construction and use of materials. A large screen and audio-visual equipment were set up at the top of the hall. The children were organised into 6 groups with 4-5 children in each group. Group membership varied across the five tasks due to attendance and other management decisions. Each group was supported by one pre-service teacher. The pre-service teacher had two roles. They acted as a facilitator wherein they organised materials, answered questions and, where necessary, reminded the group of the task criteria and parameters (e.g. sketching a plan for the design). They did not contribute any creative ideas or contribute to the intellectual activity of the group. The second role was observer, noting the decision-making of children, recording the use of disciplinary knowledge, 21^{st} century skills, alongside challenges and obstacles when engaging with tasks. All five activities were recorded by a professional video crew who used a roaming camera to gather footage of groups of children and their PST as they engaged in the each of the STEM activities.

5.4.4 Data sources and analysis

Using the seven *characteristics of high-quality STEM* education, as identified from the literature, as markers of success, the task design and implementation was evaluated through analysis of the data collected and presented in the table below. Data were collected at four different times: before, during, immediately following and one month after task implementation (identified as pre, 1, 2 and 3 respectively in Table 5.2 below). The data consisted of fieldnotes, and observations made by the researchers of activities, presentations and discussions during the college preparatory sessions, digital video footage of the five STEM lessons and written documentation made by PSTs of their observations and reflections. The researchers incorporated reference to the seven characteristics of high-quality STEM education when taking fieldnotes and during the focus group conversations with the pre-service teachers (Table 5.2).

Table 5.2

Study data sources and phases

Data sources	When	Researchers	Pre-service teachers
Field notes of PST designing and testing tasks	Pre	✔	
Weekly reflective journal entries	Pre		✔
Field notes - observations of group work	1	✔	✔
Video recording of task implementation	1	✔	✔
Focus group discussion of preservice teachers and pre-service teacher group members	2	✔	✔
De-briefing conversation and reflection	2	✔	
Guided-reflective journal entry	3		✔
Final group presentations	3		✔

Data were analysed using two different phases or passes through the data. Inductive analysis occurred first. It involved an open coding strategy which facilitated the emergence of codes and themes in an effort to generate meaning and establish patterns that would shed light on the integrated STEM lessons. One theme relating to mathematics emerged from the data. This theme, *Rich STEM lessons, with an emphasis on engineering and 21st century skills; but where's the mathematics?*, subsequently became the focus for the second pass through the data which was guided by a deductive analytic framework. The goal of the deductive analysis was to identify factors that contributed to, or inhibited, a focus on mathematics within the integrated STEM lessons. The reporting of the findings is structured according to these phases of data analysis, reporting firstly on the nature of the integrated STEM lessons and the role of mathematics, before discussing the factors that impacted the (limited) focus on mathematics.

5.5 Findings, discussion and recommendations

We present and discuss the findings in two parts. The first part reports briefly on our observations following the implementation of the STEM tasks, noting the strength of the task in leveraging some STEM learning (notably engineering and 21st century skills) and highlighting the absence of meaningful mathematics integration throughout the five tasks. The second section seeks to offer some retrospective insight into *why* mathematics appears to have been neglected in these lessons. We discuss the three factors that contributed to the neglect of mathematics and offer some recommendations on how we might address these shortcomings. We conclude with a discussion of a final theme that emerged from reflection on the lessons, with a view to recommending an approach to forefront mathematics within STEM units. In an effort to exemplify our findings and recommendations, the case of *The Harmless Can Holder*, the first of our five STEM tasks, is presented across both parts as a worked example. We use this example to illustrate the contrast between our initial task as it was implemented (see Figure 5.1), and its potential, when modified, to serve as a mathematically-rich integrated STEM task (see Figure 5.2), within a STEM inquiry cycle.

5.5.1 Part One: Rich STEM lessons, with an emphasis on engineering and 21st century skills; but where's the mathematics?

> I just realised the power of STEM, you know? It can really bring through so much, all those 21st century skills. There was so much communicating, so much problem solving in just one lesson. [Joe, Harmless Holder]

The post-implementation data suggest that each of the five tasks designed and delivered, promoted key components of high-quality STEM education, as outlined in the literature review. The lessons were all centred around a real-world context that provided rich and authentic problem-solving opportunities. PSTs observed the effect this had on the children:

> It meant the kids were engaging in an activity that was relevant to their lives as it was the local environment. So, it was personally and socially relevant and that meant that they engaged in the task in a meaningful way. [Ciara, *Harmless Holder*]

The PSTs considered the tasks to be open-ended and inquiry based, with multiple solution paths, and were surprised by the uniqueness of the children's designs.

> Even though it was a prescribed task, there was no prescribed solution, or correct solution to the problem. So, the children had to work together in a meaningful way to discover their own creative solution to the problem. [Rebecca, *Harmless Holder*]

> With other lessons you'd have to go off and do your own work, or listen to the teacher the whole time, but with this it's like, them taking control. It's really student-led. [Melissa, *Kicking Machine*]
> ...and there was no right way of doing the task either. They could do it whatever way they wanted. There was no specific way that they had to do it, which was really good. And then everyone had very different designs at the end. [Claire, *Harmless Holder*]

The PSTs highlighted the centrality of the engineering design process in each lesson and recognised its role in the promotion of key competencies. Each group gave accounts of children demonstrating communication, collaboration, critical thinking and creativity. They were intrigued by the resilience of the children, and their attitudes toward failure.

> It was the engineering design process that fostered the 21st century skills. All through the process they were communicating (negotiating, discussing how they would go about this or that, or overcoming problems), collaborating (they were working together throughout) and thinking creatively to come up with a plan. Creativity was shown right through it [Joe, *Harmless Holder*]

> The kids were not afraid. If it fell apart the first time, they just fixed it and moved on... they just kept going.... developing their problem-solving skills (Susan, *Weight-bearing Bridge*)

> Collaborative learning led to a lot of dialogue that allowed them [the children] to maximise their use of scientific language while developing higher order thinking skills [Ciara, *Harmless Holder*]

> None of them were afraid to do something wrong, or failing. You know the way sometimes you're sitting in maths class and you can see they're afraid to get the wrong answer, whereas here, none of them were afraid to go wrong, because they knew they could redesign it. They just kept persevering, which I thought was a great thing, because life, like you're going to have to alter and change things...you might not always get there the same way, so I liked the fact that the task leads them to redesign stuff [Claire, *Harmless Holder*]

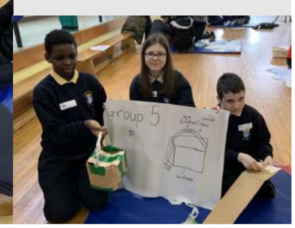
When exploring the disciplinary nature of the task, PSTs and mathematics educators all agreed that engineering was the primary focus of each task. Although they played a *supporting* role in terms of content and context respectively, science and technology were evident across the five tasks. It was clear, however, that little to no mathematical learning took place over the five lessons. While some low-level mathematical *activity* was present amongst the students, such as measuring and computation, there was no evidence of planned, grade-appropriate mathematical teaching and learning across the five lessons. The mathematics involved was incidental for the most part and involved the children utilizing known skills and knowledge, far below their grade level expectations. When asked about the mathematical content of the lessons, PSTs reported on the presence of mathematics such as:

> the weight element...they [the children] were saying it's too heavy (Oonagh *Harmless Holder*)
>
> counting in 10's... measuring 50cm... using the weights at the end (Susan, *Weight-bearing Bridge*)
>
> measuring, things like that.... totting up the creativity points at the end (Valerie, *Rollercoaster*).

It was evident that the PSTs had difficulty in recognising the mathematical deficiencies of the tasks, initially viewing these unambitious and incidental activities as authentic mathematics integration. Furthermore, they struggled to identify meaningful opportunities to explore rich mathematical content to promote mathematical thinking and required extensive scaffolding from the mathematics educators in recognising opportunities for appropriately challenging mathematics integration. This was surprising given that this PST cohort had completed all core mathematics education modules and was undertaking this STEM elective as part of a mathematics specialism.

Figure 5.1

Case lesson: The Harmless Can Holder lesson outline

Setting the context: The PSTs facilitated a whole class discussion on river life, possible threats, and the issues of pollutants in our rivers. They explored the danger that plastics posed to fish, birds and other wildlife, in and on the riverbank.	 
Presenting the problem: Students were given a letter from Limerick City and County Council outlining the problem of plastics in the local river and the risk to wildlife. The STEM challenge requires them to design and build an environmentally friendly holder that would easily allow a person to carry four full cans.	
Materials were distributed and students sketched a design for the *Harmless Holder.* Materials included: *cardboard, 4 cans, variety of tapes, string, scissors, lollipop sticks, hessian material, foil and paper.*	 
Building, testing, redesigning: Students built their holder, tested it, made amendments to improve their design and presented their prototype.	 

5.5.2 Part Two: Why was there so little evidence of mathematical learning?

5.5.2.1 An over-focus on engineering from the beginning

The pace of STEM policy and curricular change in Ireland gives impetus to exploring ways of preparing our future teachers for interdisciplinary approaches. As discussed previously, STEM content has traditionally been taught as discrete disciplines across the sectors. Given that integrated STEM is a nascent approach, preservice teachers have limited experiences as STEM learners themselves. As expected, while they communicated confidence in teaching mathematics and science, the PSTs in this study reported unfamiliarity with engineering practices and were concerned about how such practices could be incorporated into the primary classroom.

Given the novelty of engineering, focus was placed on the engineering design process. STEM tasks modelled in class sought to allow the PSTs to experience engineering practices through the eyes of the learner, while at the same time modelling innovative STEM pedagogies they could adopt when teaching. While prioritizing the engineering design process, however, we underestimated the need to maintain the spotlight on mathematics. In the developing enthusiasm for designing and making, the engineering design process slowly became the overall focus of the tasks and mathematics became almost 'a given'. This finding lends support to the caution provided by Shaughnessy (2013) of the risk of mathematics becoming the silent 'M' in STEM and emphasizes the challenges identified by English (2016) in maintaining a balance between the different STEM disciplines. We also made assumptions about the ease with which PSTs would apply prior learning in mathematics education modules to the design and delivery of their integrated STEM task.

Recommendation: Integrated STEM tasks must contain reference to relevant explicit mathematics disciplinary content

5.5.2.2 No curriculum-based learning outcomes were identified

Owing to this over-focus on the engineering design process, there were no explicit objectives for mathematical learning in the task design. While the potential for mathematics was identified and discussed when planning for the lesson, specific objectives from the curriculum documents were not identified. This proved insufficient in ensuring that mathematics learning was translated into the lesson. PSTs were initially satisfied with the level of mathematics involved in each task and, as already outlined, offered examples of menial mathematical activities as evidence of integration and referred to children's enjoyment engaging in these mathematics tasks. These observations support the finding, arising from a review of US integrated STEM curricula, of improvement in dispositions towards mathematics and the absence of evidence for gains in mathematics learning outcomes (Honey et al., 2014). When probed, however, on the mathematics component and the suitability of such experiences for the grade level, PST began to reflect on the appropriateness of the mathematics involved:

> It was weak enough for their class level like you know, just informal measuring and stuff. No… there was nothing concrete. Say if we went to the curriculum now, I'd say we'd struggle to pull out their learning objectives. So as a task, I'd say it wasn't the best from a maths point of view [Joe, *Harmless Holder*]

PSTs identified their unfamiliarity with the class as a reason for the lack of mathematical challenge as indicated by Ciara in the following extract:

> It would have been beneficial if we had known pupils' maths ability prior to the lesson, because then we could have integrated more meaningful maths at a developmentally appropriate level for them (Ciara, post-teaching reflections).

The standalone nature of the teaching experience and the unfamiliarity with the class were certainly challenges in designing a meaningful STEM lesson. That being said, the mathematics evident in the tasks did not reflect expectations for the fifth class in the national curriculum. It appears that PSTs had difficulty in identifying appropriately challenging objectives from the mathematics curriculum. Consequently, PSTs were unprepared to deal with potentially rich mathematics when they arose, as recognized by Evan in the following focus group extract:

> There was definitely some opportunities for integration that we've missed, you know, they were coming out with like, isosceles triangles, one of them said that, and I just, I certainly didn't anticipate a lot of the things they were coming out with. [Evan, *Earthquake Tower*]

This challenge is not unique to PSTs and was also identified by Tytler et al. (2019) who reported the challenge for practicing teachers in "extracting meaningful mathematics from cross-disciplinary topics in ways that can extend students' mathematical thinking" (p. 63).

Recommendation: Integrated STEM tasks must incorporate grade-appropriate learning objectives for the development of mathematics skills and understanding

5.5.2.3 The task criteria and materials available did not stimulate mathematical thinking

Following each task implementation, each group of PSTs reported that they would adjust their criteria and materials used to improve the quality of the STEM task more generally, to assist the running of the lesson from a classroom management perspective, and to enhance and support the mathematical nature of the task. Two groups (*Earthquake Tower* and *Rollercoaster*) felt they had too many, overly restrictive criteria that stymied the creativity of the children and their designs. The remaining three groups reported that the criteria they provided could have been clearer, more detailed, and included specific requirements that would have compelled their students to consider the mathematics involved in the task. Following the *Kicking Machine* task, it was suggested that amending the criteria to focus on the distance it could travel, rather than hitting a target (i.e. getting the ball in the cup), could have promoted mathematical thinking by encouraging the students to investigate angles, heights, and lengths. Meanwhile, in the *Earthquake Tower* task, the group felt that their challenge description (*to build the tallest earthquake resistant tower*) did not reflect the direction of the lesson, whereby the children had to concentrate on creating *a* tower that would stand at all, thereby shifting the focus from *height* to *stability*, and changing the mathematic lens from *measures* to *geometry.*

> Kathryn: We did bring maths in with the models and explaining shape, but we could have focused on it more...
>
> Aine: I thought we'd be focusing on height and so the emphasis would have been on measure, but shape was more the focus

Some groups also considered the materials and resources they distributed and how that could encourage or curtail mathematical thinking and reasoning. The *Weight-bearing Bridge* group, for example, stated that if reteaching the lesson, they would give the children access to weights throughout the activity to encourage more authentic measuring opportunities. The *Kicking Machine* and *Rollercoaster* groups could have encouraged the exploration of angles by providing angle checkers, anglegs, geostrips and protractors (an opportunity that was capitalized on by one pupil, who ran back to his class for his maths set during the rollercoaster activity).

Recommendation: ‘Mathify’ the parameters and criteria of existing integrated STEM tasks to maximise the mathematics potential and ensure the provision of multiple opportunities to engage in grade-appropriate mathematical thinking and reasoning.

5.5.3 Mathifying a STEM task: The case of The Harmless Can Holder

During the focus group discussions and in follow-up module activities, PSTs and mathematics educators reflected on the role of mathematics in the lesson and considered possible adaptions they could make to reposition the mathematics within the STEM task. We present one case, *The Harmless Can Holder* task, as an example of the PSTs' efforts to redesign the STEM task with an enhanced mathematical focus (see Figure 5.2).

Figure 5.2

Case lesson: The Harmless Can Holder lesson observations and suggested adaptions

Image 1

Image 2

Image 3

Image 4

Observations from lesson	**Suggested adaptions to promote mathematics within this task**
Observation 1: Little to no mathematical thinking was involved in this task. Mathematical content was incidental and required skills and knowledge explored in the early years (such as non-standard units [see *image 2*])	**Identify appropriate curriculum objectives** • select and use appropriate instruments of measurement • estimate and measure length/weight using appropriate metric units • renaming units of length, *mm* to *cm* • identify the properties of the circle • construct a circle of a given radius or diameter
Observation 2: The task was open-ended and allowed for creativity. However, the vague criteria did not stimulate mathematical thinking	**Purposefully building mathematics into the criteria and constraints** • e.g. *"It must be designed to hold four cans only", "cans must remain upright"* and *"using the least cardboard possible".* • This would necessitate more precise measuring, as many of the containers designed gave no regard to the dimensions of the container and could hold much more than four cans [see *images 3 and 4*]
Observation 3: The materials provided did not stimulate grade-appropriate mathematics or mathematical inquiry. Giving the cans out during the planning and building phases removed much of the potential mathematical challenge (tracing the outline of the can [see *image 1*] and using the cans themselves to measure [see *image 2*]). Also, the lack of mathematics resources discouraged the children from considering the role of mathematics within the task.	**Careful consideration of the materials provided to encourage/compel mathematical inquiry** • Only give the dimensions of the can (height, diameter, weight, etc.) and not the can itself, to encourage the students to apply curriculum-based mathematical knowledge and skills. • Distribute one can during the planning phase, allowing the children to determine the dimensions themselves for their designs. • The cans themselves could be accessed, early on, perhaps, as a differentiated support during the planning and making phase if needed, and later for groups to test their designs. • Include a range of mathematics resources and instruments to prompt and allow for meaningful mathematical activity (e.g. compass, rulers, weights, scales)

5.5.4 Spotlighting and positioning mathematics in STEM inquiry cycles

Outside of possible adaptions to the STEM task itself, PSTs discussed other means of incorporating meaningful mathematics integration. Given that this was an isolated STEM teaching block, there was little opportunity to build upon discrete mathematics learning. PSTs identified future potential for building specific STEM tasks into their long-term planning. In the case of the *Harmless Can Holder*, for example, we explored the value of this STEM task as a rich context to build upon discrete mathematics lessons on the properties of the circle, in which student would apply their developing geometric understandings in their designs and constructions. Arguments were also made concerning the task's capacity to act as a springboard to introduce children to explorations on the properties of the circle.

Arising from a review of Australian STEM learning initiatives, Tytler et al. (2019) recognised "the application of mathematics to projects that were 'authentic' and meaningful to students and involved them either in developing mathematics that was new, or applying known mathematics in new ways" as the "fundamental principle of STEM-focused mathematics" (p. 77). Based on our findings, we have offered some recommendations, or considerations, to forefront mathematics teaching and learning when designing or modifying a STEM task (see Table 5.3). When attempting to reposition the 'M' in STEM, we should consider *where* we place specific STEM tasks in the mathematics learning sequence; that is, we need to make conscious decisions about *when* and *where* we position both mathematics and STEM in our teaching. Perhaps we might consider **mathematics *for* STEM** and **mathematics *from* STEM.** By mathematics *for* STEM, we refer to the specific disciplinary knowledge and skills, developed in preceding discrete mathematics lessons, to be utilised and developed in new ways during the STEM task. Mathematics learning *from* STEM, on the other hand, refers to new mathematical knowledge and skills developed during the STEM task. Furthermore, it may also refer to new mathematical concepts that the STEM task presents. In this case, the STEM task acts as both a rich context and a springboard for future mathematics inquiries.

Table 5.3

Mathematics for STEM and Mathematics from STEM, planning prompts for teachers

When thinking about planning mathematics *for* STEM, teachers might ask;

- What are the key mathematical concepts and skills needed to complete this authentic task?
- What mathematics should I explore in my discrete mathematics so children can apply this knowledge during the task?
- Where would this task most meaningfully fit into my long-term mathematics plan/ scheme of work?

Teachers might also consider opportunities for mathematical inquiry that may arise *from* a specific STEM task;

- What new mathematical knowledge or skills could be developed during the task?
- Are there potential mathematical discoveries or 'aha' moments within the task?
- What mathematical unknowns might arise that could be used as a springboard into a future (discrete) mathematics lesson?
- Is there an obvious follow-up mathematics lesson, for which this STEM task could serve as a rich context?

5.6 Conclusions

The STEM tasks explored in this study were effective in terms of the key characteristics identified in the review of literature. Each of the five tasks presented an engaging engineering design task, rooted in a real-world context. Students were challenged to use and develop key 21st century competencies in solving an authentic problem and were deeply engaged in their work. Our findings, however, support the work of Lehrer (2017, 2016), who contends that, while engaging for students, integrated STEM projects can fall short of engaging students in deeper disciplinary practices, failing to promote a curriculum agenda that would characterise a coherent knowledge progression (Tytler, 2020; Tytler et al., 2019). While some lower order, procedural mathematical activity was observed, the lessons failed to leverage rich skills and proficiencies promoted by mathematics education research and advocated in reform curricula (NCTM, 2014; NRC, 2001). As Baldinger et al. (2020) caution, although the experiential, materials-based engineering design challenge approach can be highly creative, "it may predispose students to use mathematics in a manner that could be restricted to measurement and computational skills", and may in fact "inadvertently equate mathematics with measurement and routine, procedural work" (pg.69). Therefore, we need to ensure that rich curriculum-appropriate mathematics are incorporated in our STEM tasks from the outset. In our attempts to introduce and promote engineering practices and 21st century competencies, we let the mathematics become a service tool, and failed to position it as a site of learning itself (Baldinger et al., 2020). In our eagerness to develop aspects of 21st century skills, we lost the emphasis on disciplinary-specific knowledge that is incorporated in influential frameworks of 21st century competencies (Beswick & Fraser, 2019). Our retrospective analysis however, identified ways in which we might mitigate this shortcoming and develop rich mathematical learning opportunities that support the promotion of key competencies.

We need, therefore, to carefully consider how best to balance the demands of disciplinary knowledge development with the opportunities for interdisciplinary mathematics. Developing rich mathematical learning opportunities in STEM tasks is a recognised challenge for teachers. Our recommendations offer practical guidance for maintaining the spotlight on mathematics in STEM. Reflecting on opportunities for mathematics before, during and after STEM tasks, in the planning phase, could support teachers in recognising opportunities for meaningful inquiry cycles, whereby discrete disciplinary learning could inform meaningful interdisciplinary work, and vice versa. Such attempts to *mathify* the STEM and *STEMify* the mathematics could uphold the integrity of disciplinary knowledge, while reaping the benefits of interdisciplinary approaches.

5.7 Chapter conclusion

This chapter reveals some of the challenges of integrating authentic mathematics teaching and learning in integrated STEM tasks. Furthermore, it highlights how aspects of *Intervention 1*, with its emphasis on engineering and 21st century skills, took the spotlight off the M in STEM, contributing to its neglect. It also exposed the assumptions I made about the ease with which PSTs would apply their developed disciplinary knowledge in an interdisciplinary setting. This chapter contributes to the existing knowledge base, by providing practical recommendations for PSTs and novice STEM teachers to support them in maintaining the spotlight on mathematics. However, it raises further questions on how best to prepare PSTs to facilitate integrated STEM. While the papers in Chapter 4 and 5 have identified key learning activities that have supported the development of STEM literacy among the PSTs in *Cohort 1*, they raised concern about the positioning of mathematics within *Intervention 1*. The following two chapters seek to address this issue with a new group of PSTs, *Cohort 2*. While still seeking to identify opportunities for STEM teacher development, Chapter 6 and 7 introduces a second, concurrent research aim; that is to design a mathematics-focused integrated STEM intervention for PSTs that aims to maintain disciplinary balance, by foregrounding statistics education within the unit.

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Chapter 6: Exploring the plight of the honeybee: Using data sensors and CODAP to support Emerging Bilingual Learners in reasoning about big statistical ideas

Chapter 6: Exploring the plight of the honeybee: Using data sensors and CODAP to support emerging bilingual learners in reasoning about big statistical ideas.

Preamble

The following two chapters report data from *Intervention 2*. With a new cohort of PSTs, this intervention sought to build on the previous year's iteration of the module, by purposefully foregrounding mathematics within an integrated STEM task. This chapter reports specifically on PSTs' and researchers' observations from the STEM classroom as Emerging Bilingual children, a traditionally marginalised group in STEM education, engage in data comparison. It should be noted, that while majority of the children could be described as such, this is not a study *about* Emerging Bilingual learners. Instead, this paper seeks to identify how digital technologies and linguistically responsive pedagogies (Coady & Ankeny, 2020) supported this group of learners and their peers to engage in statistical reasoning within a STEM inquiry unit. Findings reveal the influential role of digital technologies in highlighting the relevance of statistics in understanding societal issues and developing students' statistical agency. This article has been accepted in a Special Issue of *Statistics Education Research Journal* (SERJ) on Inclusive Statistics Education with Digital Resources and is due for publication in July 2024.

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Statement of authorship;

I hereby declare that I, Michelle Fitzpatrick, am a named co-author on this article. The following statements outline my contributions to the work:

• Equal contribution to the conception and design of the work; the acquisition, analysis and interpretation of data for the work; AND

• Drafting of work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

See Appendix H for Signed Statement of Authorship
See Appendix I for signed letter from Prof. Dr. Daniel Frischemeier (Editor of Special Issues, SERJ) confirming the status of this article

6.1 Abstract

Children require access to high-quality statistics education to develop the skills to participate in a technological and data-reliant workforce. This study consisted of a five-lesson integrated STEM unit designed to develop the statistical literacy of 62 6th-grade (aged 11-12) Emerging Bilingual (EB) learners. Learning was situated in the study of the honeybee, utilising innovative technologies to gather data and support data visualisation and analysis. Lesson Study was used to design lessons targeting understandings of distribution, centre, variability, data comparison and informal measures of association and inference. This paper reports on the data comparison lesson. It reveals the influential role of digital technologies in highlighting the relevance of statistics in understanding societal issues and developing students' statistical agency. This qualitative study also reveals that the development of statistical understanding was supported by the use of inclusive pedagogies guided by the principles of universal design and the incorporation of data analysis technologies.

Keywords: Innovative technologies; Emerging Bilingual learners; Pollinators; Informal Inference; Data comparison

6.2 Introduction

We live in times of change driven by scientific advances, accelerating globalisation and rapid technological development. These changes challenge education systems to prepare students for jobs not yet created and solve problems not yet predicted. The PISA 2021 Mathematics Framework (OECD, 2018, p.3) for 2021 acknowledges that education must respond to this rapidly changing society:

> In recent times, the digitisation of many aspects of life, the ubiquity of data for making personal decisions involving initially education and career planning, and, later in life, health and investments, as well as major societal challenges to address areas such as climate change, governmental debt, population growth, spread of pandemic diseases and the globalising economy, have reshaped what it means to be

> mathematically competent and to be well equipped to participate as a thoughtful, engaged, and reflective citizen in the 21st century.

As referred to in the quote, the proliferation of big data and open data make urgent demands on the need for a statistically literate society and poses fundamental questions for statistics educators about how to equip learners to reason in more integrated ways and move fluidly and responsively between disciplinary knowledge. The capacity to make statistical inferences is becoming a critical skill to enhance cross-disciplinary understandings that are fundamental to supporting scientists and engineers in drawing conclusions from the data they receive about the world. These STEM-related data are viewed as ‘numbers with context’ (Moore, 1990), and the science and engineering contexts within school STEM environments provide the data context and driving questions that motivate learners to seek and explain patterns revealed in the data (Leavy & Hourigan, 2016a; Shaughnessy & Pfannkuch, 2002; Watson, 2018; Wild & Pfannkuch, 1999).

6.3 Review of Literature

6.3.1 Informal inference at the primary level

Developing primary students’ informal inferential reasoning (IIR) not only supports STEM reasoning; it develops readiness for more formal STEM learning at a later stage (Ben-Zvi, 2006; English, 2010, 2012; Makar & Rubin, 2009; Makar et al., 2011; Paparistodemou & Meletiou-Mavrotheris, 2008). However, identifying the statistical skills that support IIR is complex because IIR integrates various statistical concepts (Chance, delMas & Garfield, 2004). Considered together, however, the frameworks developed by Makar and Rubin (2007, 2009) and Zieffler et al. (2008) provide important guidance, describing IIR as (1) making generalisations that extend beyond the data, (2) drawing on prior knowledge to the extent that the knowledge is available, (3) providing evidence-based justifications for generalisations, and (4) using probabilistic language and making reference to levels of certainty when drawing conclusions. Making generalisations beyond the data requires learners to draw on a broad range of competencies, not least, understandings about centre and variability, distribution, graphical representations, samples and sampling (Gil & Ben-Zvi, 2014), viewing data as an aggregate (Rubin et al., 2006) and focusing on proportions rather than absolutes (Ben-Zvi, 2006). There is an abundance of research demonstrating the ability of primary learners to harness these understandings when making informal inferences about data (English, 2018; Frischemeier, 2018, 2020; Hourigan & Leavy, 2020, 2021; Leavy & Hourigan, 2016a; Meletiou-Mavrotheris & Paparistodemou, 2015; Watson 2018).

6.3.2 Supporting inclusion in primary-level statistics education

Inclusion in mathematics education has warranted an increased spotlight in the policy, research, curriculum design and instructional practices arenas. This broad scope of attention has been posited by Artiles, Kozleski, Dorn and Christensen (2006) as a factor contributing to the absence of an agreed definition for inclusion (Graham-Matheson, 2012). A recent review of the literature by Roos (2018) on the definitions and roles of inclusion in mathematics education concluded that inclusion is used *ideologically* and refers to inclusion from a societal perspective or *as a way of teaching* and considers inclusion from a classroom perspective. In response to the need identified by Roos (2018) for mathematics education researchers "to connect and interrelate the operationalisation and meanings of inclusion in both society and in mathematics classrooms" (p.25), we present a positioning on inclusion that coordinates both societal and classroom-level perspectives.

Ideologically, we consider inclusion from a STEM education perspective by valuing diversity in statistics education. Inequities in participation in STEM education lead to inequity in participation in STEM careers for minority students and females. Given that these inequities are manifested as early as subject-choice decisions during the transition from primary to secondary school, we consider it the right of all learners to access high-quality STEM instruction from as early as primary school. From a teaching perspective, we recognise the affordances of digital technologies alongside a range of inclusive strategies as tools to encourage the participation of all learners in STEM education. Using technologies in this study, we provide learners access to an authentic STEM societal issue, thereby harnessing their interests and promoting their engagement in high-quality statistics instruction. We believe that generating the curiosity and interests of young learners in STEM through providing access to real-world data and inclusive and technology-enhanced pedagogies that support STEM instruction will provide high-quality inclusive learning experiences that will meet our ideological and classroom-level values and perspectives.

6.3.2.1 Emerging Bilingual (EB) Learners.

Due to growing mobility, multilingual classrooms are increasingly prevalent in EU countries (European Commission, 2015) and further afield (Education Office Review, 2018). Recent surveys suggest that 13% of Irish students and 21% of those living in the US (approx. 60 million) speak a language other than English in their homes (Central Statistics Office, 2017; Ryan, 2013). It is critical that emerging bilingual (EB) learners, who are learning the language of instruction as a second language, receive appropriate supports to reach their potential (Gardiner-Hyland, 2021). Multilingual classrooms are not homogeneous, and while research reports that many EB learners thrive in multilingual environments (Barwell et al., 2017; Clarkson, 2007; Moschkovich, 2007), there is also evidence of poorer mathematical outcomes and the marginalisation of some learners due to language challenges (de Araujo et al., 2018) particularly learners from linguistic and ethnic minority groups living in low-resource communities (National Mathematics Advisory Panel, 2008; Sarama & Clements, 2009). Research reports a relationship between general language ability and proficiency in mathematics (Fuchs et al., 2015; Trakulphadetkria et al., 2017) alongside challenges EB learners face due to the linguistic complexity of word problems (Barwell et al., 2017; Vilenius-Tuohimaa et al., 2008) and mathematics assessment tasks (Abedi, 2009; Abedi & Lord, 2001). The sophisticated vocabulary and disciplinary language demands of mathematics, which differ from everyday English, pose particular challenges in English language classrooms (Barwell et al., 2017; Saxe & Sussman, 2019).

A meta-analysis by Sharma and Sharma (2022) identified four statistically effective practices in multilingual mathematics classrooms: dual language programmes, professional development for teachers, curriculum intervention and cognitively focused interventions. Examining these studies and others points to several effective pedagogical approaches and learning activities. Such strategies include linking mathematical concepts with *multiple representations* such as concrete, symbolic, number lines and dynamic graphing software (Barwell, 2005; Borgioli, 2008; Saxe & Sussman, 2019; Warren & Miller, 2015), using visually stimulating materials to maintain *engagement and focus* on mathematical concepts (Warren & Miller, 2015), *teacher professional development* that emphasises positive mathematics mindset and that challenges myths about who can and cannot learn mathematics (Anderson et al., 2018), and the use of *technology-enhanced* instruction that emphasises learning trajectories (Clements et al., 2013). In-depth qualitative studies of multilingual classrooms have also generated valuable insights into the benefits afforded by the use of *high cognitive demand tasks* that are open-ended, involve multiple entry points and solution paths, and require nonverbal representational and oral communication skills (Borgioli, 2008; Secada et al., 1995); classroom participation norms emphasising broad student participation and *collaboration* over competition (Nieto 2000); and a *paradigm shift* away from deficit models to seeing language as a resource, thereby emphasising the strengths that EB learners bring to the mathematics classroom (Borgioli, 2008; Lesser et al., 2016; Nieto, 2002; Ní Ríordáin & Flanagan, 2020; Sharma & Sharma, 2022). In addition to these specific inclusive strategies determined to be beneficial to EB learners, general features from the *Universal Design for Learning* (UDL) framework (Grapinski et al., 2012; Meyer et al., 2014), a framework that recognises variability in learning and differentiates instruction for all children including those who need diverse support, inform good pedagogical practices that optimise the learning opportunities for all students. The three UDL design features – multiple representations of information, multiple methods of action and expression, and multiple means of engagement – align closely with the needs of students from diverse backgrounds and EB learners (Chita-Tegmark et al., 2012; Doran, 2015; Ralabate & Nelson, 2017).

6.3.3 Using digital technology to support statistical understanding and citizen engagement

Technology was utilised for two purposes in this study. The first purpose was to support learners in using data as a tool to engage with critical societal issues and thus address the criticism of school statistics as using 'toy data sets' that address questions of little social or personal relevance (Ridgway & Ridgway, 2019). This use of statistics as a tool for citizen engagement aligns with the goals of the National Council of Teachers of Mathematics (NCTM) to support students to "identify, interpret, evaluate, and critique the mathematics embedded in social, scientific, commercial, and political systems" (NCTM, 2018, p. 11) and reflects a growing effort to engage young learners in analysing societally-relevant data (Estrella et al., 2021; Verbisck et al., 2023; Zapata-Cardona, 2023). To this end, data sensors were used in this study as a *conveyance technology* (Dick & Hollebrands, 2011) which facilitated the collection, storage and transmission of beehive conditions (temperature, humidity and sound) that would be otherwise inaccessible to learners in primary classrooms. A web-based data science tool, the Common

Online Data Analysis Platform (CODAP), was then used to analyse these authentic real-world data sets. Consequently, CODAP served as a *math action technology* (Dick & Hollebrands, 2011) by allowing learners to explore and analyse data in ways not possible using traditional pen-and-paper approaches. Hence, this math action technology supported the second purpose of technology use in this study (i.e., supporting the development of statistical understandings).

Math action technologies such as CODAP, which by their nature support the construction of representations and carry out complex manipulations necessary to solve problems, have been shown to support EB learners in accessing complex mathematical concepts (Saxe & Sussman, 2019) and enhance student learning (Borgioli, 2008; Gadanidis & Geiger, 2012). Indeed, McCulloch et al. (2021) extend the concept, developed by Cohen, Raudensbush and Ball (2003), of 'instructional triangle' to refer to the mathematical spaces generated when teachers work with students to use math action technologies in carefully selected tasks. McCulloch et al. (2021) provide examples of dynamic graphing technologies, virtual manipulatives and interactive applets, which, when combined with carefully designed tasks "create spaces in which all students are positioned as explorers of mathematics" (p. 740). CODAP is a math action technology that enables learners to become statistical explorers by facilitating investigation, identifying patterns, and constructing and testing conjectures.

Although Technology Enhanced Learning (TEL) has become a universally adopted term (Brown et al., 2008), its advantages are not uncontested. Critics argue that TEL is rarely defined, is under critiqued and often assumes an overly optimistic stance concerning gains arising from their use (Kirkwood & Price, 2014; Selwyn, 2017). Concerns also have been voiced about technology use as "an aid to efficiency or productivity, rather than for learning" (Ryan et al., 2020, p. 2), and there is a growing body of research questioning the extent to which technologies are indeed transforming education and highlighting the "limitations of technology to transform long-standing patterns of educational opportunities and outcomes" (Facer & Selwyn, 2021). Consequently, we must remain mindful that even if the relationship between technology use and learning gains is established, longstanding concerns exist regarding the digital divide and how unequal access to educational technologies may exacerbate educational inequality (UNICEF, 2020).

6.4 This study

Building on the review of the literature, this study focuses on two research questions:

1. In what ways can digital technologies support Emerging Bilingual Learners to engage meaningfully in statistical inquiry?
2. How do we support Emerging Bilingual Learners to develop conceptual understanding of big statistical ideas?

6.5 Research methodology

6.5.1 Study setting and participants

The study involved designing and teaching a five-lesson integrated STEM curriculum unit to develop the STEM understandings and statistical literacy of 62 6th-grade (aged 11-12) EB learners in an inner-city school in Ireland. The school has 426 children, many of whom are newcomers from 46 different countries. The study was conducted as part of a mathematics education elective, wherein 28 pre-service teachers (PSTs) worked with three mathematics teacher educators for 3 hours per week across an 11-week semester.

6.5.2 Lesson Study structure and study stages

Japanese Lesson Study (Lewis & Tsuchida, 1998; Stigler & Hiebert, 1999) was used as an organising framework to guide the lesson design, implementation and revision. It was selected due to its iterative and extended process of collaborative planning, classroom implementation, guided observation and reflection aimed at enhancing student learning (Murata, 2011). Within this process, the researchers, who were the mathematics teacher educators teaching the course, guided pre-service teachers through all Lesson Study stages while assuming the role of 'knowledgeable others' (Hourigan & Leavy, 2019, 2021; Leavy, 2010; Leavy & Hourigan, 2016b; 2018).

The Lesson Study process consisted of three stages closely aligned with the 11-week semester.

- *Stage 1 (weeks 1–5), the research and preparation stage*, engaged participants in reading research relating to the practices of Lesson Study (Fernandez & Yoshida, 2004; Lewis & Tsuchida, 1998), understandings about pollinators and the role of data science for citizenship (Makar, Fry & English, 2022; National Biodiversity Data Centre, 2021; Science for Environment Policy, 2020), statistical concepts (Hourigan & Leavy, 2020, 2021; Leavy &

Hourigan, 2016a) and inclusive strategies to support EB learners (Baker et al, 2014; Little & Kirwan, 2021; Selmer & Floyd, 2012). PSTs formed five Lesson Study groups (5-6 members in each group), and each group designed one of a series of 5 consecutive lessons. Lesson 1 (The Honeybee) focused on bee characteristics, including their lifecycle, the hive and various bee roles (e.g. drone, queen bee, worker bee) and introduced the two local beehives where data regarding temperature, sound and humidity (inside and outside the beehives) had been collected using sensors. Lesson 2 developed a conceptual understanding of measures of centre and variability, while in lesson 3, children explored a data distribution representing sound in one of the beehives. Lesson 4 supported the development of informal inferences by comparing the distributions of temperatures in the two hives. Lesson 5 explored the relationship between temperature and sound in one hive.

- *Stage 2 (weeks 6–9), the implementation stage*, involved teaching the series of 5 lessons across five consecutive days to one 6th grade class consisting of 31 EB learners (age 11-12). Each 60-90 minute lesson was taught by a PST and observed by the Lesson Study group members and the three mathematics teacher educators. Following each lesson, a post-lesson meeting facilitated sharing of observations, reflections and feedback. Subsequently, each lesson was revised and re-taught 7–10 days later to a second comparable group of 6th grade EB learners in the same school (N= 31).
- *Stage 3 (weeks 10–11), the reflection stage*, involved each Lesson Study group making an in-class presentation. The presentation reported learning regarding children's statistical understandings, the role of technology, and inclusive strategies when summarising and analysing their taught lessons. PSTs also completed individual written reflections at selected intervals during the semester.

6.5.3 Spotlight on the data comparison lesson (Lesson #4)

Given that this paper examines lesson 4, the development of inferences through data comparison, a brief lesson summary is necessary. At the start of the lesson, after being made aware that the optimal temperature in a beehive is 35 degrees Celsius, the class were introduced to a fictitious character, Jane the 'Bee Girl' and informed that, on visiting the two beehives, she was concerned that one of the hives may be in threat of colony collapse disorder. However, given that beehives should not be opened during the colder months of Winter and Spring as a drastic drop in temperature or change in humidity in the hive may be detrimental for bees, the class must make an informed, data-based recommendation to open a hive only if necessary. Children were asked to work in groups to compare the temperature data from the beehive sensors to conclude which, if any, of the beehives should be opened. It was emphasised that recommendations must be justified using data-based evidence collected by the sensors.

The class was divided into six groups that moved between 3 stations. Each station represented data collected during a period in 2022: May-June (Figure 6.1), July (Figure 6.2), September-October (Figure 6.3). At each station, a group of 4-6 children worked with a PST, who guided them in analysing and comparing the temperatures of the two beehives for the designated period. To ensure consistency of conversation across groups that maintained the focus on higher-order statistical thinking and, in particular, avoided over-prompting and 'telling' on the part of PSTs, we developed a set of prompts and questions (Figure 6.4) drawing from previous positive experiences using this approach (Leavy et al., 2021). Each group of children explored and analysed the distributions using CODAP on a laptop (Figure 6.5). In addition, the PST labelled relevant statistical landmarks and measures on an A3 laminated printout (Figure 6.6) while children recorded landmarks and measures on their worksheets (Figures 6.7-6.8).

Figure 6.1
Hive 1 and 2 temperature data from sensors in May-June

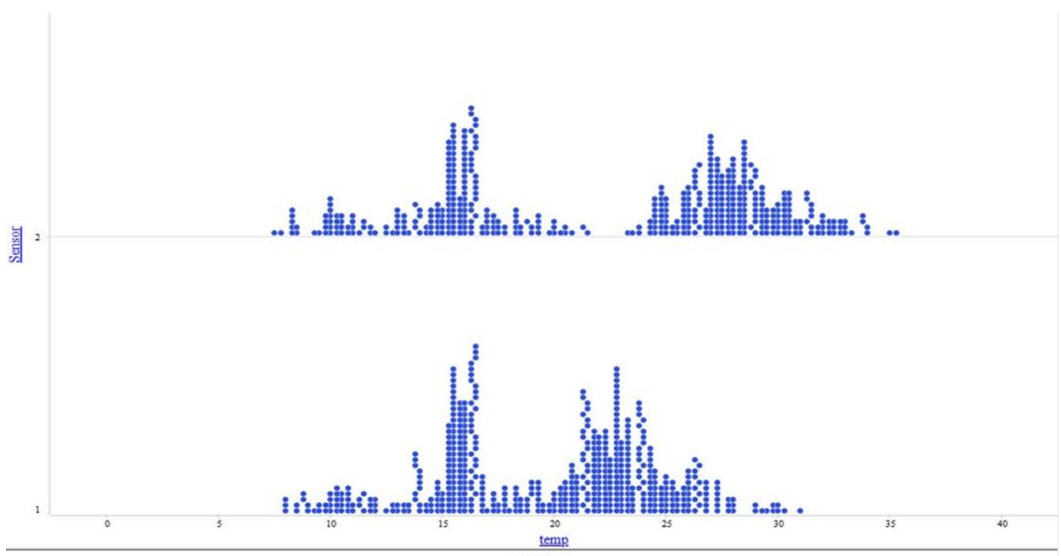


Figure 6.2

Hive 1 and 2 temperature data from sensors in July

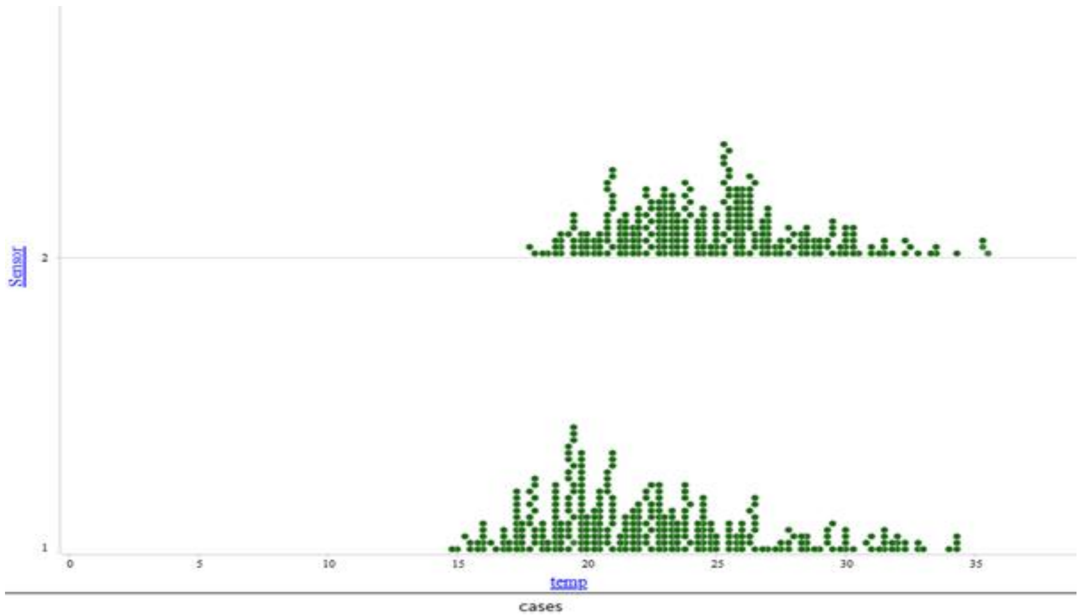


Figure 6.3

Hive 1 and 2 temperature data from sensors in September-October

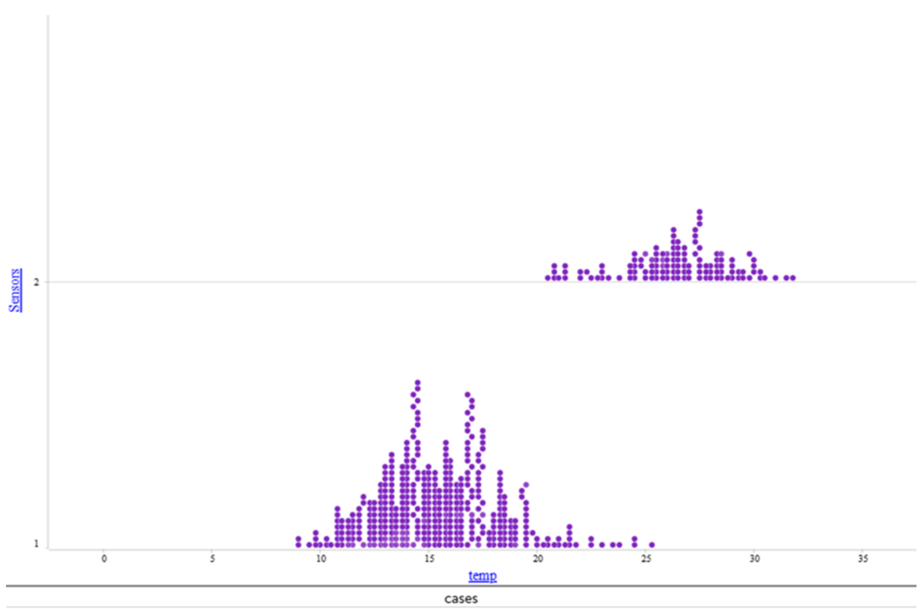


Figure 6.4

PST prompts and questions

Opening Questions
What can you see from the data?
What does the data tell us about the hives?
Is there a difference between hive 1 and hive 2?
What time period do you think this data is from? Why do you think this?

Reading the data
What tells you that one hive is warmer?
So, do you think the bees were ok during this time?
Which hive records the coldest temperature?

Identifying and Reasoning about Statistical Measures
Let's look for the mean…
Predict where the mean could be….
What does the mean tell us about the temperature in the beehives?
What is the median?
What does the median tell us about the temperature in the beehives?
What is the mode?
Predict the mode… which occurs the most?
What is the range? What does it tell us about the temperature in the beehives?
Looking at the graph, what do you think the range is?
What does the range tell us about what we know about the typical temperature of hives?
Are there any gaps in the data?
Can you see any outliers?
Are there any temperatures that occur together (clusters)?
What do you notice about the shape of the data?
What does the shape of the data tell us about the temperature in the hives?
Do you think this hive is at the optimum temperature from what you have learnt?

Reading beyond the data
Is temperature an issue in the hives? Why do you think this? What is your evidence to support this point?
What would you need to see to be concerned?
What temperature would you like to see the hives at?
Do you think that the sensors are accurate?
Which hive, if any, do you think is in trouble and why?
What would be enough evidence to make a convincing and 'correct' argument?

Figure 6.5

Comparing distributions interactively on CODAP

Figure 6.6

Modelling of landmarks and measures on A3 printout

Figure 6.7

Group completing worksheets

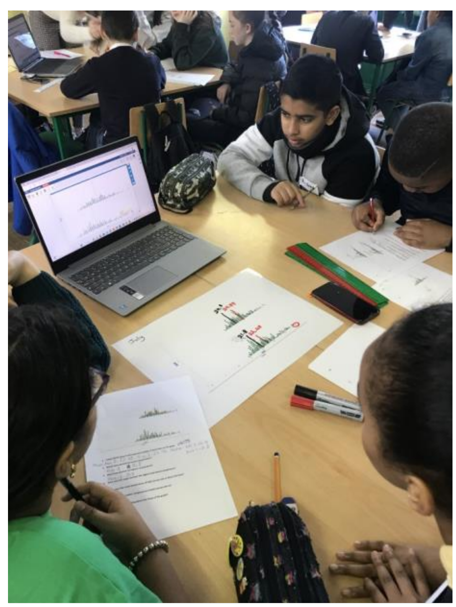
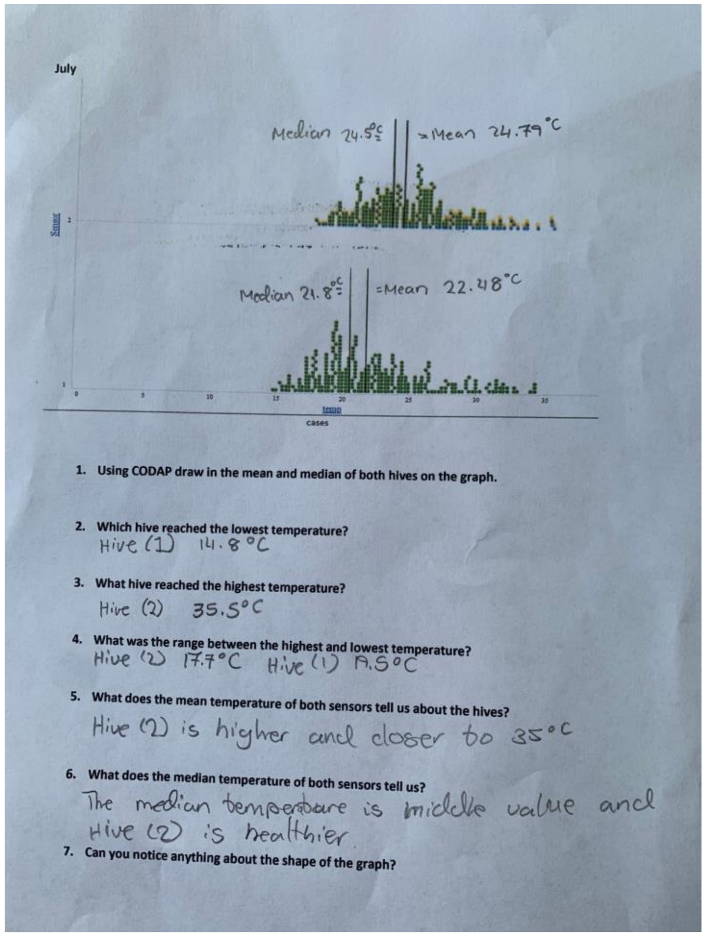


Figure 6.8

Sample of completed worksheet for July data


July

Median 24.5°C | | = Mean 24.79°C

Median 21.8°C | | = Mean 22.48°C

temp

cases

1. Using CODAP draw in the mean and median of both hives on the graph.

2. Which hive reached the lowest temperature?
   Hive (1) 14.8°C

3. What hive reached the highest temperature?
   Hive (2) 35.5°C

4. What was the range between the highest and lowest temperature?
   Hive (2) 17.7°C Hive (1) A.5°C

5. What does the mean temperature of both sensors tell us about the hives?
   Hive (2) is higher and closer to 35°C

6. What does the median temperature of both sensors tell us?
   The median temperature is middle value and Hive (2) is healthier

7. Can you notice anything about the shape of the graph?

6.5.4 Data sources and data analysis

The qualitative data collected across the study is presented in Table 6.1, which outlines the links between the Lesson Study cycle and the data collection process.

Table 6.1
Data collection across the Lesson Study cycle

Stage of Lesson Study	Data Sources
Stage 1. Research and preparation	Researcher field notes taken during lectures, work sessions and Lesson Study group discussions Record of resources used to research and design lesson All versions of the lesson plan Feedback on initial drafts of lesson plans Researcher reflective journal entries
Stage 2. Implementation	PST reflection after implementation 1 Record of changes made to the revised lesson and justification for changes Feedback on drafts of second lesson plan Classroom observations of lesson implementation Audio recordings of children's group work during lesson implementation Samples of children's work Focus group conversations with PSTs following each lesson. Researcher conversations and reflection
Stage 3. Reflection	PST group presentations Researcher observations and fieldnotes PST written reflection Researcher conversations and reflection

The systematic data analysis was grounded in nature. After initial data collation and familiarisation, one researcher undertook the preliminary data analysis stages. This involved examining the data corpus to allocate initial codes closely linked to the relevant literature and responding to the two research questions. This resulted in codes that included *conceptual understanding*, *misconceptions*, *language challenges*, *inclusive strategies*, *engagement*, *real context*, *technology affordances*, and *limitations of technology*. At this stage, a second researcher became involved in the data analysis and together, the researchers completed a succession of examinations, identifying potential relationships between initial codes and instances where they could be merged. This process of constant comparative analysis involving multiple iterations through the data (Charmaz, 2014; Glaser & Strauss, 1967) culminated in the 'firming up' of two broad themes that contribute to our understanding of environmental conditions that support EB learners to develop desirable statistical understandings (Creswell, 2009).

Prolonged engagement of the researchers within each stage of the Lesson Study enhanced the study's credibility (Lincoln & Guba, 1985). To further increase credibility and reduce bias, the researchers collected data across all Lesson Study stages (see Table 6.1). Transcripts reflected verbatim accounts of researchers' and PSTs' reflections and opinions. In addition, the triangulation methods employed (Lincoln & Guba 1985; Patton 2002) included data triangulation (the use of multiple sources of information), researcher triangulation (observations of multiple researchers), and methodological triangulation (multiple methods of data collection, Table 6.1). The involvement of two researchers in data analysis reduced the possibility of the findings being influenced by the researchers' personal biases (Suter, 2012).

6.6 Finding and discussion

The two research questions drove the analysis of the data:

1. In what ways can digital technologies support Emerging Bilingual Learners to engage meaningfully in statistical inquiry?
2. How do we support Emerging Bilingual Learners to develop conceptual understanding of big statistical ideas?

Two main themes and associated subthemes were identified. The first theme uncovers the influential role of digital technologies in (a) highlighting the relevance of statistics in understanding societal issues and (b) developing students' statistical agency. The second theme reveals the development of conceptual understanding of big statistical ideas at the primary level supported by (a) the incorporation of inclusive pedagogies and the principles of universal design and (b) data analysis technologies.

6.6.1 Digital technologies played an influential and constructive role in supporting learning

6.6.1.1 Subtheme #1: Digital technologies supported learners in seeing the relevance of statistics in understanding societal issues

Children demonstrated high engagement and motivation when reasoning about the data presented at each station. Our analyses reveal this was associated with the use of technology, which facilitated a meaningful local connection to a universal societal issue and allowed children to engage with real data to explore and provide recommendations to solve an authentic problem:

> Because the context was real, this context of the bees engaged and motivated the children to learn. They were not just examining random data sets - the data collected was from beehives in relatively close proximity to the school! Many children were familiar with the area where the hives were situated. The problem required them to compare the temperature in hives across time. It did not have a definite 'yes' or 'no' answer which meant the children had to critically investigate and provide evidence to support their reasoning. Integrating this element of STEM [technology] and using real-life temperatures, gathered by specially designed sensors, added more meaning and depth to the lesson. (Stage 3, Kay, (PST), written reflection)

The station activities provided children with first-hand experiences of data-based reasoning, which increased their awareness of the power of data in informing decision-making, as commented upon by Cora in the quote below. However, this new appreciation of the value of statistics in interrogating societally relevant data was not limited to the child-participants in the study. As seen in the reflections from PSTs below, they also acknowledged that the experience heightened their awareness of the role of statistics in real-world decision-making (see quote from Reba) and would inform and influence PSTs' future practice (see quote from Joanna). Zapata-Cordona (2023) argues that developing awareness of the role and value of using nontraditional data sets in classrooms is essential for those who teach statistics to young children.

> The use of CODAP provided the children with an authentic statistical data experience, allowing them to discover why we monitor sound and temperature in the hives. (Stage 3, Cora (PST), group presentation)

> The context of the bees and the use of real data made it highly relevant for both the students and the teacher. It made me realise the importance of statistics as a teacher. It is not just part of the curriculum that we have to cover, it helps us understand information better. If this real-life context of the bees helps a teacher's understanding, it will inevitability improve children's understanding. (Stage 2, Reba (PST) focus group)

> … when planning statistics lessons, I will use more practical examples to motivate the children but also to highlight the use of statistics and STEM in their everyday lives. (Stage 3, Joanna (PST), written reflection)

PSTs and researchers observed that the children took their decision-making responsibility seriously. One PST, Kay, noted in her final written reflection, "The work of the pupils was driven by the reality that the formulation of inaccurate conclusions would cause harm". This was evidenced in the comment of one child, who, after engaging with the three stations, in response to the question "Which hive do you believe to be in trouble based on all the data?", was reluctant to recommend the opening of a hive and stated:

> Well, I don't know which hive we should open. I'm scared to open the wrong hive! What if I end up killing the healthy bees? (Stage 2, group work transcript, boy age 11)

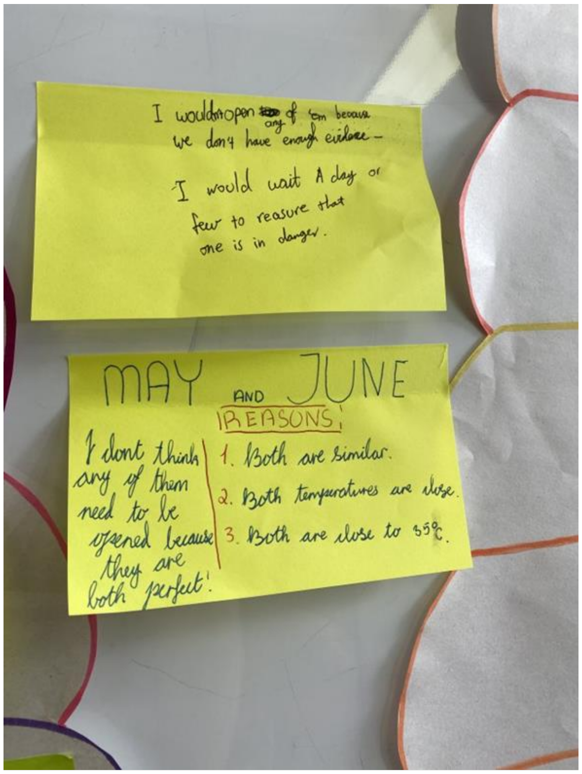
Sensitivities such as these were common within groups across both classrooms. However, despite their apprehension about the potential consequences of their recommendations, children in both classes demonstrated an ability to synthesise their analysis across the three time-period comparisons to come to conclusions and to engage in statistical discourse about these (see Finding #2). A smaller number of children, in light of the potential risks of opening a hive, contemplated, "What if I don't want to open any of the hives?" (Stage 2, group work transcript) as they did not believe there was sufficient evidence to warrant this action. The recorded 'official responses' from groups (see Figure 6.9) included the recommendation that neither hive should be opened.

Such conclusions highlight children's deep engagement with the context, investment in the process and confidence in the valuable role of data in informing their decision-making. This opportunity to work with real data about an important societal issue, in other words, 'numbers with context' (Moore, 1990), represents a departure for school statistics from working with 'toy data sets' (Ridgway & Ridgway, 2019) and facilitates making a connection with the real world by examining non-traditional data about societal issues (Estrella et al., 2021; Zapata-Cordona, 2023).

In summary, children developed an appreciation for the usefulness of statistics as a tool to interrogate data, identify patterns and reveal insights into beehive conditions. Our analysis shows how children used data-based reasoning to support inferences and justify actions about the beehives. Furthermore, through their efforts to find evidence to support their conclusions, they used digital tools to explore data and, in turn, develop their mathematical proficiency. Harnessing the relevant and engaging context of the beehives contributed to the development, we argue, of a productive disposition towards the use of data.

Figure 6.9

Sample of children's data-based recommendations not to open either hive



Upper response:

I wouldn't open any of 'em because we don't have enough evidence.

I would wait a day or few to reassure that one is in danger.

Lower response:

May and June

I don't think any of them need to be opened because they are both perfect!

REASONS:

Both are similar

Both temperatures are close

Both are close to 35 degrees

(Stage 2: Samples of children's work)

6.6.1.2 Subtheme #2: The use of digital technologies supported the mathematical agency of children and positioned them as powerful doers of statistics

Analysis of our data suggests that our efforts to ensure equitable access to STEM education showcased the understanding and abilities of children. CODAP provided the opportunity for children to interact collaboratively with mathematical objects. Through engaging in the dynamic exploration of data distributions, they identified relationships and patterns, made inferences, and engaged in statistical reasoning. Thus, the technology provided a shared learning space where they could make predictions, test those predictions (by comparing means, for example) and engage in statistical discourse, thus becoming 'mathematical explorers' (McCulloch et al., 2021). For example, when presented with the hive data, children launched into data exploration – ahead of any instruction to do so! The majority of their attention immediately focused on exploring and comparing both hives' temperatures in terms of their means, medians, and range:

> Initially, I noticed that each group of children launched into analysis before I could give them any guidelines. They were extremely capable of comparing the data presented to them on the graphs but could also hypothesise the ideal conditions as a third data set. The children compared the mean of hives 1 and 2 and concluded that hive 2 had a higher mean and, therefore, better conditions for the bees. They then stated that although the mean of hive 2 was higher than hive 1, hive 2's mean was still a distance away from 35 degrees (the optimum temperature). (Stage 3, Ella (PST), written reflection)

At the three stations, some children focused on landmark features of distributional shape, such as clusters, to compare distributions. Similar to young students in the study by Zapata-Cardona (2023), they interpreted graphic representations and made inferences that could not have been made without using the data visualisation tool. The excerpt below from the conversation between a PST and a child, recorded as one group worked at a station, illustrates their focus on clusters:

PST: So far, what decisions have your group made? What hive, if any, might need to be opened based on the data you examined in the previous two stations?

Aisha: We think we should open hive 1 because hive 2 is always warmer.

PST: Why do you say that?

Aisha: Because it's colder because the cluster [in hive 2] is between 25 and 30 [degrees]. And for hive 1, it's somewhere around 13 to 18 degrees.

After comparing the hives' temperatures across the three stations (Figures 6.1-6.3), as part of group discussions supporting children to identify trends across time periods, PSTs asked, "Which is the best beehive?" In a group conversation below, we see Daniel's statistical reasoning as he coordinates understandings of variability and central tendency to inform the construction of informal inferences. Furthermore, when the PST presents contradictory information by highlighting attention to the minimum temperature in hive 2, Daniel demonstrates agency in making an argument to support and justify his decision. This type of reasoning, demonstrating an understanding of numbers in context as references for measuring variability in the real world, was also evidenced by Estrella et al. (2021) in their work with primary children when working with tsunami data.

Daniel: Hive 2 is better because it reached the largest temperature, it had the highest mean and median, and it is hotter.

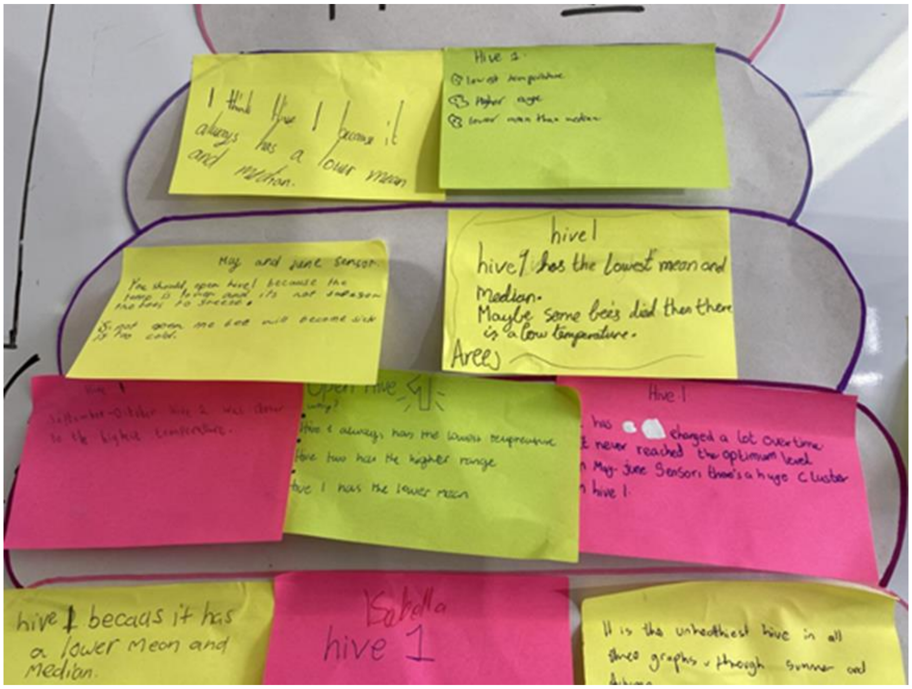
PST: Ok…but didn't hive 2 also have the lowest temperature?

Daniel: Yeah, but the lowest temperature in hive 1 is 8 [degrees], and the lowest temperature in hive 2 is 7.5 degrees which rounds to 8 anyways.

Children were comfortable making data-based conclusions responding to the driving question, "Which hive, if any, is in trouble?" They were asked to justify their inferences and conclusions by presenting evidence, in the form of three reasons, to support their decision. Many children recommended opening hive 1. Their selected evidence (see Figure 6.10) provided valuable insights into the statistical reasoning underpinning their recommendations. They referred to three main statistical observations: (1) the lowest temperature, (2) the highest range of temperatures and (3) the lower mean and median values. Thus, the affordances provided by CODAP as a math action technology (Dick & Hollebrands, 2011) to construct the representations that facilitated the identification of data ranges, alongside carrying out the calculations of measures of central tendency, enhanced student learning (Borgioli, 2008; Gadanidis & Geiger, 2012) and provided access to complex mathematical concepts (Saxe & Sussman, 2019).

Figure 6.10

Sample of children's data-based recommendations to open hive 1



In one group, when children were supported to examine trends across the three time periods, it became apparent that one child, Nicolas, had independently found 'the average of averages', that is the mean temperature across the three time periods. This additional layer of analysis provided further evidence to support this group's conclusions.

PST: When you're looking at the highest temperature, is hive 1 ever higher than hive 2?

Sophia: No, but hive 2 was once lower than hive 1.

Nicolas: I figured out that the average of the averages in hive 2 is higher by six degrees.

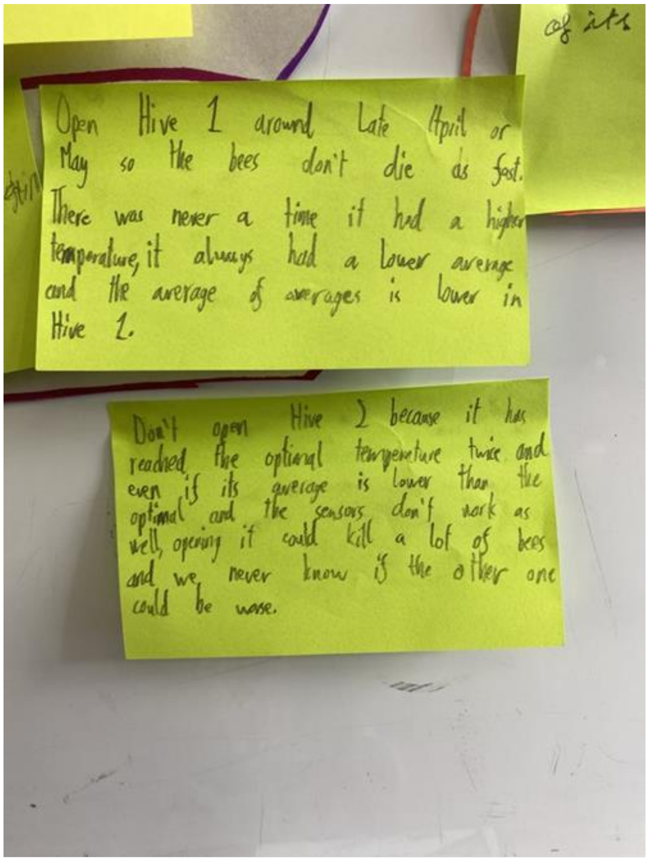
PST: So, did you work out the averages of the hives across all the data you have? Tell us about that.

Nicolas: It's 18.963 and so on [degrees] for hive 1, and then hive 2 is 24.6 [degrees], so it's higher by roughly 6 degrees.

Nicolas' group used this analysis in the class discussion to support the recommendation that hive 1 was in trouble. As they stated in their presentation: "Hive 1 is in trouble because hive 1 never had the highest temperature. It always had a smaller average. And the average of the averages for hive 2 is warmer by six degrees" (Stage 2: Researcher classroom observation). This child subsequently provided more detailed recommendations to Jane the 'Bee Girl' within their written response focusing on the conditions in both hives (Figure 6.11).

Figure 6.11

One child’s data-based recommendations for hives 1 and 2



Upper response:

Open Hive 1 around late April or May so the bees don’t die as fast. There was never a time it had a higher temperature, it always had a lower average and the average of averages is lower in hive 1.

Lower response:

Don’t open hive 2 because it has reached the optimum temperature twice and even if the average is lower than the optimum and the sensors don’t work as well, opening it could kill a lot of bees and we never know if the other one could be worse.

(Stage 2: sample of children’s work)

During the final whole class discussion, where individual children shared their recommendations and justifications, their agency and capacity to communicate and justify conclusions that were informed by understandings of various statistical concepts became apparent:

PST: Have you decided maybe one hive is in trouble? (children nodding)Yeah? Does anybody see anything that might be interesting?

Zach: I think Hive 1 might be in trouble.

PST: Why do you think hive 1?

Zach: I think hive 1 because as she (pointing to a child in the group) said, if there is less difference between the maximum and the minimum and has less range, it means the hive is doing well. But if it has a higher change this means it has lots of changes in it.

PST: That is very good. If it has a wider range, it means it has lots of changes. So which one has a wider range? You think hive…

Zach: Hive 1 has lots of changes.

PST: That is very good, and if you look as well at September and October, that one has a smaller range for hive 2. Excellent! Does anyone else agree with Hive 1 being in trouble?

Mira: Yes! Because hive 1 never had the highest temperature, it always had the smaller average. And the average of the average for hive 2 is warmer by 6 degrees.

PST: Ok. So, it always had a lower average and a lower mean and never reached the highest temperature. OK, does anybody else want to agree?

Kai: Yeah. I think both [hives are in trouble].

PST: So, do you think both are in trouble? Do you want to tell us why?

Kai: Because in the September graph it has like less.

PST: Yes, like less data, less values. So, it could be in trouble. Is there anything else you would like to say about it?

Kai: Yeah, we might not know if the batteries are not working.

PST: That's a very interesting point. So, you think the sensor might have run out of batteries because there's less data together, and then we don't know if it's in trouble or not.

In addition to drawing on understandings of centre and variability, there were many examples across the data set of children using probabilistic language such as "might" or "maybe", as is evident in the contributions from Kai and Zach above, to communicate their levels of certainty about their recommendations (Makar & Rubin, 2007; 2009; Gil & Ben-Zvi, 2014).

6.6.2 Development of conceptual understanding of big statistical ideas at the primary level

6.6.2.1 Subtheme #1: The incorporation of inclusive pedagogies and the principles of universal design supported the development of statistical understandings of EB Learners

A variety of inclusive practices and strategies were purposefully incorporated into the lesson. Combined with a meaningful real-world context, local large data and relevant conveyance and math action technologies, these pedagogies supported children in accessing statistical learning opportunities. This supports the stance of Borgioli (2008) that fairness and equity in mathematics education is possible "but *only if* the teacher *purposefully* attends to it as a goal" (p. 186).

Firstly, a range of relatively pedagogically undemanding yet powerful strategies were implemented to help overcome the challenges associated with introducing or revising sophisticated vocabulary and disciplinary language demands (Saxe & Sussman, 2019). In earlier lessons, the use of *visually stimulating images and video* (e.g. photographs) (Warren & Millar, 2015) and the *provision of vocabulary* about pollinators provided support for many learners (see Figures 6.12a and 6.12b). Additionally, simple definitions and alternative terms (e.g., the use of the words 'ideal' and 'best' as alternatives for the word 'optimal') ensured clarity for EB learners. For the PSTs, witnessing the benefits of such strategies firsthand within the second classroom implementation highlighted the benefits for learners:

> Each component and resource of the lesson needs to be demonstrated, simplified, rephrased or illustrated using a visual cue. This can support children to understand new vocabulary and gain attention if props and active demonstrations are used. They can see what is being said to make the learning and meaning less abstract and can hear explanations in a simplistic version to help comprehension. (Stage 3, Joanna (PST), written reflection)

Multiple representations (Saxe & Sussman, 2019; Warren & Millar, 2015) of concepts and graphs were provided. For example, in lesson 2, when teaching the mean, we offered a kinaesthetic experience of the 'levelling' analogy through the use of manipulatives that closely reflected the CODAP representation (Figure 6.13). Multiple representations, digital and hard-copy, of graphs were presented through CODAP-constructed dynamic distributions on laptops, printed large A3 laminated sheets for group work and individual student worksheets. These constituted another intentional support facilitating exploration (CODAP graphs) and recording and annotating (A3 and individual printouts). PSTs modelled how to locate and label data landmarks (e.g. minimum value, gaps, outliers), mark and annotate measures of centre (mean, median, mode) and calculate measures of variation (range) on the laminated A3 graphs (Figure 6.6). This supported EB learners in accessing, locating and reinforcing understandings of the statistical concepts and related terminology:

> I used the laminated A3 sheet to demonstrate the measures and features I was discussing by marking them on the graph. This gave all learners a visual object and location (e.g. the mean is 21 degrees, and that's 'here' on the graph) to look at to support them in completing their worksheet, as measures were presented visually, not just referred to orally. It also aided their comprehension as they could follow what I was saying through what I was drawing. I also wrote spellings of new words on the A3 sheet so they could copy them instead of spending time trying to create the correct spelling of the words. (Stage 2, Anna (PST), focus group)

Across all groups, children used their worksheets (graph labels and workings) to support them in selecting and reporting their inferences, conclusions and justifications. The PSTs agreed that there was further potential in future practice to "use reference points (e.g., PowerPoint slides/flashcards/posters with key terminology and complementary images) and annotated graphs to support children's engagement and understanding" (Stage 3, Ella (PST), group presentation).

In addition, the opportunity to *work collaboratively in groups* when comparing data distributions naturally supported EB learners to make initial observations about features of individual distributions, propose the use of specific measures to make comparisons, communicate their understandings about observed differences between distributions, and engage in high-level statistical reasoning by coordinating these shared understandings in the construction and communication of informal statistical inferences. For example, Figure 6.14 illustrates a group reporting their shared response to a question. In the quote below, we see a PST reflect on how these groups were safe spaces, thus promoting collaborative rather than competitive participation, which is recommended for EB learners (Nieto, 2000).

> The students in both classes were great at working together and helping each other, which helped keep EB learners involved and engaged. These intimate group

settings provided EB learners with a safe space to share thoughts and ideas and to ask questions. However, this teaching model also allowed us, as teachers, to work with these pupils on a more personal level. We were able to model activities, prompt conversation and aid differentiation in such a way that helped us to broaden pupils learning and help them to reach their full potential. For these reasons, I believe that group work tasks are a great resource for teaching children with various language needs. (Stage 3, Kay (PST), written reflection)

Across the lesson, the ongoing opportunities to collaborate in groups assisted all children in participating (Nieto, 2000). In addition, multiple means of communication were promoted during group work, including oral and nonverbal representational communication (Borgioli, 2008).

Figure 6.12a

Provision of vocabulary about pollinators

Figure 6.12b

Images and vocabulary about life-cycle stages and bee-types

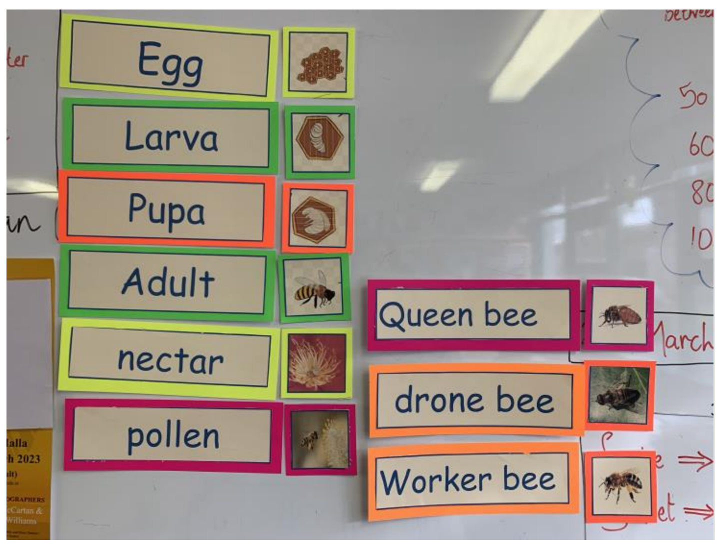
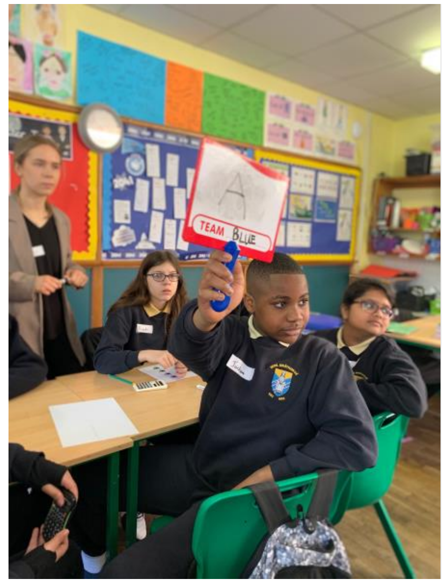


Figure 6.13

Developing the 'levelling' analogy of the mean using cubes

Figure 6.14

Group sharing their response to a problem



6.6.2.2 Subtheme #2: The use of data analysis technologies supported the development of conceptual understanding

The use of technologies fast tracked the development of children's conceptual understanding of statistics in three ways: carrying the procedural load of calculations, supporting the exploration of data sets and revealing statistical misconceptions.

Firstly, the measuring tool feature of CODAP instantaneously calculated means and medians, and represented them visually, thereby *freeing up time* for children to interpret the meanings of the measures of centre and contributing to their unfolding understandings of the data distributions (Saxe & Sussman, 2019). In the reflections of Anna and Ella below, they commented on how CODAP facilitated children in exploring big data sets and effortlessly determining the locations of measures of variability and centre. Also, the researcher fieldnote below, made during observation of the lesson, provides insight into how CODAP supported the development of statistical understandings.

> Statistical concepts frequently need complex calculations and vast datasets. The bee data set was quite vast as we covered all three different time periods. Each of

> these data sets had timestamps for almost every hour and day in these months. In our class, we used CODAP and had laptops at each station. Incorporating this use of technology made it easier for the students to explore and analyse the data. (Stage 3, Anna (PST), group presentation)

> The CODAP platform enabled the data to be accurately represented on the graphs, in comparison to creating graphs on paper…Then, while teaching the lessons, each group had access to the graphs from the CODAP platform on a laptop. Children were then able to get the accurate value of each point on the graphs, e.g., the minimum point. Furthermore, they were enabled to find the exact values of the central tendencies of the mean and median… which would not have been possible to do so on paper. (Stage 3, Ella (PST), written reflection)

> Children in one group made inferences and predictions about the impact of outliers on measures of central tendency by modifying or deleting outliers and observing the impact of these changes on the measures of central tendency! (Researcher Fieldnotes, Lesson 4)

Furthermore, by not having to calculate the means and medians of large data sets, time was freed up to support the comparison of temperatures between hives 1 and 2 across three different time periods; this would not be possible with traditional pen and paper activities. Thus, time was dedicated to analysing and comparing large sets, providing opportunities for consolidation of statistical understandings and honing their statistical literacy. This was evident in exploration of the meaning of measures within the context of the bee dataset. For example, PSTs focused on the meaning of the range, highlighting that a larger range means more variation or changes within the hive, whereas a smaller range suggests less variation and change in temperatures. Children were then asked, "Do you think the bees prefer more changes or less changes in the hive temperature?" they agreed, "Less changes". Their understanding of the range was evident within the lesson conclusion when they were discussing evidence to support the opening of one of the hives:

Kamal: So, I think hive 1 should be opened because here [pointing] for the temperature, there is no gap between. Over here [pointing] the temperature, the difference between temperatures in hive 1 it's bigger than hive 2, and … when there are less changes, that means that hive is doing better.

PST: So, is that your first piece of evidence? [child nods]

What were you focusing on there?

Kamal: The range

(Stage 2, group work transcripts)

A second affordance of technology was that it supported children's *data explorations* and allowed them to generate inferences and make and test conjectures. For example, when building on children's prior understandings of measures of centre and variation developed over the previous days' lessons, PSTs encouraged children to estimate these measures (Borgioli, 2008; Gadanidis & Geiger, 2012). These estimations, and the reasoning underpinning the selected estimates, provide valuable insights into and confirmation of the development of conceptual understanding. In the following excerpt from the post-lesson focus group, one PST describes how a child in the group she was working with made considered and informed predictions about the mean value in hive 1 (see Figure 6.1). It is evident from the excerpt below that the child is engaging in relatively sophisticated statistical reasoning to inform their prediction of a mean value. He identifies two clusters of data which each contain a high density of data values; such clusters have been referred to in the literature as 'modal clumps' (Konold & Higgins, 2003; Frischemeier, 2020; Leavy & Middleton, 2011; Lehrer & Schauble, 2002). Furthermore, he then engages in proportional reasoning about these clusters, provides a preferential weighting to one of the clumps based on the higher data frequencies, and uses this rationale to situate the estimated mean within the cluster. Further evidence of conceptual understanding is his coordination of variation through consideration of the range to justify the location of the estimated mean:

> When focusing on the mean of hive 1, one child estimated the mean temperature to be 22 degrees. When I challenged him as to why he thought the mean was 22 degrees, he stated that "there is a lot of data between 15-20 and a lot of data between 20-25, but there is more data between 20-25". He also used the maximum and minimum values to support his reasoning, outlining, "It only goes up to 31 and 7.5/8, and I feel it would be 22 or 21 degrees". (Stage 2, focus group)

Finally, through freeing up time to engage in reasoning about the distributions of data, there were opportunities to *address misconceptions* as they arose within the context of comparing data. For example, when predicting the location of the median temperature of the hive for May, further opportunities to address developing (mis)understandings became evident:

PST: Where do you think the median is?
Talia: [Pointed to the middle of the range but did not consider the distribution of data values within that range of data]
PST: Why do you think it is there?
Talia: It is halfway between maximum and minimum
PST: Do you think half the values are above and below this point? [child nods]

(Stage 2: group work transcript; classroom observations)

While children could state that the median is the value that falls in 'the middle' of a data set, it became evident that some needed further support to help them develop a thorough understanding of the median, as half of the temperatures in the hive being lower than this temperature and half of the temperatures in the hive being higher; rather than the median being the midpoint of a number line extending between the minimum and maximum data values.

> I highlighted the need to consider the clusters of data to make sense of the location of the median on the graph. (Stage 2: Anna (PST), focus group)

Another example was of technology facilitating the identification of misconceptions related to interpretations of the range. For some children, there were difficulties understanding the meaning attributed to the range as a measure of variation when comparing distributions. Initially, some children demonstrated confusion when interpreting the contextual relevance of larger and smaller ranges of temperature when comparing distributions of temperature between both beehives, considering a larger range to be preferable:

> The range of hive 1 is 19.5 degrees, and hive 2 is 17.7 degrees, so hive 1 is better as it is closer to 35 degrees. (Stage 2: group work transcript)

PSTs observed and commented on technology completing the more arduous and tedious lower-order skills (Saxe & Sussman, 2019) relating to procedures such as calculating means and medians. They remarked on how technology facilitated children in reasoning about these measures rather than merely calculating them. Moreover, it provided a link between theory and practice. By having the opportunity to observe children developing conceptual understanding rather than dedicating time to procedural skill development, PSTs gained an appreciation for the goals of statistics education as espoused in contemporary statistics education research:

> The children could use CODAP, knowing how to find the mean and median but also knowing that hovering the arrow over a dot shows the exact value of the timestamp. This has made me realise that teaching statistics does not revolve around drawing graphs but can instead focus on interpreting and comparing them and has influenced me to incorporate technology into teaching statistics going forward. (Stage 3, Kay (PST), written reflection)

6.7 Summary and conclusions

One of the greatest challenges of mathematics education is convincing children of the relevance and utility of the discipline. In this study, situating opportunities to engage in informal inference within the context of societal issues is in stark contrast to criticisms of instruction on inference being taught as an isolated subject (Rossman & Chance, 1999). Findings of this study illustrate that engaging children with real data about important societal issues (Ridgway & Ridgway, 2019) stimulates interest in and engagement with data, develops conceptual knowledge of big statistical ideas, advances statistical literacy, and cultivates the development of a critical stance and a disposition to engage with evidence. It seeded an interest in seeking out evidence to support their data-based inferences and inform conclusions and actions stemming from their analysis of the issue.

The strategic two-fold utilisation of technology in the study, as conveyance and math action technologies, was critical to ensuring that we provided "more equitable access and opportunities for each and every learner to actively engage and participate in the learning of mathematics" (NCTM, 2023). While the data sensors collected and conveyed data, the use of CODAP promoted inclusivity. In contrast to some mathematics classrooms where technology use emphasises drill and remediation, thereby perpetuating inequity (McCulloch et al., 2021), free-to-use CODAP challenges this inequity by providing linguistically diverse children in this setting with the opportunity to engage in cognitively challenging tasks thus addressing critiques of technology use (Facer & Selwyn, 2021; Ryan et al., 2020) and freeing up instructional time for EB learners to become mathematical explorers (McCulloch et al., 2021).

The findings of this study reveal the power of inclusive strategies to support all learners to engage with big statistical ideas. This study lends support to the conclusions of Barwell (2009) that focusing on language when teaching extends beyond considerations of vocabulary to supporting *ways of doing* mathematics such as mathematical discourse and argumentation. Across all aspects of the study, there is compelling evidence of the centrality of the teacher aspect of the instructional triangle (McCulloch et al., 2021). While technology plays a critical supportive role, technology alone is not sufficient in promoting EB learners to become explorers of statistics. Only through the careful selection of meaningful, open-ended tasks, the purposeful integration of inclusive strategies and explicit teaching to promote conceptual understanding of statistical concepts can the affordances of math action technologies such as CODAP be optimised, thus enabling EB learners to access authentic statistics experiences. These skills are the remit of the classroom teacher, who needs to possess appropriate pedagogical knowledge for teaching statistical concepts, combined with statistical content knowledge, in order to facilitate all children to reap the rewards of engaging with big data through such math action technologies. This requires investment in initial teacher education and continuing professional development for practicing teachers.

The research has a number of limitations. Firstly, this is a case study of two 6th grade (age 11-12) classes of EB learners; hence, the results of this study cannot be generalised to all children of this age. There is potential for further study to examine EB learners' experiences across a variety of class grades and educational settings. A second limitation is that the study examines the impact of one math action technology (i.e., CODAP) within an instructional unit focused on the living conditions of beehives. It cannot be assumed that equivalent outcomes would be achieved when focusing on a different societal context. In addition, the findings cannot be generalised to all math action tools. Finally, despite the collection of qualitative data across the 11 weeks, the study does not measure statistical learning outcomes. While acknowledging these limitations, the study findings illustrate the nascent potential that exists for all learners to access and analyse nontraditional datasets in the service of interrogating greater societal issues.

Today's mathematics explorers are tomorrow's citizens and 'change agents' (OECD, 2018) who will be required to possess statistical literacy skills that complement STEM disciplinary knowledge. Furthermore, they will require the critical ability to think across the boundaries of STEM disciplines, thus compelling them to extend their disciplinary knowledge and reason in integrated ways to draw conclusions from the data they receive about the world. The findings of this study hold great promise for all children, particularly EB learners, in realising their potential as change agents of the future.

6.8 Acknowledgements

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6.9 Chapter conclusion

This paper presents an integrated STEM lesson in which mathematics maintained the leading role, strongly supported by technology, in a rich scientific context. The lesson was successful in promoting high-order mathematics thinking and reasoning, something which had been lacking in the lessons in *Intervention 1*. Statistics proved a powerful integrator, while the rich societally relevant context seeded an interest in seeking out evidence to inform data-based conclusions. Utilising a free, open-access math-action platform engaged these EB learners, supporting them in accessing authentic statistic experiences, in turn breaking down traditional barriers to STEM. While reference is made to some prior learning and data collected in previous and subsequent lessons to support claims made in relation to children's development, publishing requirements limited this paper's scope to detail the trajectory of children's learning across the four other lessons in this STEM inquiry unit.

The findings in this paper reveal the PSTs' awareness of the benefits for children. Drawing on the work of Lesh and Kelly (1997), this paper also reflects a three tiered teaching experiment, in which "a teaching experiment for students was used as the context for a teaching experiment for teachers, which, in turn, was used as the context for a teaching experiment for researcher" (p.398). While this paper focuses on children's statistical engagement in the classroom, it is firmly rooted in the PSTs' experiences. What they observe and what they notice about the children responses is an important aspect of this study, not just in terms of the paper's findings, but in terms of the collective contributions that these make to PSTs overall understandings of integrated STEM and their emerging STEM teacher identity. In turn, it offers insight into learning experiences that contribute to initial STEM teacher education, thus informing the overall action research inquiry. The following paper, reported in Chapter 7, turns the spotlight on the PSTs' themselves, examining how their own experiences of engaging in a mathematics-focused STEM intervention influenced their attitudes towards statistics.

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Chapter 7: "*Rather than simply learning statistics, we aimed to learn about the bees, from the bees*": An exploration of the factors influencing the development of positive teacher attitudes towards statistics

Chapter 7. "Rather than simply learning statistics, we aimed to learn about the bees, from the bees": An exploration of the factors influencing the development of positive teacher attitudes towards statistics

Preamble

As we examined PSTs' evolving understandings of integrated STEM education, we were also keen to consider the extent to which mathematics-driven integrated STEM would influence disciplinary perspectives. The following article reports quantitative and qualitative data to report on PSTs' (*Cohort 2*) changing attitudes towards statistics, revealing the nature of these attitudes, and the intervention characteristics that PSTs attributed with such change. This article is under review at the *Journal of Statistics and Data Science Education*

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Statement of authorship;

I hereby declare that I, Michelle Fitzpatrick, am the principal author of this article. The following statements outline my contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis and interpretation of data for the work; AND

• Drafting of work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

See Appendix H for Signed Statement of Authorship

7. 1 Abstract

The proliferation of data in all aspects of our lives positions statistical literacy as a critical skill in the 21st century. As teachers' attitudes towards statistics have far-reaching implications for their future learning and that of their students, there is an impetus to identify the types of experiences that support the development of positive attitudes towards statistics. Using Japanese Lesson Study as a guiding framework, this study examined the impact of an 11-week, practice-based mathematics elective on 28 pre-service primary teachers' attitudes towards statistics. We report on quantitative and qualitative data to reveal the nature and trajectory of teacher attitudes across the duration of the elective and particular course features attributed to such changes. Our findings indicate that the pre-service teachers credited the exploration of locally generated, societally relevant data, and the use of math action technology to support data analysis with positive changes in attitudes towards statistics. Furthermore, opportunities to collaboratively design, deliver and extend rich learning experiences in the classroom were associated with improved attitudes.

Keywords: *Attitudes towards statistics, pre-service primary teachers, statistics education, innovative technologies, active citizenship.*

7.2 Introduction

We live in an information age where our daily decision making is largely data-based. The use of sensor technologies is prevalent in smart homes and smart cities and in efforts to ensure sustainability and enhance efficiency. Sensing technologies produce data on public infrastructures (e.g., roads and traffic), consumption (e.g., fuel gauges), and temperature (e.g., manufacturing and agriculture) and are also used in biomedical (e.g., blood oxygen and cardiac monitoring) and biometric devices (voice and face recognition). The proliferation of networks of physical devices embedded with sensors that are connected and exchanging data, referred to as the Internet of Things (IoT), raises fundamental questions regarding how to prepare today's children for an everchanging world.

The proliferation of data in all aspects of life places greater impetus on developing statistical literacy skills. While such skills are largely cognitive, there is growing acknowledgement of the role of non-cognitive, or dispositional elements such as attitudes, in developing statistical literacy (Gal, 2002; Schau & Emmioğlu, 2012). Many theories and conceptualisations of attitude exist that try to understand how and why a learner responds to an event in a particular way and identify the factors contributing to attitude development. These theories converge on the understanding that attitudes are multidimensional and composed of affective, cognitive and behavioural dimensions (e.g., Gal, 2002; Eccles & Wigfield, 2002; Deci & Ryan, 1985). Such is the influence of attitudes on guiding learning that educators now position attitudes as course outcomes considered as worthy of consideration as cognitive outcomes (Ramirez et al., 2012; Schau & Emmioğlu, 2012) and identify the improvement of teacher attitudes towards statistics as a goal of educational reform (Ramirez et al., 2012; Tishkovskaya & Lancaster, 2012).

7.2.1 Attitudes Towards Statistics

7.2.1.1 Attitudes Towards Statistics at the University Level.

An introductory statistics course is a core requirement for undergraduate students across many disciplines (Ridgway et al., 2007; Utts, 2003). While some studies reveal positive attitudes (Evans, 2007; Griffith et al., 2012), a large body of evidence suggests the presence of negative attitudes towards statistics. Students often perceive statistics as boring or difficult (Gordon, 2004), and negative attitudes are often present prior to course uptake (Roberts & Saxe, 1982). Even amongst students demonstrating positive attitudes, many are unwilling to study statistics if it was not a requirement (Evans, 2007; Gordon, 2004). Together, these attitudes influence a wide range of student behaviours, including course attendance and engagement in statistics outside of the course (Gal et al., 1997; Hilton et al., 2004), in turn impacting students' achievement in statistics (Bateiha et al., 2020; da Silva & Moura, 2020; Griffith et al., 2012).

7.2.1.2 Teacher and Pre-Service Teacher Attitudes to Statistics.

A report from the International Commission on Mathematical Instruction (ICMI) with the International Association for Statistics Education (IASE) revealed that many mathematics teachers do not consider themselves well-prepared to teach statistics (Batanero et al., 2011). Some challenges stem from statistics being a separate discipline from mathematics with its own set of tools and ways of thinking. However, many who teach statistics are educated as mathematics teachers and have not been supported in learning to think statistically. This leads to a negative cycle where students in classrooms equate statistics with mathematics and expect the focus to be on numbers, computations, formulas and correct answers. They are uncomfortable with the "messiness of data, the different possible interpretations based on different assumptions, and the extensive use of writing and communication skills" (Ben-Zvi & Garfield, 2004, p. 4). These same students who become teachers may possess negative attitudes towards statistics when they enter initial teacher education. It is argued that these attitudes extend beyond the pre-service teachers themselves and may transfer to and impact their future students' learning (Estrada & Batenero, 2008), thus perpetuating the cycle. Indeed teacher attitudes have been shown to impact pedagogical practices and curricular innovation in mathematics (Ball, 1988; Hannigan et al., 2013), the effectiveness of mathematics teaching (Gal & Ginsburg, 1994; Ma, 1999) and the use of experiential and less controlled teaching methods (Wilkins, 2008). These findings extend to the teaching of statistics with studies suggesting that negative teacher attitudes can lead to mechanical approaches to teaching inference procedures or to avoidance of teaching inference (Harradine et al., 2011; Yang, 2012). Consequently, it is important to measure and monitor pre-service teachers' attitudes towards statistics.

Research suggests that pre-service teachers hold positive attitudes towards some areas of statistics and negative attitudes towards other areas. Ruz et al. (2022) found positive attitudes towards the content of statistics and its teaching among 269 Chilean pre-service mathematics teachers. Other studies reveal similar patterns in attitudes and report that pre-service teachers are interested in and value statistics and are confident in their knowledge and skills; however, they view statistics as difficult (Hannigan et al., 2013; Leavy et al., 2021; Mustam et al., 2020, Nasser, 2004; Zientek et al., 2011). Postgraduate pre-service teachers demonstrate more positive attitudes towards statistics than their undergraduate peers, but, reflecting other studies, they still perceive statistics as difficult (Hannigan et al., 2013). While the presence of generally positive attitudes towards statistics is welcome, the perceptions of statistics as difficult are concerning due to their influence on the teaching of statistics and on willingness to engage with statistics in the future in the classroom (Estrada & Batenero, 2008). A qualitative study exploring the factors contributing to perceptions of difficulty, carried out by Leavy et al. (2013), interviewed pre-service teachers who had demonstrated low scores on the difficulty component of the SATS-36. These interviews revealed that language considerations, such as lexical ambiguity, alongside the types of thinking and reasoning unique to statistics, contributed to perceptions of difficulty. Furthermore, and most concerning, these prospective teachers communicated a decreased willingness to teach statistics in their future classrooms.

7.2.2 Measuring Attitudes towards Statistics

A review carried out by Nolan et al. (2012) of the fifteen scales commonly used to measure attitudes towards statistics identified three scales as having accumulated sufficient validity (content, substantive, structural, and external) and internal consistency: the Statistics Attitude Survey (SAS) (Roberts & Bilderback, 1980), the Attitudes Toward Statistics (ATS) (Wise 1985) and both versions of the Survey of Attitudes Toward Statistics (SATS-28 and SATS-36) (Schau ,1992, 2003). Nolan et al. (2012) concluded that the SATS-36 demonstrated the strongest levels of construct validity and internal consistency.

Widely used across students of different levels and in different disciplines internationally, the Survey of Attitudes towards Statistics (SATS-36) (Hilton et al., 2004; Schau, 2003) consists of 36 items measuring six attitude components namely *Affect* (students' feelings concerning statistics), *Cognitive Competence* (students' attitudes about their intellectual knowledge and skills when applied to statistics), *Value* (students' attitudes about the usefulness, relevance, and worth of statistics in personal and professional life), *Difficulty* (students' attitudes about the difficulty of statistics as a subject), *Interest* (students' level of individual interest in statistics), and *Effort* (amount of work a student expends to learn statistics). It was developed from the original SATS-28, which addressed 4 attitude components (Affect, Cognitive Competence, Difficulty, and Value). There has been extensive analysis providing support for the multidimensionality of the SATS-28 and SATS-36 constructs and confirming the reliability and validity of the scales (e.g., Coetzee & Van Der Merwe, 2010; Persson et al., 2019; Vanhoof et al., 2011) alongside a valuable synthesis of the literature documenting challenges associated with the SATS instruments in populations other than undergraduate students (Whitaker et al., 2022).

7.2.3 Factors Impacting Attitudes to Statistics

A variety of different interventions have been used in efforts to improve college students' attitudes towards statistics. The use of common instruments, in many cases the SATS (Schau, 2003), facilitates comparison of changes in attitudes as a result of course participation. Outcomes from studies generally suggest little or no change in attitudes during the college years. Following completion of an introductory statistics course, a small but non-significant decrease was found by Bond et al. (2012) in all attitude SATS subscales; similarly, a decrease in three attitude subscales (Value, Interest, Effort) was identified by Schau and Emmioğlu (2012). Other studies report no evidence of improvement in attitudes (Carnell, 2008; Paul & Cunningham, 2017), no change in some attitude components (e.g. no changes in the SATS subscales of Affect, Cognitive Competence and Difficulty were found by Schau and Emmioğlu (2012)) or changes in some attitude components (Carlson & Winquist, 2011; Posner, 2011). There is evidence to suggest, however, that student attitudes fluctuate, up and down, during the semester (Kerby & Wroughton, 2017). Course delivery methods may also impact attitudes with online delivery methods resulting in more negative attitudes (DeVaney, 2010; Gundlach et al., 2015); although a recent study suggests that the attitudes of online students may also fluctuate over the duration of a course (Matsuo et al., 2022).

Compared to traditional statistics courses focusing on procedures and calculations, it was expected that reform-based statistics courses and teaching methods that emphasise statistical literacy, thinking and reasoning may have more affective responses and influence attitudes (Gal et al., 1997). Those studies examining pre-service teachers' attitudes present mixed evidence of the efficacy of reform curricula. While Olani et al. (2011) found improvements in self efficacy but no change in students valuing of statistics; in contrast, improvements were found for 361 elementary pre-service teachers across all six SATS subscales following engagement with a reform-based statistics module (Leavy et al., 2021). The general stability of attitudes is one reason Gal and Ginsburg (1994) proposed to account for the small observed changes in attitudes towards statistics. More recently, Olani et al. (2011)

suggest the need for a combination of reform practices rather than isolated activities to bring about changes in attitudes towards statistics.

Indeed, additional reform practices are emerging that complement those reform approaches focusing on enhancing the conceptual understanding of statistics. Two practices that show promise target the *data context* and the use of *technology*. Pre-service teachers often view mathematics and statistics as boring, apolitical and neutral (Thanheiser & Koestler, 2021) and as possessing little value or relevance for their own lives. Consequently, there has been a call to action in statistics education advocating for the use of real-world data sets that promote social awareness and critical citizenship (Kazak et al., 2022; Weiland, 2017; Zapata-Cardona, 2023). Responses have focused on selecting contexts that engage learners in using mathematics to critically read and write the world (Gutstein, 2003), promoting citizen empowerment and engagement (Gal, 2022; Ridgway & Ridgway, 2019; Skovmose, 2011). The vital role of context in statistics is evident in studies engaging young learners in examining real-world natural phenomena such as geyser eruption times (Shaughnessy & Pfannkuch, 2002) and plant growth (Lehrer et al., 2007). A more critical and citizen-focused stance has emerged recently, visible through the engagement of school students in the examination of societally-relevant data focusing on tsunamis (Estrella et al., 2021), carbon dioxide emissions (Zapata-Cardona, 2023), nutrition and diabetes (Roberto et al., 2022), ecosystem dynamics and human impact on Earth (Wilkerson & Laina, 2017), and wealth distribution in the United States (Gutstein, 2003). Teachers are increasingly engaged in exploring real-world issues such as sustainability and water shortages (Verbisck et al., 2023). Thus, through their careful selection of datasets, educators have positioned statistics as central to illuminating and critiquing issues relating to students' own lives and broader society. This work holds great promise as there is evidence of changes in pre-service teachers' attitudes, from seeing mathematics as boring and unimportant, to seeing it as interesting and useful (Thanheiser & Koestler, 2021) and recognising the value of using data-driven arguments when analysing social justice issues (Casey et al., 2023).

Another complementary reform practice is the use of *technology* as a tool to support the analysis and visualisation of data. This beneficial role of technology in statistics education has been emphasized for decades (Bakker et al., 2003; Shaughnessy, 2007). Dick and Hollebrands (2011) coined the terms *math action technology* to refer to technology, such as statistical software, that supports learners' development of statistical understanding by facilitating the exploration and analysis of data in ways not possible using traditional pen and paper approaches. Pea's (1985) notion of technology as amplifiers and re-organizers has traction in our conceptualization of the use of technology in statistics education. Technologies act as an amplifier by extending learners' capabilities through expediting traditional drill and practice tasks (e.g., calculating measures of central tendency of large data sets). Moreover, they act as organisers by helping us transform our thinking by steering our attention towards statistical meaning-making. In reference to this latter role, a range of technologies which, when combined with carefully designed tasks, have been shown to support development of statistical reasoning and in turn attitudes towards statistics. The use of digital games, for example, has been shown to have a positive effect on motivation and learning of statistical concepts for students (Asbell-Clarke et al., 2012) and teachers (Meletiou-Mavrotheris et al., 2018). Dynamic statistics learning environments, such as Tinkerplots (Konold & Miller, 2011) and Fathom, make heretofore unreachable statistical ideas accessible. Tinkerplots has facilitated the comparison of groups by children (Frischemeier, 2019, 2018) and pre-service teachers (Frischemeier and Biehler 2017) and the construction of statistical models by children (Ainley & Pratt, 2017; Aridor & Ben-Zvi, 2017) and pre-service teachers (Biehler et al., 2017; Justice et al., 2018). It also supports the development of children's informal and data-based inferences (Bakker, 2004; Meletiou-Mavrotheris & Paparistodemou, 2015). Technology has been successfully used to develop simulation-supported learning environments that contribute to pre-service teachers' probabilistic thinking skills (Koparan & Rodríguez-Alveal, 2022) and technological pedagogical statistical knowledge (Lovett & Lee, 2017).

7.2.4 This Study

Batanero (2012), reporting on the Joint ICMI/IASE Study organised by the International Commission on Mathematical Instruction, concluded that 'Few current teacher training programmes adequately educate teachers for their task to prepare statistically literate citizens' (p. 5). Indeed, the need for teacher programmes to include tailored modules in statistics was identified by Hannigan et al. (2013) as was the need to promote teachers' statistical literacy and monitor attitudes towards statistics during initial teacher education. However, it isn't entirely clear what components of successful interventions are necessary to enhance pre-service teachers' attitudes towards statistics. There is some guidance in the research literature which recommends that prospective teachers experience full cycles of research in statistics (Batanero, 2012), analyse statistical projects (Godino et al., 2008) and experience the affordances of technologies in teaching and analysing data (Lee & Hollebrands, 2008).

Following Olani et al.'s (2011) recommendation for a combination of reform practices to bring about change in attitudes towards statistics, this study takes a multi-pronged approach to intervention. In the semester following engagement in a reform-based statistics module, we engaged pre-service elementary teachers in a practice-based module that incorporated emphasis on a strong *data context* and the use of *technologies,* all of which were situated within the context of a school practicum experience. We believe that promoting positive attitudes towards statistics, which acknowledge the valuable role of statistics in our lives, are important contributors to success as a learner and future teacher of statistics. Consequently, we chose the data context of sustainability that attended to the study of the honeybee based on data collected from sensors in local beehives. Sensors served as a conveyance technology by conveying information about the internal conditions in the beehives. A second core belief is in the value of technologies in carrying the procedural load associated with graph construction and calculations thereby allowing us to transform our thinking about statistics by focusing on conceptual understanding and meaning making. This was enabled through the use of the Common Online Data Analysis Platform (CODAP), a web-based data science tool which served as a math action technology, facilitating the analysis and visualization of data.

It was our goal that by engaging pre-service teachers in working with children in schools on the exploration and analysis of a meaningful dataset with a strong societal context, combined with the use of technologies to gather and analyse that data, that we would support the development of positive attitudes towards statistics. The following research question guided our study:

How does a practice-based mathematics elective impact pre-service teachers' attitudes towards statistics?

7.3 Methods

7.3.1 Participants

Participants were 28 third-year pre-service elementary teachers (PSTs) enrolled in an 11-week mathematics education elective within their 4-year initial teacher education degree programme in Ireland. All participants had completed five compulsory mathematics education courses, the last of which focused on teaching statistics (Leavy & Hourigan, 2020). This research examines the nature and trajectory of PSTs' attitudes toward statistics across the duration of the elective and particular course features attributed to such changes. All 28 PSTs enrolled in the elective consented to participate in the research. Ethical approval for this study was granted by Mary Immaculate College Research Ethics Committee (reference number: A19-051). All ethical guidelines were adhered to across the study.

7.3.2 Elective Structure: Japanese Lesson Study

The elective required PSTs to work with three mathematics teacher educators (researchers) for 3 hours per week across the 11-week spring semester to design and teach a five-lesson curriculum unit focusing on the honeybee to develop their understandings and statistical literacy of 6th grade pupils. Japanese Lesson Study (Lewis & Tsuchida, 1998) was the organising framework used to guide the lesson design, implementation and revision process. It was selected due to its iterative process of collaborative planning, classroom implementation, guided observation and reflection that focused on enhancing student learning (Murata, 2011). Within this process, the researchers in their role as mathematics teacher educators, guided PSTs through all three Lesson Study stages:

- Stage 1 (weeks 1–5), the *research and preparation stage*, involved PSTs reading research relating to the practices of Lesson Study, understandings about pollinators and statistical concepts (Hourigan & Leavy, 2020, 2021; Leavy & Hourigan, 2016a). PSTs formed five Lesson Study groups (5-6 members in each group) and each group designed one of a series of 5 consecutive lessons. Lesson 1 (The Honeybee) focused on bee characteristics e.g., lifecycle, habitat and roles (e.g., drone, queen bee, worker bee) and introduced the two local beehives where sensors had collected data (internal and external temperature, sound and humidity). Lesson 2 developed conceptual understanding of measures of centre and variability. Lesson 3 introduced a focus on statistical distribution through the use of CODAP to visualize and analyze sensor data about sound in one of the hives. CODAP was utilized again in Lesson 4 to compare the temperature distributions in the two hives. Lesson 5 explored the relationship between temperature and sound in the hive using CODAP.

- Stage 2 (weeks 6–9), the *implementation stage*, involved the lesson study groups teaching the series of 5 lessons across five consecutive days to one 6th grade class (31 pupils (age 11-12)). One PST taught the lesson and was observed by the remaining Lesson Study group members and the three teacher educators (researchers). Immediately after each lesson, a post-lesson meeting facilitated sharing observations, reflections and feedback and decision making regarding necessary revisions to support learning. Subsequently, each revised lesson was re-taught 7–10 days later to a comparable 6th grade class in the same school (N= 31).
- Stage 3 (weeks 10–11), the *reflection stage*, involved each Lesson Study group making an in-class presentation reporting learning when planning, implementing and reflecting on their taught lessons. PSTs also completed individual written reflections at the end of semester.

7.3.3 Data Collection and Analysis

7.3.3.1 Quantitative Data: Survey of Attitude Towards Statistics (SATS)

The SATS-36 scale was used to measure PSTs' attitudes towards statistics at the start and end of the elective. This instrument measures six attitudes components: Affect, Cognitive Competence, Value, Difficulty, Interest and Effort. The SATS scale consists of 36 items, each presented as a statement requiring a response on a scale from 1 (strongly disagree) to 7 (strongly agree). Nineteen statements are negatively worded. There are 6 items in the Affect and Cognitive Competence components, 9 in the Value component, 7 in the Difficulty component and 4 in both the Interest and Effort components.

The pre-survey SATS-36 was administered on entry to the elective course in week 1 of the spring semester. At the end of the elective course, the same version was administered as a post-survey. 26 PSTs completed the pre- and post-survey. Data were inputted for both surveys, and surveys with missing data were removed from the analysis. Negatively worded items (e.g., items 4, 5) were reverse coded and items were grouped within the appropriate component (e.g., items 6, 8, 22, 24, 30, 34 and 36 were grouped as part of the Difficulty component). To measure the internal reliability of each component, Cronbach alpha values were calculated for each component of both pre- and post-surveys (Table 7.1). These values, except for the Effort component (post-survey), indicate acceptable internal consistency.

Table 7.1

Cronbach Alpha values for the SATS-36 components in this study

Scale Component	Number of items	Alpha (pre-survey)	Alpha (post-survey)
Affect	6	0.73	0.79
Cognitive Competence	6	0.75	0.75
Value	9	0.71	0.6
Difficulty	7	0.6	0.77
Interest	4	0.83	0.87
Effort	4	0.60	0.42

For each of the 6 components, a mean component value was calculated for each participant for both the pre-surveys and post-surveys. As the SATS scores represent averages from a 7-point Likert scale, higher scores indicated more positive attitudes. Component values between 0 and 3.5 were interpreted as reflecting negative attitudes, 3.51 and 4.49 neutral attitudes and 4.5 and 7 positive attitudes. Descriptive data analysis was completed to determine PSTs' attitudes to statistics across components (Table 7.2, 7.3).

Subsequently, to gauge the impact of participation on participants' attitudes to statistics, the pre and post surveys were matched using unique identifiers used across the study resulting in 24 matched surveys. The 4 unmatched surveys were due to absenteeism on one of the administration days. Descriptive and inferential analyses were completed to examine the nature of changes in participants' attitudes across the elective course (Table 7.4). Given the lack of normality within distributions, the Wilcoxon signed-rank test was used as a non-parametric alternative to the t-test, to determine whether changes in PSTs' attitudes within the respective SATS-36 components were statistically significant.

7.3.3.2 Qualitative Data.

While SATS-36 offered a measure of PSTs' attitudes towards statistics at the start and end of the elective, further insight into PSTs' *perceived* changes in attitude was sought through qualitative methods. Although a range of qualitative data was collected over the course of the Lesson Study cycle (lesson notes, prompted journal responses, researcher fieldnotes), this paper focuses on data collected through group presentations and individual written reflections at the end of the elective (Stage 3). These data offered insight into the nature of the perceived change, as PSTs identified key moments and interactions that led to improved attitudes towards statistics. The addition of qualitative data provided the rich, thick descriptions needed to reveal the complexity of PSTs' lived experiences and to locate the meanings they place on events (Miles et al., 2020).

Following initial collation and familiarisation with the data, two researchers worked together to generate preliminary codes. This first cycle coding (Saldaña, 2016) resulted in codes such as *PST's misconceptions, tongue-tied, technology affordances, power of context, children excited* and *increased conceptual understanding.* Second cycle coding generated pattern codes and began to reveal the threads of comparison between each participants' data corpus. Regular research meetings facilitated the refining of codes and categories, leading to the development of five overarching themes. The first theme outlines the PSTs' attitudes towards statistics prior to the intervention and perceived changes in attitudes as a result of the elective. The remaining four themes present features of the intervention, commonly reported by the PSTs to have influenced their growing positive attitude towards statistics.

7.4 Findings

The findings suggest that the PSTs who completed the pre-survey held a positive attitude towards statistics for 5 of the 6 SATS-36 components, with the exception of the Difficulty component (Table 7.2). These findings suggest that at the start of the elective, having already completed a compulsory reform-based statistics education course, PSTs were prepared to invest effort into studying statistics (Effort) and appreciated the usefulness of statistics in their lives (Value). They also had positive attitudes about their own personal feelings towards statistics (Affect), their interest in statistics (Interest) and their own knowledge and skills as applied to statistics (Cognitive Competence). However, scores reflecting PSTs' views of the Difficulty of statistics indicated neutral attitudes.

Table 7.2

Mean and standard deviation for each pre-survey SATS-36 component

Scale component	**Pre-survey**	**Standard deviation**	**N**
Affect	5.01	1.04	25
Cognitive Competence	5.32	0.76	26
Value	5.37	0.72	26
Difficulty	3.8	0.6	25
Interest	5.29	0.88	26
Effort	6.41	0.81	26

26 PSTs also completed the post-survey. Analysis suggests that, reflecting the pre-survey findings, post-survey mean values remained positive in all components except 'Difficulty'. Notably, more positive attitudes were evident across all SATS-36 components, as reflected by higher mean component values (Table 7.3).

Table 7.3

Mean and standard deviation for each post-survey SATS-36 component

Scale component	Post-survey	Standard deviation	N
Affect	5.34	1.03	23
Cognitive Competence	5.63	0.74	26
Value	5.74	0.58	24
Difficulty	4.11	0.96	23
Interest	5.51	0.89	26
Effort	6.68	0.44	26

To uncover the precise nature of changes in the six attitude components, we further analysed the matched surveys, i.e., only comparing PSTs who had completed both pre and post-survey. This data analysis examining changes from pre-survey to post-survey confirmed consistent increases in mean values across all 6 components (Table 7.4). This finding indicates that PSTs possessed more positive attitudes towards statistics after completing the elective course. Further analysis examined whether increased component values for the respective scale components were statistically significant. The Wilcoxon signed rank test revealed that the only SATS-36 component where the difference was statistically significant ($p \leq 0.05$) was the Difficulty component (Table 7.4). This finding is interesting, given that Difficulty was only SATS-36 component, where PSTs possessed neutral attitudes. However, it is welcome that the findings suggest that participation in the elective course had a positive and significant impact on PSTs' perception regarding the difficulty of statistics.

Table 7.4

Comparison of pre and post-survey mean (SD) for each SATS-36 component

Scale component	Pre-survey	Post-survey	Statistical significance of change
Affect	5.12 (0.99) n=22	5.36 (1.05) n=22	0.25
Cognitive competence	5.34 (0.79) n= 24	5.63 (0.74) n=24	0.06
Value	5.52 (0.6) n=23	5.69 (0.54) n=23	0.07
Difficulty	3.87 (0.61) n=23	4.11 (0.96) n=23	0.05
Interest	5.26 (0.88) n=24	5.49 (0.92) n=24	0.36
Effort	6.42 (0.85) n=24	6.67 (0.46) n=24	0.09

Analysis of qualitative data supplemented the quantitative findings and provided valuable insights into PSTs' attitudes to statistics and the factors effecting attitudes, thus further answering the research question 'How does a practice-based mathematics elective impact pre-service teachers' attitudes towards statistics?' Five themes emerged, namely PSTs' perceived attitudes to statistics; Collaborative planning and teaching, Witnessing first-hand through classroom experience, Power of a real-world context and Role of technology.

7.4.1 Theme #1: PSTs' Perceived Attitudes to Statistics

Notwithstanding the predominately positive scores revealed through the SATS-36 pre-test, many PSTs reported initial negative attitudes toward statistics at the beginning of the elective. Despite school experience and studying statistics education the previous semester, many PSTs felt their statistical understanding was 'poor', thus reflecting their cognitive competence. Participants referred to their experiences of learning statistics in school, reporting limited primary school engagement, which centered around "colouring in bar charts and learning about pie charts" (Finn, Group 5), and an emphasis on "definitions and calculations" at post-primary level, with little to no focus on "understanding what these actually meant; how they were useful in real-world applications" (Laura, Group 3). Others, who reported more confidence in their knowledge and understanding of the concepts reported being uncertain about how to teach statistics in the classroom, with many expressing their concern about the level of difficulty it posed for primary school children.

However, PSTs perceived that engaging in the elective eased their initial apprehension about teaching statistics in the classroom and improved their knowledge and skills in both subject content and pedagogy:

> When I found out that statistics and data was our focus for this year's Lesson Study, I was a bit nervous as statistics would be my weakest area in maths... I thought my understanding around some of the statistical concepts was poor and I would not be able to sufficiently teach children about this if I did not understand it myself. Engaging in Lesson Study has definitely had a massive influence on how I think about teaching these statistical concepts now... I have learned so much about the statistical concepts that I taught throughout the lessons and how they should be taught" (Susan, group 3).

The nature of the elective was credited with changing attitudes towards statistics amongst the participants, with all PSTs identifying key moments and interactions that led to these perceived changes. Factors that led to change fall under the four remaining themes.

7.4.2 Theme #2: Collaborative Planning and Teaching

The collaborative nature of the Lesson Study cycle afforded the PSTs the opportunity to co-plan, co-teach, co-reflect and reteach their lesson as a group. The PSTs recognised the benefits of such an approach, particularly in relation to their own knowledge and skills relevant to teaching statistics. Engaging in rich discourse on statistical concepts and exposure to a variety of teaching ideas during the planning phase, resulted in perceived affective gains (from feeling nervous, to feeling confident about statistics) as well as reported improvements in conceptual understanding of statistics amongst the participants.

> My general attitude towards statistics, as well as my overall morale and confidence in teaching it, were very low before I participated in this lesson study process. But after

researching different ways to teach the topic, and after various discussions with the other members in my group, I gained a lot more confidence in myself and in teaching this statistical concept, and I believe I will not dwell on teaching it in future placements (Ava, Group 3).

> Working collaboratively with my peers, and lecturers, to explore various statistical concepts has exposed me to new ideas and ways of thinking. This has helped me to broaden my mindset and deepen understanding of the world of data and statistics. In turn, by improving my knowledge of this subject area, I now appreciate the complexity of this topic and the commitment that it takes to teach the various statistical concepts. (Kristina, Group 4).

PSTs reported that collaborative planning and teaching exposed them to a variety of approaches to developing statistical concepts and deepened their conceptual understandings, thus developing more positive attitudes regarding their cognitive competence:

> Working collaboratively in a group allowed us to discuss these concepts with one another while making our lesson plans. This process helped me identify my own strengths and weaknesses within statistics. We worked as a group to help clear up any misconceptions we had ourselves before going into the classroom. Personally, I've always struggled with the mean, median and mode. I knew the median was the middle value in the data set, and I knew how to find it. But when I really thought about it, I did not understand what the median actually was, same for the mean... (Susan, Group 3)

One PST, Susan, identified opportunities to watch peers demonstrate their understanding of various statistical concepts e.g., sharing out unifix cubes to exemplify the 'fair share' model of the mean as "aha moment. I had never looked at this statistical concept as an equal-share before".

Collaborative planning involved "pooling their ideas together" (Finn, Group 5) and was associated with quality promotion, as "every student helped in providing nuanced approaches to all sections" resulting in a "variety of pedagogical ideas aiding the motivation of all learners" (Sasha, Group 5). For example, Mai (Group 2), who was confident and enjoyed statistics identified that those PSTs in her group who reported struggling more with statistics in school and during college modules, and communicated less positive attitudes to statistics, provided valuable insights and student-centred considerations during co-planning:

> I thought that I would do a good job at teaching it. When we initially started brainstorming to come up with a plan, I realised how much I did not consider. Some of the others who have never enjoyed maths or found data and the concepts difficult were able to add much more to the lesson that I was. They...remembered the difficulty they had ...and knew that they wanted to make the lesson accessible and enjoyable for everyone, and how to achieve that. Had I just followed my idea, the students would not have gained any real understanding of the concepts of mean and median.

7.4.3 Theme #3: Witnessing Firsthand through Classroom Experience

Although many participants regarded statistics as a ‘difficult’ subject, describing it as ‘complex’, ‘complicated’ and ‘challenging’, there was a shared sense that good pedagogy and the development of rich classroom experiences is a powerful mediator in learning statistics. This was exemplified to PSTs through their observations of classroom implementation. While they acknowledged the emphasis placed on key pedagogies (such as the importance of developing a rich data context, the use of concrete materials, math action technology) during previous mathematics education modules, it was “seeing first-hand the difference” it made (Mai, Group 2) that convinced the PSTs of their worth.

Participants were surprised by the children’s responses which exceeded their expectations, and revealed the potential for deep statistical reasoning within the primary setting. Cara (Group 2) was “amazed at the students’ capabilities in statistics”, while Isla (Group 4) suggests that the “constant questioning which the students showcased, highlighted issues which we did not think about prior to the lesson”. Many of the PSTs referred to specific classroom interactions that exposed gaps in their own conceptual understanding of statistics and emphasised the importance of strong teacher content knowledge. During *Teach 1*, Mai (Group 2) reported that she got “tongue tied and muddled up” while trying to describe measures of central tendency, claiming that if “you are not 100% confident on a topic yourself, you cannot teach it”. Similarly, Alison (Group 5) questioned her understanding of the line of best fit during *Teach 1*, as she “listened to the children’s reasoning and looked at the lines, and began to wonder if what they were saying was true”, pointing to her need “to learn more about the link between the line of best fit and graphs with no relationship”.

Coming to these realisations during *Teach 1 and* being afforded the opportunity to reflect, improve and re-teach the lesson, allowed the PSTs to address their own misconceptions, deepen their conceptual understanding and try new teaching approaches. Susan, and others, commented that "time for reflection" as part of Lesson Study, encouraged PSTs to identify and work on their own "statistical misconceptions" in turn improving not only their *Teach 2* lesson, "but any future teaching of these concepts" (Susan, group 3). Along with the possibility to "recognise mistakes and... think of solutions", it was the opportunity to see their adaptions and improvements "come to fruition" during *Teach 2* (Nina, Group 2) that had a profound perceived effect on PSTs, with Alison suggesting that following *Teach 2* her "knowledge of and confidence with the statistical concepts in my lesson have more than doubled". Through witnessing these improvements and benefits of good pedagogy for learners in action, their attitude towards statistics in the classroom has changed;

> I have a different view of the statistics classroom now. Typically, when I used to think of primary school myself, I remember endless questions in my maths book. But now I hope to provide children with integrated learning experiences, a classroom full of discussion, collaborative work, engaging activities and projects; learning through hands-on, minds-on experiences. A maths classroom much different to the one I remember. (Ava, Group 3)

7.4.4 Theme #4: Power of a Real-World Context

Analysis of the qualitative data suggests that all PSTs recognised the role of a rich context as central in their changing attitudes towards statistics, PSTs reported initial difficulty in recognising opportunities for integrating the bee data context in the classroom, seeing mathematics as a "stand-alone subject" (Finn, Group 5). Kristina (Group 4) states that "initially, the idea of integrating bees and beehives into a maths lesson baffled" her, while Emer (Group 1) simply questions, "*Bees?* What do they have to do with statistics?". Such attitudes changed, however, with all participants relating the real-world context to the usefulness, relevance and worth of statistics in everyday life;

> This context has changed my beliefs and attitudes about statistics as it highlighted their importance in the world. (Rona, Group 1)

> The context of the bees made the data real life. It made me as a teacher realise the importance of statistics... It is not just part of the curriculum that we have to cover, it helps us understand information better. If this real-life context of the bees helps a teacher's understanding, it will inevitably improve children's understanding. (Rachel, Group 3)

For the PSTs, developing a series of lessons around the real-world context of the honeybee had two main benefits: providing engaging and motivating driving questions that promoted optimum engagement and critical thinking and the use of data-based reasoning *(thus positively impacting Affect, Value* and *Interest);* and supporting the conceptual understanding and communication of statistical concepts by providing a meaningful and authentic data set *(thus positively affecting Cognitive Competence* and *Difficulty*). Nina (Group 2) refers to the power of a rich context that piques interest while supporting conceptual understanding of the data, suggesting that "the focus was not just on the figures; The context brings the figures to life and almost gives the lesson a heartbeat". PSTs agreed that giving the children an insight into the plight of the honeybee early in the week (during Day 1) and introducing some fundamental scientific knowledge, was important, as it "captured children's imaginations" (Maya, Day 5) and "provided the backdrop against which we introduced the data and statistical measures" (Laura, Day 3). The STEM context proved a powerful means of both promoting, and applying, rich statistical reasoning for teachers and children. For Maya, the relatable context provided the opportunity to "use knowledge gained in other subjects [science of the honeybee] to help fully understand the statistical relationships", recognising the support a meaningful context offers in interrogating the data. Statistics, however, were also used to "understand the science", highlighting for the PSTs the relevance of statistics in understanding real world issues. As Cara (Group 2) points out:

> The cohesive learning context allowed us to fully explore the context of the bees through knowledge and understanding of statistics. Rather than simply learning statistics, [we] aimed to learn about the bees, from the bees.

All groups pointed to the significance of using locally sourced data. PSTs recognised the strength of presenting a "truthful, rather than imaginative problem" (Alana, Day 4). Again, PSTs reflected on their own school experiences of statistics, commenting on the use of "unintriguing" data, that focused on "amounts of sweets and fruit, or clothes and cars. There was no real-life problem... I was thinking about what I would have enjoyed in primary school and this STEM context would certainly have motivated me" (Alana, Group 4). Aisha (Group 1), who initially found the idea of statistics "daunting", states that the context has not only given her the confidence to teach statistics, but also enjoy it, due to "the many topics that can be linked to a statistic lesson". Indeed, others agreed that by moving from "random data sets... [to] using ones which meant something" the context of the beehives made it "an easy, enjoyable and accessible way to learn about and study data" (Ava, Group 3).

By using locally-sourced data, there was an investment in this context from the beginning, as it "gave their work a purpose" (Enya, Group 3), encouraging PSTs and students "to engage as they were part of a mission to help the bees" (Isla, Group 4). Preconceived notions of statistics being about technical definitions were challenged by the context, with PSTs reporting the promotion of statistical skills through engagement with authentic data:

> I realised that the emphasis on precise definitions should be replaced with an emphasis on the actual data in the classroom. It is through the exploration of actual data that true learning occurs and enables the pupils to transfer their knowledge and interpret other graphs that they may come across (Laura, Group 3).

In turn, the PSTs could recognise "how valuable this form of education is for students' futures" (Julianna, Day 2), in creating "responsible future citizens" (Emily, Group 2) and in "understanding how data can be used to inform decision-making in various fields, including STEM-related industries" (Finn, Day 5).

7.4.5 Theme #5: Role of Technology

Technology facilitated the use of these authentic, real-world data. PSTs engaged with technology in two ways during this elective. Firstly, the data they used were collected through sensors in local hives. This *conveyance* technology facilitated the collection, storage and transmission of beehive conditions (temperature, humidity and sound). Using living data "that was happening in real time, and in the locality" focused interest in learning statistical concepts when they could "see their practical applications in real- world scenarios" (Amelia, Group 4). Exploring data "generated close to home [made] the data more realistic and worthwhile investigating" (Emily, Group 2). Secondly, these authentic real-world data sets were analysed using an open-access, web-based data science tool, the Common Online Data Analysis

Platform (CODAP). CODAP acted as a *math action technology*, thus supporting an exploration of a large data set that would not be possible using pen and paper techniques.

Although the PSTs had been introduced to CODAP as part of their compulsory mathematics education module that focused on the teaching of statistics, this was the first time that PSTs had the opportunity to use it in the classroom. Some participants reported negative attitudes towards CODAP prior to the elective, stating that "as a third-year college student, it stressed me out! I would never have considered it to be an option when teaching primary level students" (Mai, Group 2). Others felt that they "never truly understood how to work it, and certainly found it intimidating to use with children" (Alana, Group 4). Engaging with CODAP in the classroom however, alleviated this stress as they witnessed its affordances in the classroom and observed it as "a source of enjoyment for the pupils" (Nina, Group 2).

Through thorough engagement with CODAP during planning and teaching, the PSTs became more comfortable in using and appreciated the affordances of this technology in data analysis. CODAP was used to prepare graphs, allowing PSTs to create and identify the most appropriate representations for each lesson to support the exploration of specific statistical concepts with the class. Laura (Group 3) acknowledges the adaptability afforded by CODAP:

> We constructed various graphs on CODAP and then selected the most appropriate graphs to teach the statistical concepts i.e., they had a clear minimum and maximum points as well as outliers, gaps, bumps and clusters to be identified...This highlighted for me the value of technology in statistics, and the powerful tools in CODAP that could be utilised... little pupil knowledge can be gained from teaching concepts with poor graphical representations.

Using CODAP also revealed to the PSTs that "data does not revolve around drawing graphs, but can rather focus on interpreting and comparing them" (Alana, Group 4). Amelia (Group 4) acknowledges that although statistical concepts frequently involve "complex calculations and vast datasets", CODAP made it "easier to explore and analyse the data" by carrying the procedural load. By accessing the data through CODAP, the PSTs could calculate measures of central tendency and variability "using the features online" (Chloe, Group 3). In turn, by shifting the focus from 'calculation' to 'analysis', critical thinking and a deeper understanding of the data was promoted, emphasising the role of "making inferences and drawing conclusions based on the evidence" over large computations, and helping the PSTs to "realise that statistics is not just all written work but can be seen all around us" (Isla, Group 4).

7.5 Discussion

This study supports and contributes to the literature on PSTs' attitudes towards statistics. Analysis of the SATS-36 pre-survey data confirms the findings of other studies reporting college students' positive attitudes towards statistics (Evans, 2007; Griffith et al., 2012). PSTs in our study demonstrated positive attitudes on five (effort, value, interest, affect, cognitive competence) of the six components. The lower scores on the Difficulty component are consistent with previous studies which report that PSTs view statistics as difficult (Batanero et al., 2005; Hannigan et al., 2013; Leavy et al., 2021; Mustam et al., 2020; Nasser, 2004; Zientek et al., 2011). However, the positive attitudes demonstrated on the five components in this study, ranging from 4.5-7.0 on the 7-point likert scale, were higher than those reported by Schau and Emmioğlu's (2012) analysis of 2200 students taking over 100 different sections of statistics courses. In the latter study, college students' attitudes were categorised as neutral (falling in the range of 3.51-4.49). The higher scores in our study may be attributed to the fact that participants had already completed a semester-long statistics education course modelled on reform approaches to teaching and learning statistics thus contributing to their high attitude scores.

Analysis of the post-survey SATS-36 data reveals improvements in all 6 component scores thus supporting the finding by Leavy et al. (2021) of the malleability of pre-service teacher attitudes toward statistics. However, the relative high pre-survey component scores may have resulted in a ceiling effect that contributed to the finding of non-significant increases in attitudes on 5 components, and a statistically significant increase in attitudes on the Difficulty component. Another possibility, suggested by Whitaker et al. (2022) to account for the absence of demonstrable change in 5 of the attitude components on many studies using the SATS instrument may be the small sample size. Given the tenacity of perceptions of difficulty, the finding of statistically significant improvements in attitudes towards the Difficulty component were welcome and supported in studies carried out by Carlson and Winquist (2011) and Posner (2011). Combined with the lower pre-survey component mean score which may have provided the room for demonstrable change, the findings of significance may be attributable to the combination of reform practices (Olani et al., 2011) and a study design that was not limited in scope (Whitaker et al., 2022).

Despite the absence of statistical significance in the SATS-36 gain scores on five of the components as a result of the intervention (i.e. elective), the qualitative data provide evidence of the practical significance of the increase in scores suggesting that the changes in attitudes are large enough to have meaning in the real world. These qualitative data provide more nuanced insights into participant attitudes and the factors influencing changes in attitudes. For example, while the pre-survey SATS instrument reveals positive attitudes towards statistics, the qualitative data reveal dissatisfaction with experiences as learners of statistics and uncertainty about teaching statistics. Invaluable, however, are the PSTs' perspectives on factors that contributed to improvements in attitudes over the course of the semester. It was a welcome, though not entirely unexpected, finding that participants benefitted from the inclusion of two carefully selected and research-informed reform practices – the use of a compelling data context and the incorporation of technology as a data visualisation and analytic tool. Engaging with nontraditional, real-world data revealed to the PSTs the limitations of using "toy data sets" that so rarely relate to real issues (Ridgway & Ridgway, 2019). Our findings support the work of others who call for the use of societally-relevant data in statistics education (Estrella et al., 2021; Verbisck et al., 2023; Zapata-Cardona 2023). By using data generated in local beehives, the PSTs were offered an authentic reason to analyse large, messy and complex, nontraditional data (Noll et al., 2023) and use statistics as a tool for citizen engagement. Current curricula have been criticised for ignoring the data revolution (Ridgway, 2016).

Using sensors and CODAP as *conveyance* and *math action* tools allowed the PSTs to engage with data that would remain out of reach through traditional approaches. PSTs recognised the affordances of these technologies, reporting that by carrying the procedural load, CODAP permitted the PSTs to maintain their focus on statistical meaning making, thus reflecting Pea's (1985) view of technology as amplifiers and re-organisers. Our findings extend the literature suggesting that technologies, when combined with carefully designed tasks, support development of statistical reasoning and in turn attitudes towards statistics (Frischemeier & Biehler, 2018). Just as statistical data sets used have been criticised for their lack of relevance to the real world, similarly, the nature of experiences provided in initial teacher education have been criticised for their isolation from real classroom practices. Efforts to close this gap between theory and practice have been fruitful through the creation of links between pre-service teachers and elementary students via letter writing initiatives (Leavy & Hourigan, 2020, 2022) and through the involvement of pre-service teachers in maths-focused placements and research engagement in lesson study (Hourigan & Leavy, 2021; Leavy & Hourigan, 2015, 2016, 2018,). The influence of collaborative planning and witnessing classroom practices on attitudes towards statistics was, perhaps, a somewhat unexpected, but welcome finding.

7.6 Conclusion

The primary objective of this study was to examine the impact of a practice-based mathematics elective on pre-service teachers' attitudes towards statistics. Attitudes towards statistics were measured using the SATS-36 (Schau, 2003) prior to and following the completion of a mathematics elective. The 11-week elective engaged groups of pre-service teachers on the design, implementation, revision and reteaching of five-lesson unit of statistical instruction to two classes of 6th grade children. Findings reveal that the real-world data context (focused on examination of the conditions within honeybee hives) using data collected by local sensors (conveyance technology) provided impetus to engage in a meaningful statistical inquiry. Furthermore, using CODAP (math action technology) facilitated an emphasis on statistical thinking and reasoning over technical calculations, thus leading to perceived positive change in PSTs' attitudes towards statistics. Other features of the intervention, such as opportunities for collaboration and classroom practice were acknowledged for their role in uncovering new content and pedagogical knowledge, and affirming prior learning, in turn improving attitudes towards statistics.

The findings illustrate the impact of participation on PSTs' attitudes towards statistics and features of the statistics elective that PSTs valued and associated with positive developments in these attitudes. This study emphasises the capacity of a sustainability context to drive meaningful statistical investigations using real-world data, and the role technology can play in supporting analysis and reasoning. Findings therefore, have implications for teacher educators as well as curriculum and policy developers as they plan to enhance statistical literacy. For example, including features of the intervention (such as collaborative lesson design and using societally relevant datasets) in core statistics education modules, has potential to enhance experiences of all elementary PSTs. Further study could examine the stability of attitudes as participants progress through their initial teacher education and particularly after engaging in subsequent school placement experience. Additionally, there would be value in tracking participants' attitudes as they progress along the continuum of teacher education beyond qualification.

This is a case study that uses a non-representative sample thus limiting the generalisability of results. Furthermore, given the authors conducting the research also developed the elective and taught and evaluated participating PSTs, they may have been conservative in reporting negative experiences. While acknowledging these limitations, the study makes a significant contribution, adding weight to the body of relevant research.

7.7 Declarations

Data Availability Statement: The data that support the findings of this study are openly available in *The Open Science Framework* at https://osf.io/qr5tk?view_only=6ab2e1c223fe4d20b8db1c4270397dea .

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7.8 Chapter conclusion

This chapter illustrates the impact of an authentic integrated STEM inquiry on PSTs' attitudes towards statistics. It also positions statistics education as a powerful integrator, that demands number in context, thus maintaining the spotlight on mathematics throughout the inquiry (which was a noted shortcoming in the previous iteration of the module). This paper also exposes key characteristics of *Intervention 2* that PSTs associate with positive changes in their development as STEM teachers. These perceived influences noted by *Cohort 2*, reveal common positive experiences as identified by *Cohort 1* the previous year, thus supporting the findings from *Intervention 1* which point to the importance of collaborative journeying, opportunities to experience STEM as learners, and the power of witnessing STEM-in-action through authentic classroom engagement. The following chapter presents the fifth and final paper in this dissertation, returning to the PSTs in *Cohort 1*, one year after their engagement in *Intervention 1*.

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Chapter 8: Drawing the past to envision the future: Supporting the development of primary STEM teacher identity

Chapter 8. Drawing the past to envision the future: Supporting the development of primary STEM teacher identity

Preamble

This chapter revisits the PSTs from *Cohort 1* over a year later as they approach the final weeks of their undergraduate programme. Having completed a STEM-focused mathematics education specialism over two years (Year 2 is not reported in this dissertation, see conference paper in Appendix C for details of their final experiences in year 2), and engaged in an extended school placement experience, PSTs were invited to reflect on their emerging STEM teacher identities. Using *STEM story-lines* as an innovative graphing tool, *Cohort 1* take a retrospective look at past experiences and anticipate their future teacher selves, as they negotiate becoming integrated STEM teachers. This article has been peer-reviewed and published in *Irish Educational Studies* (IES).

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Statement of authorship;

I hereby declare that I, Michelle Fitzpatrick, am the principal author of this article. The following statements outline my contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis and interpretation of data for the work; AND

• Drafting of work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

See Appendix I for signed letter from Dr. Audrey Bryan (General Editor at *IES*) confirming the status of this article

8.1 Abstract

Growing interest in STEM education and imminent curricular reform places new demands on teachers, giving impetus to re-examining how we prepare primary teachers for more integrated approaches. In addition to the acquisition of knowledge and skills, sustainable change demands the development of teacher identity, in which teachers are seen by themselves and others as STEM teachers. This paper reports on the emerging STEM teacher identities of five preservice primary teachers. Using STEM story-lines as an innovative graphing exercise and semi-structured interviews, participants were prompted to reflect on key events that shaped their journey and share future-oriented narratives as they negotiated becoming STEM teachers. Findings suggest that although their own school experiences were varied and influential, an integrated STEM intervention was the common turning point in their STEM identity development, whereby participants aligned critical components of STEM with personal experiences and values. The reflective tools used supported identity work, by triggering a rediscovery and reinterpretation of their experiences with the benefit of increased knowledge for teaching STEM and, in turn, provided a means to re-envisage the future.

Keywords: STEM education; teacher identity; initial teacher education; primary education; identity work

8.2 Background and introduction

There has been growing interest in the field of STEM (Science, Technology, Engineering and Mathematics) since the term was first coined in 2001. Similar to global trends, the call for STEM literacy has led to an explosion of STEM policy in Ireland over the past two decades. Economic competitiveness spurred initial interest, as evidenced in the *Strategy for Science, Technology and Innovation* (GOI, 2006) which highlighted the role of STEM in accelerating national growth. Educational policy quickly followed, with early strategies focusing on specific disciplinary areas. *Smart Schools = Smart Economy* (GOI, 2009), for example, aimed at enhancing technological capacities, while the *Literacy and Numeracy Strategy* (DES, 2011) targeted the improvement of mathematics outcomes. The national *STEM Education Review Group*, established in 2013, was tasked with reviewing STEM education across the sectors, and as outlined in the *Action Plan for Education* (DES, 2017a), an integrated national STEM Education Policy Statement *2017–2026* (DES, 2017b) soon followed. This indicated the formal introduction of 'STEM education' policy in Ireland and was accompanied by the *STEM Education Implementation Plan 2017–2019* (DES, 2017c).

Recent attention, however, has moved beyond economic imperatives, and STEM is being acknowledged for its role in supporting active citizenship. In an increasingly technological and data-driven world, there is need to support the development of well-informed consumers and critical decision-makers, prepared to tackle the 21st century challenges they will face in their lifetime (Kurup & Li, 2022; Maass et al., 2022, 2019; Mohr-Schroeder et al., 2020). Integrated STEM education offers the potential to develop important key competencies and dispositions needed both personally and professionally (Falloon et al., 2020; Leavy et al., 2023). Curriculum reform is now converging with STEM policy, recognising the importance of STEM literacy for all students. The most recent developments position STEM education as one of the five new broad curriculum areas of the new Irish Primary Curriculum Framework (NCCA, 2023), and preparations for the development of a STEM curriculum specification are underway. Yet despite the abundance of national and international policy, STEM education itself is a relatively nascent field of research. There remains much to learn about STEM teaching and indeed, teacher education. While the literature suggests an enthusiasm amongst teachers for more integrated approaches (Delahunty et al., 2021; Hamilton et al., 2021; Hourigan et al., 2022; O'Dwyer et al., 2023), there are many obstacles that impede effective STEM enactment in the classroom, not least, teacher preparedness (Bartels et al., 2019; El Nagdi et al., 2018; Margot & Kettler, 2019; Shernoff et al., 2017). Primary teachers need more than disciplinary content and pedagogical knowledge in order to integrate STEM in practice. In addition, they require meaningful and authentic experiences as both STEM learners and teachers (Fitzpatrick & Leavy, forthcoming; Galanti & Holincheck, 2022; Holincheck & Galanti, 2023).

As teachers are, unequivocally, the core of educational change (Datnow, 2020), it is on their shoulders that integrated STEM initiatives come to fruition (El Nagdi et al., 2018). Imminent reform in the Irish educational landscape gives impetus to re-examining how we support the development of STEM teachers. Sustainable change is dependent on more than "moral commitment to reform" (El Nagdi & Roehrig, 2020, p. 3) and attention must be paid to developing teacher identity, in which teachers see themselves and are seen by others as STEM teachers (El Nagdi et al., 2018; Galanti & Holincheck, 2022). Given the malleability of teacher identity (Beijaard et al., 2004; Holincheck & Galanti, 2023) and the strong positioning of initial teacher education as fertile ground for change (Leavy & Hourigan, 2018), it is timely that we pause and consider the development of integrated STEM identities for our future teachers.

8.2.1 The move towards integrated STEM education

While often thought of as the individual, and siloed, disciplines of science, technology, engineering and mathematics (Sanders, 2009), STEM education is increasingly being viewed from an integrated perspective (Anderson, 2020; English, 2017; Honey et al., 2014). This has been motivated by the opportunities integrated approaches provide students to experience the meaningful interaction between the disciplines, that reflect real world applications more honestly and realistically, rather than creating artificial subject divides, so rarely present in real world scenarios (Breiner et al., 2012; Glancy & Moore, 2013; Honey et al., 2014).

The degree of this boundary crossing, however, varies (English, 2016; Li, 2014) and a range of integrated STEM conceptualisations are evident in the literature. Numerous frameworks have been offered to help navigate the "epistemic obstacle" (Leung, 2020, p. 1) presented when attempting to span disciplinary knowledge domains. Vasquez et al.'s (2013) continuum of approaches to STEM curriculum integration, for example, offers four increasing levels of integration and interconnectedness between the disciplines, moving from *disciplinary* (where concepts and skills are presented separately in each discipline), through *multidisciplinary* and *interdisciplinary* approaches before offering a *transdisciplinary* approach (which utilise real-world problems, requiring application of knowledge or skills from two or more disciplines).

While the many published integrated STEM frameworks differ in their conceptualisations and emphases (Moore et al., 2020), common characteristics remain prevalent, such as the importance of basing lessons on real world problems, building disciplinary and interdisciplinary knowledge, the use of appropriate STEM pedagogies such as inquiry-based and project- based learning, the development of key competencies or 21st century skills and the promotion of engineering design practices (Butler et al., 2020; Guzey et al., 2016; Johnson et al., 2021; Kelley & Knowles, 2016; Moore et al., 2014). With these characteristics at its core, STEM becomes more than the sum of its component disciplines, but can be "the way that teachers and students understand the changing world and its complexity" (Galanti & Holincheck, 2022, p. 3).

The many definitions of STEM education are problematic (Moore et al. 2020) and the range of integrated STEM conceptions held by teachers is a challenge to its effective classroom implementation (Radloff & Guzey, 2016). Teachers, therefore, need to be "intimately familiar with the interrelationships within the STEM disciplines" (Breiner et al., 2012, p.10). Yet, traditional teacher education programmes have focused on developing skills and knowledge in discrete disciplines, with little emphasis on integrated approaches to STEM (Huang et al., 2022; Lo, 2021; Zhang & Zhu, 2022). Notwithstanding the obvious need for sound knowledge in the discrete disciplines, we have reported elsewhere (Fitzpatrick et al., in press) on the difficulties experienced by preservice teachers in applying their disciplinary knowledge for teaching (notably mathematics) to interdisciplinary lessons. Therefore, we have joined the call of others (Corp et al., 2020; Shernoff et al., 2017) for a specific focus on integrated STEM in initial teacher education, to prepare preservice teachers for the demands of the 21st century classroom.

When considering the types of support needed for reform, it has been argued that teacher education has focused on what teachers need to do in their classrooms, in turn neglecting the affective impact of pedagogical change (Keiler, 2018). Indeed, challenging issues of reform are often found resistant to change, and demand a "deep and all-encompassing process, including both how teachers narrate themselves and how they interpret the teaching-learning world in which they engage" (Shabtay & Heyd-Metzuyanim, 2018, p.162). There has long been an acknowledgement that teachers' identities, both as teachers and as learners, shape how and what teachers learn, respond to instructional innovation and interpret and implement reform (Drake et al., 2001). This has led to calls for conceptualising teacher learning as teacher identity learning (Beijaard et al., 2022). This study, therefore, examines preservice primary teachers STEM development, through the lens of teacher identity.

8.2.2 STEM Teacher identity

Much like the term 'STEM education' itself, conceptualisations and interpretations of teachers' professional identity vary (Avraamidou, 2014; Beauchamp & Thomas, 2009; Beijaard, et al., 2022). Described as both a product and a process (Beauchamp & Thomas, 2009; Sfard & Prusak, 2005), teacher identity has been accepted as a dynamic, ongoing and evolving construct (Beijaard et al., 2004; 2005; Flores, 2020; Flores & Day, 2006; Sachs, 2005). Teachers must constantly interpret and reinterpret their experiences and social interactions over time, in the complex interaction between the personal inner landscape, and the contextual (Beijaard, et al., 2022; Hong et al., 2017). The literature points to a number of factors that influence teacher identity formation and "leave it in continual flux" (Izadinia, 2013, p. 695). Researchers have examined the role of affect, including motivation and emotions (cf. He, 2022; Schutz et al., 2020), and external variables, such as context and past experiences; including memories of school and experiences of failure (cf. Lutovac, 2020; Miller & Shifflet, 2016). Indeed, Heyd-Metzuyanim (2017, 2019) considers the construct of identity as the nexus of affect and discourse, positioning identity as an anchor for unifying cognitive and affective frameworks when exploring teacher change and professional development. Teacher identity is, therefore, at the heart of the profession, supporting teachers in constructing their own ideas of "how to be", "how to act" and "how to understand", all the while negotiating their evolving identity "through experience and the sense that is made from that experience" (Sachs, 2005, p.15).

It has also been recognised that teachers form subject- specific identities and that storied identities can vary greatly from subject to subject (Drake et al., 2001). To date, much of the literature relating to STEM teacher identity relates to discipline specific identities, such as mathematics related teacher identity (cf. Lutovac & Kaasila, 2014, 2019) and science teacher identity (cf. Avraamidou, 2014, 2018). Recently, a small number of studies have begun to look towards the integrated STEM identity of in-service primary teachers (Holincheck & Galanti, 2023) and post-primary teachers' developing identities in emerging STEM schools (El Nagdi et al., 2018; Jiang et al., 2021). However, integrated STEM teacher identity remains vastly under-researched. Moreover, we know very little about how pre-service primary teachers, who already have to contend with multiple identities across a range of subjects, can be supported in renegotiating these identities within the integrated STEM context.

8.2.3 Future oriented identities

As Lutovac and Kaasila (2014) contend, preservice teachers "do not limit their thoughts to the present moment", and identity, therefore, should be understood as "extending to past and future selves" (p. 131). While retrospective reflection (analysing past events) is most often prioritised, anticipatory reflection and future-oriented discourse can also offer opportunities for thinking about one's teaching, examining pedagogical intention, and improving practice (Conway, 2001; Miller & Shifflet, 2016; Urzúa & Vásquez, 2008). An individual's future identity expectations can be conceptualised as possible selves (Markus & Nurius, 1986; Oyserman & James, 2009), that is, preservice teachers' hoped for selves (the teacher they would like to become) and their feared selves (the teacher they are afraid of becoming) (Lutovac, 2020; Pellikka et al., 2022). It has also been thought of in terms of *ideal* identity (Beauchamp & Thomas, 2010; Lauriala & Kukkonen, 2005), one's hopes, wishes or aspirations, or *as designated identity* (Sfard & Prusak, 2005), that is a "narrative presenting a state of affairs which, for one reason or another, is expected to be the case, if not now then in the future" (p.18). Such future-oriented discourse, it is argued, can create roadmaps and motivation for preservice teachers, allowing them to envisage and consider what can be approached or avoided, acting in turn as an incentive for current behaviours (Miller & Shifflet, 2016).

8.2.4 Teacher identity work

Teacher identity is formed within, but also out of, "the narratives and stories that form the "fabric" of teachers' lives" (Mockler, 2011, p. 519), allowing people to make sense of their experiences (Lutovac & Kaasila, 2014). Narratives can, therefore, be viewed as both a process of identity development, and the empirical data for analysis (Dugas, 2021). Indeed, Sfard and

Prusak (2005) define identity as a collection of stories about an individual that are reifying, endorsable and significant. From this narrative perspective, therefore, participants' stories are accepted for "what they appear to be: words that are taken seriously and that shape one's actions" (Sfard & Prusak, 2005, p. 21). Finding answers to such identity questions as 'who am I as a teacher?' and 'what kind of teacher do I want to become?' places great demand on the reflective capacity of teachers (Beijaard et al., 2022). Supporting preservice teachers' identity development has been described as 'messy work', requiring teacher educators who are

> willing not only to create safe spaces, but also to enter into difficult but necessary conversations with our teacher candidates, to see identity conflicts not as problems to be avoided, but as opportunities to guide teacher candidates toward a deeper self-understanding that will be indispensable in their future work (Dugas, 2021, p. 258).

Many narrative approaches have been used to support the identity work of preservice teachers, such as (but not limited to); autobiographical essays (Rouhotie- Lyhty & Moate, 2016), reflective reports (Flores, 2020; Lutovac, 2020; Muchnick-Rozanov & Tsybulsky, 2019; 2021), interviews (Arvaja & Sarja, 2021; El Nagdi et al., 2018; Lutovac & Kaasila, 2014), recorded mentoring meetings (Urzúa & Vásquez, 2008), or combinations of interviews and other written methods (Beauchamp & Thomas, 2010; Jiang et al., 2021; Pellikka et al., 2022).

In examining such narratives, an interesting graphical story-line approach, has also been reported. Bobis et al. (2021) asked the preservice teachers in their study to complete an identity graph at the beginning of their interview, to graphically represent the high and low points in their relationship with mathematics over their lifetime. Providing their participants with a pre-drawn horizontal axis (labelled key events that have shaped my identity with mathematics) and vertical axis (labelled degree of enjoyment/ dislike/confidence/anxiety), participants were encouraged to draw a line graph to represent their 'relationship' with mathematics, before annotating the graph to describe the nature of the experiences. Beijaard et al. (1999) and Conway (2001) refer to their graphical narratives as story-lines. Beijaard and colleagues (1999) asked their teachers to evaluate and clarify their current perception of an aspect of their teaching (e.g. interaction with students), by identifying themselves on a 7-point scale (1-7: from very negative to very positive). They then were asked to construct their story-lines from present to past on the graph, thus evaluating prior events on the vertical axis (7-point scale), across the horizontal axis (number of years working as a teacher).

As well as focusing on remembered experiences, Conway's (2001) use of graphical *story-lines* allowed for both anticipated experiences and reconstructed anticipations. Similar to the previous two studies, Conway (2001) asks participants to draw a line representing past experiences (in this case, comfort levels over the course of their Intern year). However, the teachers are then asked to look beyond their internship year, and project this line forward to their first-year teaching, thus incorporating both retrospective and prospective reflection. Consequently, the use of graphical story-lines, in conjunction with annotation and interviews or focus groups, could provide the 'safe space' (Dugas, 2021) needed for preservice teachers to engage in meaningful identity work, by encouraging them to "vividly represent what might otherwise be very difficult to convey, and ...help the researcher understand experiences in a manner difficult to accomplish via other means" (Conway, 2001, p. 94).

8.2.5 Context of this study

As we look towards imminent STEM developments at primary level, it is timely to pause and consider how STEM is negotiated in teachers' ever evolving identities. This study has two main aims:

(1) To explore the emerging STEM teacher identity of preservice primary teachers who completed a STEM-focused mathematics specialism as part of their undergraduate programme.
(2) To identify the potential of an innovative narrative graphing activity in supporting the identity work of integrated STEM teachers.

8.3 Methods

8.3.1 Study setting and participants

This study is set in an Initial Teacher Education (ITE) institute in Ireland. On entry to the college, students have completed 8 years of primary education and 5 years of post-primary education (3 years of Junior cycle, 2 years of senior cycle) and possibly one transition year. As part of a four-year, (8-semester) concurrent, Bachelor of Education programme, preservice primary teachers are offered elective education modules during their third and fourth years. Study participants were undertaking a mathematics education specialism. This specialism, with a cohort of 27 preservice teachers (PSTs), consisted of 3 modules, each of 12 weeks duration. The first module (semester 5) explored *Scratch* as an educational resource to support the learning of mathematical concepts and introduced STEM education via a 6-hour online, asynchronous unit of work. The second module (semester 6) focused on integrated STEM education. This module (outlined in Chapter 4) explored the theory of STEM education, introducing characteristics of integrated STEM tasks, developing STEM pedagogies, and interrogating STEM frameworks. Integrated STEM was conceptualised in this module as the integration of two or more of the STEM disciplines (Honey et al., 2014; Murphy et al., 2023; Sanders, 2009), driven by a real-world problem (Kelley & Knowles, 2016; Roehrig et al., 2021; Stohlmann et al., 2012). Given that PSTs had no formal input on engineering practices as part of their undergraduate study to date, attempts were made to present learning and teaching opportunities through engineering design challenges.

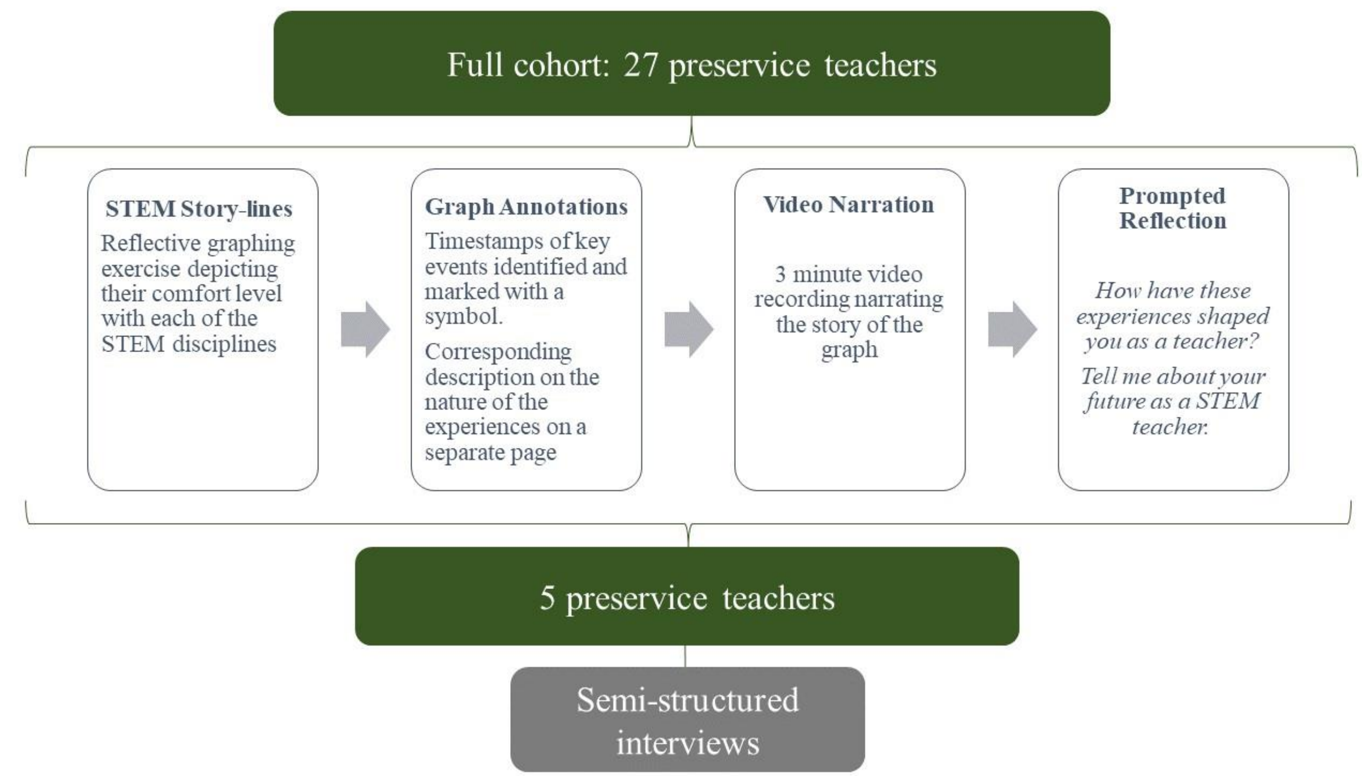
PSTs were introduced to Vasquez et al.'s (2013) continuum and explored the range of approaches to STEM curriculum integration. To develop the PSTs' STEM literacies, emphasis was placed on providing opportunities to engage in STEM tasks as learners. PSTs then co-designed a series of STEM lessons, which were implemented in a local school over 5 days of intensive STEM workshops. They then reflected on their field experience, sharing their learning and key takeaways from these lessons, and discussing modifications they would make in light of their observations. The third, and final, specialism module (semester 8) took place following an extended school placement. This module began with a focus on mathematical problem posing (week 1-8) and concluded by (re)examining the role of mathematics in integrated STEM. Arising from the difficulties experienced in foregrounding mathematics teaching and learning within integrated STEM tasks in their second module (Fitzpatrick et al., in press), we returned to the positioning of mathematics within STEM, modifying and designing mathematics-focused STEM lessons. Centred around a rich sustainability context (colony collapse and the plight of the honey bee), PSTs were tasked with collaboratively designing a STEM unit that maintained the spotlight on mathematics (see Appendix C).

8.3.2 Data generation

Several methods were used over the 3-semester specialism to gather data from the entire cohort (n=27) as part of a larger investigation into preservice primary STEM teacher education. This paper reports specifically on the data generated by these PSTs during the final weeks (semester 8) of the BEd programme (see Figure 8.1). All PSTs undertaking the specialism illustrated their *STEM story-lines* using a reflective graphing exercise (outlined below), produced a 3-minute video narrating the features of the story-line and completed a reflective task. Following initial analysis of the graphs, accompanying annotations and reflections (written and video), five PSTs were then invited to participate in a semi-structured interview. Participation in the research was voluntary. Approval was obtained from the institute's Research Ethics Committee, and all ethical considerations were adhered to.

Figure 8.1

Methods used to generate data



8.3.2.1 STEM story-lines and associated video narrative and written reflection

Participants completed a *STEM story-line* activity at the end of their final specialism module. Initially, they were invited to graphically depict their experiences in science, technology, engineering and mathematics, from earliest memories to present day. The story-line activity was adapted from the work of Bobis et al. (2021), Conway (2001) and Beijaard et al. (1999). While these researchers used the story-line activity to graph experiences in the lives/careers of participants pertaining to a specific subject (Bobis et al., 2021), internship year (Conway, 2001), or aspect of their teaching (Beijaard et al., 1999), participants in this study were asked to reflect on their relationship with each of the four STEM disciplines, with each discipline being represented by a different coloured line.

Participants were provided with a blank *STEM story-line* template (see Figure 8.2). The horizontal axis was labelled *key events and experiences in STEM* (along with space to denote the colour of each discipline line). The vertical axis was labelled *comfort,* with participants being asked to visually represent their comfort levels (from low to high) reflecting the degree of enjoyment, dislike, confidence or anxiety associated with each discipline, over the course of their experiences. The axes and what they stood for were discussed and an example (from Bobis et al., 2021) provided. Participants were then asked to construct four-line graphs to represent their relationship with each of the four disciplines, S-T-E and M. Once completed, participants were invited to identify key moments on their graph: high points, low points, or turning points. Timestamps that were significant to them were marked with a number or codeword. On a separate page, participants then wrote a corresponding short narrative (one or two sentences) on the nature of each experience and its significance. Participants were then asked to mark a point on the graph for each discipline line that represented where they envisage their comfort level being in the future (for complete sample see Figure 8.3).

Figure 8.2

Blank STEM story-line template

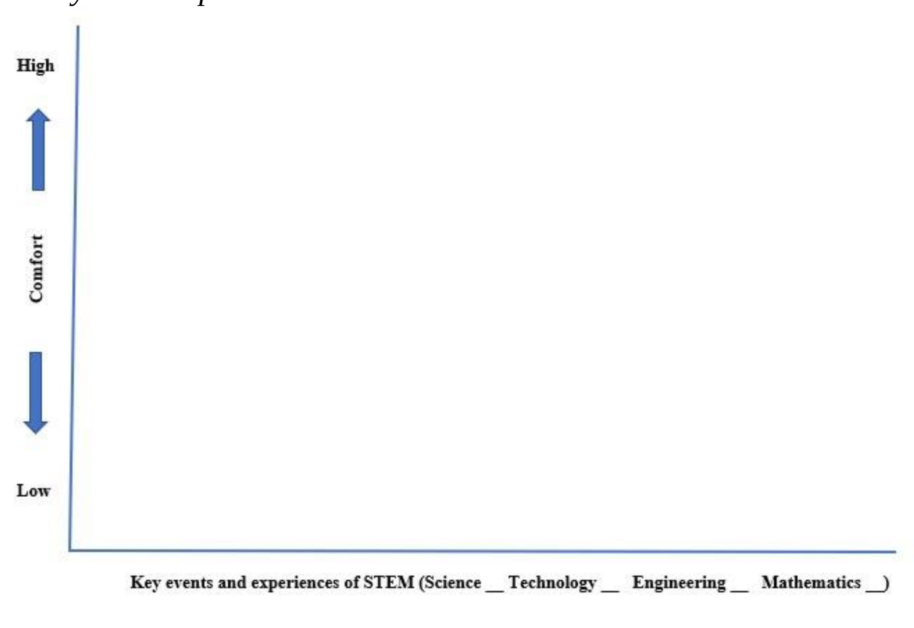
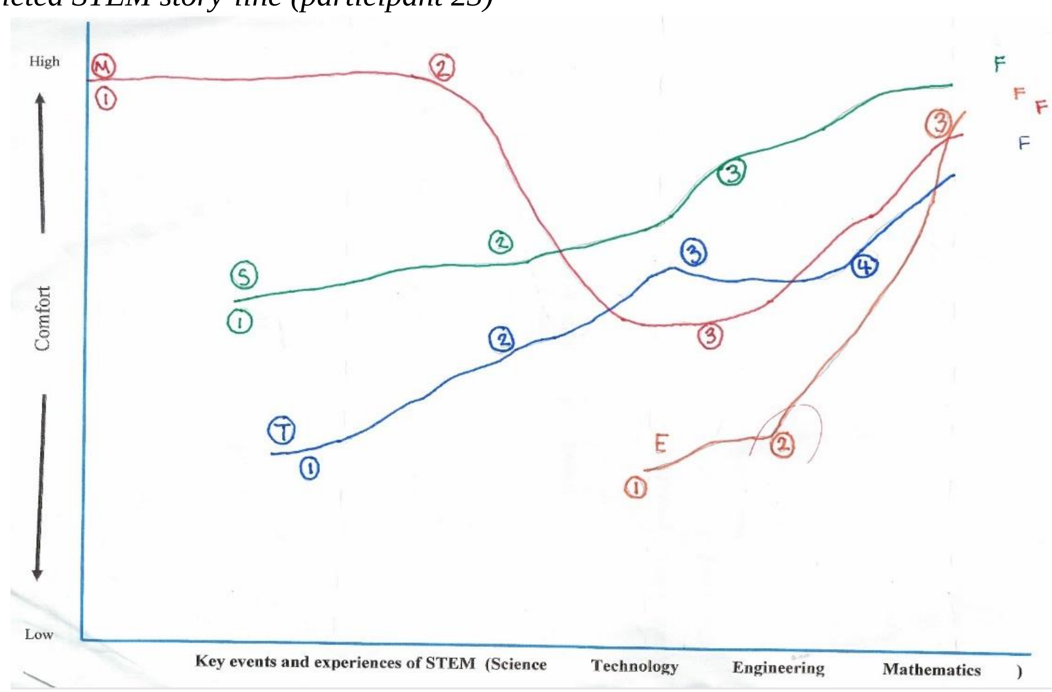


Figure 8.3

Completed STEM story-line (participant 23)



Note: Timestamps noted on disciplinary lines and key event detailed separately in annotations ('M' line: 1=primary school, 2= post-primary, 3= college. 'S' line: 1=primary, 2=post=primary, 3=college. 'T' line: 1=primary, 2=post-primary, 3 & 4= college. 'E' line: 1, 2 & 3= college).

On completion of the graph and annotations, two supplementary activities were completed. Participants recorded a short (two to three-minute) video, guiding the viewer through their story-line by telling the story of their graph, reflecting on and describing key moments across the disciplines. Finally, participants wrote a short reflection focusing on two prompts: 1.) *How have these experiences shaped you as a teacher?* and 2.) *Tell me about your future as a STEM teacher.*

8.3.2.2 Semi-structured interviews

Following initial analysis of the *STEM story-lines,* five PSTs were invited to participate in semi structured interviews. Purposeful sampling of interview participants sought to select *information-rich cases,* to examine issues of central importance in depth (Patton, 2002). Effort was also made to select participants who represented a range of prior experiences and narratives, across the four disciplines (see Table 8.1). These interviews used the *STEM story-lines* as a springboard for discussion, providing an opportunity to delve deeper into the stories behind STEM learning experiences. Interviews explored PSTs' current understanding of STEM education, and how they see their role as STEM teachers. Guided by the work of Galanti and Holincheck (2022) questions attended to participants motivation, self-image and self-efficacy for teaching integrated STEM, asking *Why do you teach integrated STEM? How do you see yourself as a STEM teacher? How confident are you to teach integrated STEM? What is your task as an integrated STEM teacher?* The remainder of the interview took a future-oriented perspective on their role as STEM teacher, as participants reflected on the kind of STEM teacher they want to be in the future, outlining their hopes and their fears. Audio-recorded interviews lasted for approximately 34 minutes and were transcribed.

Table 8.1

Interview participants

Participant	Sampling consideration
Aoife	Graph illustrates steep peaks and troughs across all disciplinary lines. Aoife has clear memories of both rich and impoverished experiences from school and reports on how these have shaped her as a teacher and future teacher.

	Her written reflections include "*I want to be known as the teacher who does STEM*".
Donna	Graph depicted earliest and strongest *engineering* line amongst participants. Reflections suggest an affinity for STEM pedagogies, emphasising her intended use of inquiry, and project-based learning. Graph annotations report *lower mathematics* comfort levels on entering specialism.
Shay	Strong steady *mathematics* line with a fluctuating *science* line. Shay emphasises specific STEM related *field experiences* during the specialism, and choosing STEM as a curriculum focus on placement, reporting that both have increased his *confidence* in STEM.
Evan	Steady incline in *technology* line, with technology reported as discipline of highest comfort at conclusion of specialism. Reflections on his future as a STEM teacher center around the development of *21st century skills.*
Grace	Very high early *mathematics* line that returns to high position after deep dip in post-primary. In her reflection, Grace tells of how knowing where difficulties arose for her across the disciplines will help her support children in her class. Grace recognises technology as the area of lowest comfort and seeks to "*research more into the technology element of STEM and how this can be emphasized*" in the future.

8.3.3 Data analysis

Early analysis adopted a narrative approach. Participants' individual stories told through their annotated graphs, videoed narratives, and their past, present and future narratives from interview, were examined and woven to create each participant's *emplotted* (Lutovac & Kaasila, 2019) STEM-story. This gave insight into the individual and unique experiences of each participant. All narratives were then thematically analysed using Braun and Clarke's (2021; 2022) Reflexive Thematic Analysis (RTA). RTA was chosen as a flexible method, that "emphasises the importance of the researcher's subjectivity as analytic *resource*, and their reflexive engagement with theory, data and interpretation" (Braun & Clarke, 2021, p. 330). The interpretive orientation of RTA allows the researcher to shift the focus from *truth-telling* to *telling a story* in a way that aims to make sense out of what is going on (Braun & Clarke, 2022). The six phases of RTA were followed. Phase 1 (familiarising yourself with the dataset) and Phase 2 (coding) had begun during the initial narrative analysis. Initial themes were generated and developed (Phases 3 and 4), before being refined, defined and named (Phase 5). Writing up the themes (Phase 6) was an iterative process, beginning in Phase 4. At the completion of Phase 6, five themes were identified which are explored in the next section.

Table 8.2 outlines the generation of the codes in Phase 2 and subsequent initial themes (phases 3 and 4) which lead to the final theme (phase 5 and 6) titled *Aligning critical components of STEM with personal STEM experiences and teaching values*.

Table 8.2

Sample of codes, initial themes and final theme

Codes	Real world context, constructivism, skill development, STEM talk, collaboration/group work, active learning, experimentation, skills and knowledge, context, importance or relating to life, link disciplines to real world, has to have engineering, maths bias?	Core values, STEM learning, novel approaches, kids love it, fun while learning, benefits for kids, skills development, like favourite teacher, communication, creativity, 21st century competencies, good memories from school, all the things we didn't do in school, I liked doing it in school	STEM seen as separate, isolated building activity, just craic no learning, need to link disciplinary and interdisciplinary, need to explore links, not just curriculum coverage, teachers in the dark, curriculum objectives? Book
Initial themes	*STEM attributes valued*	*Motivation to teach STEM*	*Critical of STEM seen*
Final Theme 3	*Aligning critical components of STEM with personal STEM experiences and teaching values*		

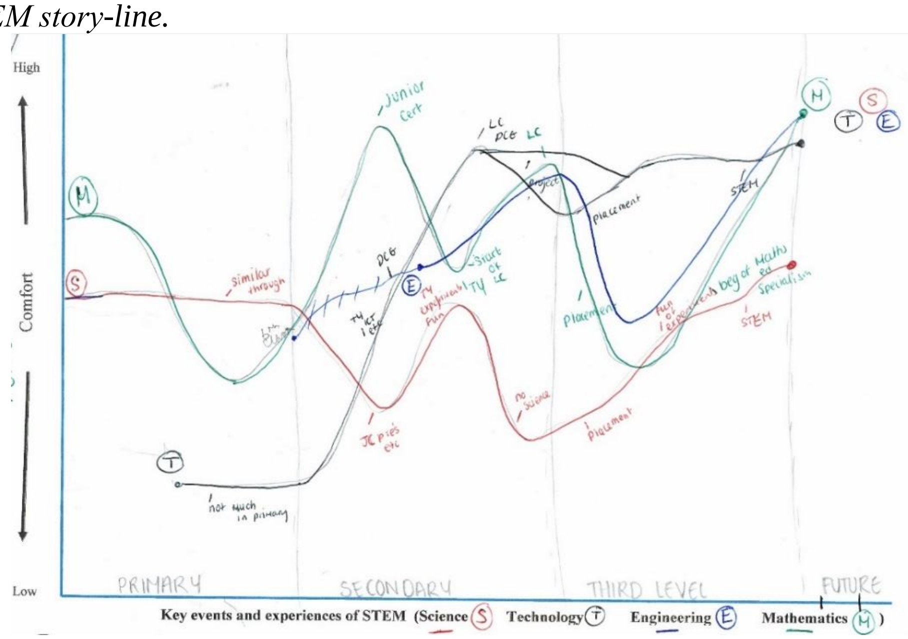
8.4 Findings and discussions

8.4.1 Theme 1: "Yeah, that's a big dip there alright". Formative experiences at every level; but even 'big dips' and late starts can be mitigated

Participants recounted varying personal histories reflecting their experiences in the STEM disciplines across the education sectors (primary, post-primary and ITE). While their *STEM story-lines* plot the unique *ups, downs* and *turning points*, their written, video and interview narratives highlight some common experiences that led to these changes. Unsurprisingly, pressures of post-primary school state examinations led to significant dips in comfort levels, particularly in relation to mathematics, while positive feedback, exam success, and individual teachers all contributed to higher levels of comfort and positive dispositions amongst participants. Aoife and Donna both attributed significant changes in their attitudes towards mathematics to an “amazing teacher”. Their enthusiasm and love for the subject “kind of worked both ways. I suppose he put so much effort in, you wanted to do the same” (Donna). For Aoife, the teacher had a stronger influence than high marks. Following negative experiences in mathematics at primary level (see Figure 8.4) where she describes being “really nervous at maths and I’d be at home with my dad, crying about the maths”, Aoife’s post-primary teacher gave her more confidence, by telling her “‘oh no, you’re really good at maths’... and then I thought, oh maybe I am. I think we all did really well in that class”. This supports the work of Bobis, et al. (2021), who found that certain social-cultural experiences could reverse downward trending relationships with mathematics. Not only does Aoife recognise an emotional change in her relationship with mathematics, she also associates this with increased competence and achievement in mathematics.

Figure 8.4

Aoife’s STEM story-line.



Note: Times noted on the horizontal axis (*primary, secondary, third level, future*) and key events detailed in annotations.

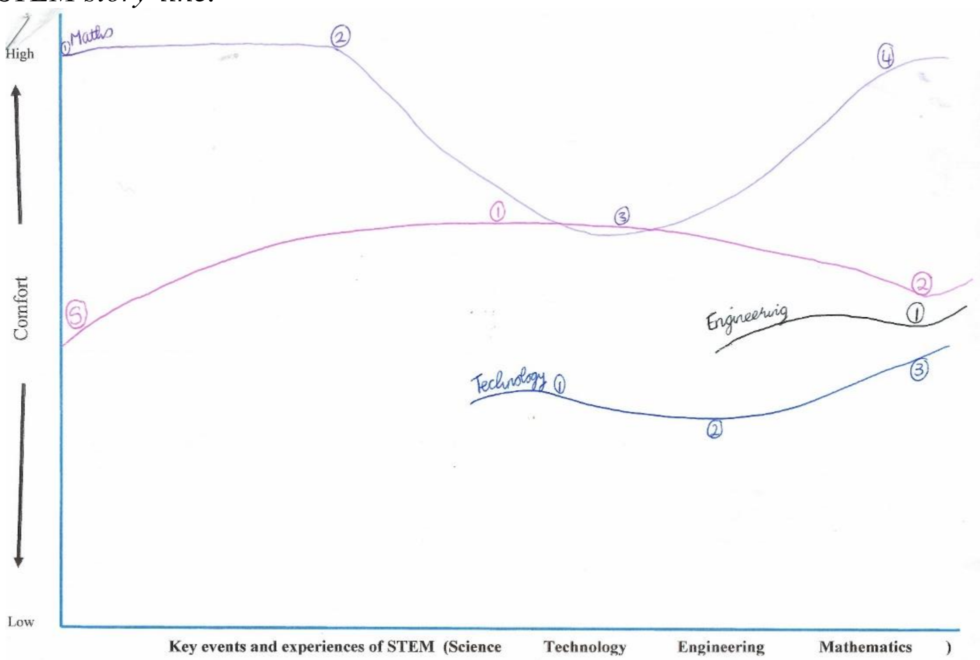
All participants, despite the challenges, reported good grades at higher level mathematics at senior cycle. Interestingly, Aoife and Evan, who both describe themselves as a 'maths person' found the transition to mathematics education modules most challenging. Although very confident in their ability to do mathematics, both reported a dip in comfort when exploring the *pedagogy* of mathematics, reflecting perhaps their strong common content knowledge and lack of specialised content knowledge or mathematics knowledge for teaching (Ball et al., 2008). Grace, meanwhile, considered mathematics education a highlight of her college experience. Following low comfort levels during post-primary (senior cycle), exploring the pedagogy of mathematics in college resulted in her "comfort level increasing rapidly" (*mathematics narrative point 3* see graph Figure 8.5) as she;

> learned about the way to teach maths and maths methodologies, different ways I wouldn't have thought of, just basing it off my own experience of primary school where the teacher would just write up a sum and you'd do it, instead of like, giving a kid a context while they're learning it (Grace).

As Galanti and Holincheck (2022) assert, perceived competence in understanding STEM content is a central dimension of STEM learner identity. By reflecting on past learning experiences, participants recognised times that challenged and supported their mathematical knowledge, both in terms of content knowledge and mathematics knowledge for teaching.

Figure 8.5

Grace's STEM story-line.



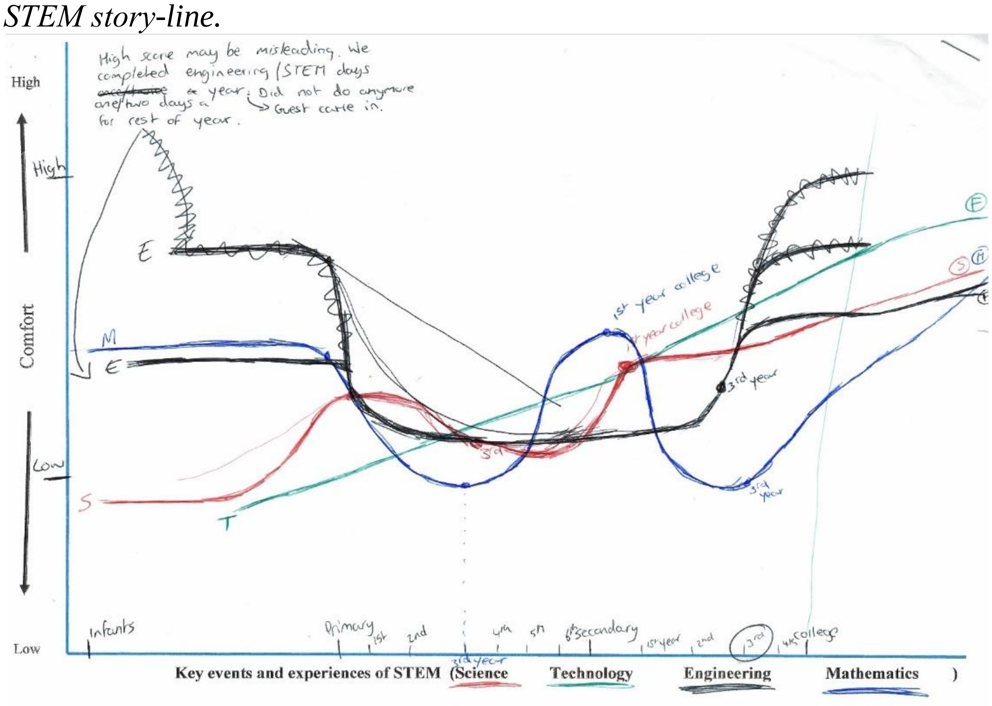
Note: Timestamps noted on disciplinary lines and key event detailed in annotations ('Mathematics' line: 1= primary, 2=junior cycle, 3= senior cycle, 4= college. 'Science' line: 1=primary, 2=post-primary. 'Engineering' line: 1= mathematics specialism in college. 'Technology' line. 1=primary, 2=post-primary, 3= college)

Participants reported little exposure to inquiry-based approaches in science at both primary and post primary level. While some positive experiences were noted in early primary level, the "hands-on nature of science decreased" with the "use of a book for science lessons [becoming] a lot more common" (Shay). Science was considered a subject they "only engaged with on a few occasions, particularly during initiatives like Science Week" (Grace). Reported 'highpoints' were often associated with post-primary Junior Cycle science (or during Transition Year), where "everything was kind of experiments" (Shay). Negative experiences related to a noted absence of inquiry, which focused on "rote -learning" and science experiences that were prescriptive and "you knew the outcome before you even got to do it" (Evan).

Technology and engineering lines on the *STEM story-lines* generally begin later (see figs. 3, 5). Participants reported little engagement with technology in primary school, with computer use often cited as "a reward" (Shay) or "golden time" (Evan). There appears to be a shift at post-primary level, where they describe the regular use of iPads, collaborative and project work using digital technologies. Participants suggested that the gradual upward trajectory of the technology line reflect the role of technology in society, as it is "constantly increasing", and through increased use and exposure they are becoming more familiar with it all the time (Shay). Engineering experiences are generally the last to emerge, with the line only beginning at 3rd level in three participant graphs. While there were many references to sustained factors that influenced participants (such as teacher approaches, assessment etc), Donna highlights the power of infrequent, but rich, experiences. Notably, Donna is the only participant to record early engineering experiences on her *STEM story-line* (see Figure 8.6).

Figure 8.6

Donna's STEM story-line.



Note: Timestamps noted on horizontal axis (infants, primary, 1^{st} – 6^{th} year in post primary, 1^{st}-4^{th} year in college) and key event detailed separately in annotations. Space to the right after 'college' refers to anticipated future comfort levels in each discipline.

She attributes this to a standout event, that happened once a year, when her friend's father (an engineer) visited the school to do activities. For Donna, these significant events had a lasting positive effect, and survived more impoverished, traditional experiences across the school levels. Despite an overall lack of exposure to engineering, these early encounters, coupled with the engineering tasks witnessed during the specialism module, were reportedly so positive that she positions engineering above everything else, stating that; "I've good memories of engineering, so I do a lot more of it".

Participants' narratives illustrate how their identities have been in formation since early childhood, and how the trajectories of their identity were impacted by different interactions in various contexts (Avraamidou, 2016; Bobis et al., 2021). Despite personal high and low points across both the disciplines and sectors, we witness an alignment of the disciplines, as the lines move closer in proximity to each other at the time of graph completion, coupled with a general upward trajectory as the PSTs look towards their future practice.

8.4.2 Theme 2: "Realistically, without the specialism, I wouldn't have known about STEM". Specialism as a turning point in the development of STEM teacher identity

While aware of the acronym *STEM*, participants reported an unfamiliarity with the concept of STEM education prior to commencing the mathematics specialism. Although each had experience in two or more of the four disciplines since primary school, these experiences represent a siloed approach to either science, technology, engineering or mathematics. For most, the specialism appears to be their first encounter of an integrated STEM approach, as described by Evan;

> I didn't have any [integrated] STEM experiences... I always would have thought before the STEM modules that a task would have to be tailored towards maths or tailored towards science. I didn't think, ever really, about the way they could correlate to one another... or how much you could get out of each discipline in one activity, as we've learned.

Participants recognised integration as a key feature of the specialism; teaching and encouraging the preservice teachers to "see what you can connect" (Shay). There is a sense that this interdisciplinary approach is new for the PSTs, and while they have had experience of thematic (multidisciplinary) planning as part of their undergraduate coursework and professional school placement, integrated STEM is more about the “intertwining of the different disciplines” (Grace).

The specialism, and STEM-related field placement opportunities, are also recognised for their role in the development of new knowledge and skills (such as 21st century competencies), improved methodologies (such as collaborative work and supporting STEM discourse), and new pedagogical approaches (such as problem-based learning). These were seen as “different kind of approaches that hadn’t [been] done in any other kind of lecture” (Donna) and positioned STEM for the PSTs as ‘innovative’, ‘fun’ and ‘exciting’. Recognising the disjuncture between their prior experiences and these promoted STEM pedagogies, and witnessing ‘personal proof’ of the benefits in practice aided the development of ‘pedagogical convictions’ (Rouhotie-Lyhty & Moate, 2016).

The specialism is credited by all participants as the key moment in their engineering education. While they felt prepared in the other STEM disciplines, perceived competence in engineering low:

> We all knew about maths... we had experience with the science and even technology to an extent, but none of us really knew about engineering. We weren’t comfortable, I wasn’t anyway, with engineering at the start. I knew very little about it. I’m a lot more confident with it now. We know about the engineering design process. We know that engineering underpins a lot of STEM tasks... So going out into schools now, I’m definitely more confident through the specialism. (Shay)

Through the specialism, the PSTs appear to have developed a group identity (Feser & Haak, 2023), setting them apart from their peers. This collaborative construct recognises the shared goals for the PSTs and their social group (the specialism group) in working towards becoming integrated STEM practitioners (Rushton et al., 2023). Shay feels that their shared experiences have shaped him, and his peers, as STEM teachers:

> Realistically, without the specialism, I wouldn’t have known about STEM, you know? I’m comparing my friends in college, they’re not as confident with STEM as *we* are because obviously, *we’ve* done the modules.

Shay’s use of the shared “*we*” is echoed by all other participants, who comment on their shared competence and preparedness to teach STEM. While not completely confident ‘yet’, Donna states that she must "feel more confident than a lot of the rest of the year. Anybody who didn't do the module". Evan reports that the specialism has developed his understanding and value of integrated STEM and equipped him with the necessary skills for designing a STEM task, suggesting that "if someone doesn't have any experiences of STEM lessons, it's very hard to jump in and put the time and effort into them as a teacher". By undertaking the specialism, therefore, they feel "prepared for the new curriculum" having "experience in coding, engineering tasks and maths in STEM" (Shay). Through their shared experience, they feel they are in a position to act as STEM champions (GOI, 2016) and advocate for high quality STEM education in their future schools. It is suggested that the PSTs would be "more confident than many experienced teachers" (Shay) in relation to STEM, and "have insights that previous teachers wouldn't" (Grace). Aoife and Evan speak with conviction about their perceived STEM capabilities, and the role they wish to play in promoting STEM.

> I have all this knowledge, so why wouldn't I do it? I've learned all this in college. So for me not to go out and do that, then that's just a waste of [my] knowledge. (Aoife)

> ...And not just the students, I'd probably be hoping to try and influence some of the teachers maybe. Maybe if I could throw [them] a few tips and tricks like I probably will. (Evan)

While this may be viewed as a limited, self-reported, future intention, Sfard and Prusak (2005) remind us that "as implied by the common wisdom that 'success begets success and failure begets failure', stories of victories and losses have a particular tendency toward self-perpetuation" (p.17). Indeed it is only when teachers are seen by themselves and others as integrated STEM teachers, that STEM teaching practices can be sustained (El Nagdi et al., 2018; Galanti & Holincheck, 2022).

8.4.3 Theme 3: "It just calls my name somehow". Aligning critical components of STEM with personal STEM experiences and teaching values

From stories of their formative experiences (both high points and low points) as identified in their story-lines, and from their narratives through interview, it became evident that the PSTs aligned certain STEM features quite closely with their own values. For Donna and Shay, these connections related to specific disciplines. Shay, who had experienced success with mathematics throughout his education, confessed to having a "maths bias", and spoke passionately about the importance of mathematics "being at the core of STEM". Meanwhile, Donna, who reports very early, positive experiences of engineering, felt that STEM tasks have to be engineering-based as "it's the engineering that makes them kind of different". Donna feels more comfortable in viewing STEM in this way, as she "has good memories" of engineering. She also has confidence in the discipline, compared to her apprehension around teaching some elements of mathematics, particularly number:

> I don't see that I'm bad at it [engineering] or I haven't experienced any weak side, so I don't really have a negative side towards that. Whereas maths, I know there's stuff I don't like... Even though I'm probably better at maths.

Donna's memories echo the work of Miller and Shifflet (2016) who argue that school experiences have a profound influence on future teaching and learning, referring to the positive memories and 'ghosts' that adults carry with them and apply to the next generation.

Others highlighted key components of STEM education that related to their learning preferences and teaching philosophies. For Evan, the focus was on inquiry-based learning, spurred by his enjoyment of this at second and third level, with the noted absence of such approaches in primary school. He states that his motivation for teaching STEM is the development of 21st century competencies, promoting creativity, decision making, problem-solving and especially communication, which he sees as a need in primary education. Aoife and Grace valued the role of a real-world context or problem in STEM. Grace felt that the hands-on, real-world problems of STEM education sit well with her "core values as a teacher" which are constructivist in nature. Drawing on positive learning experiences during second level mathematics, that were centred around understanding, developing curricular links and providing context, Aoife associated integrated STEM with sense-making, encouraging children to make links between the subjects and links to the real world;

> Like you go out and see a tree, that's science, and then the angle of the tree to the ground, you know, it all just links in the world, so why wouldn't you do it in the classroom.

The PSTs were critical, overall, of the limited STEM activities they had witnessed in schools. Although they are motivated to teach STEM because it is enjoyable for students, there was a consensus that STEM needs to be *more* than just fun. They called for purposeful tasks, with clear learning goals, that are “more than just building something” (Shay). Participants refer to the need for integrated STEM tasks to fulfil curriculum objectives in respective core disciplines (e.g. mathematics and science), highlighting the importance of “going to the curriculum see what we can add in here, or what learning objectives are they [the children] going to achieve from doing this task?” (Shay). Participants also advocate for maintaining a balance between disciplinary and interdisciplinary work. Two of the participants had developed understandings of where they position STEM in their planning, suggesting that STEM units could link disciplinary and interdisciplinary lessons, by perhaps using it as an assessment piece in which students would apply disciplinary knowledge in new ways (Shay), or as a consolidation activity or a “tool to drive home learning” (Grace). By actively drawing on experiences, choosing them as meaningful and aligning these new STEM pedagogies to their existing expectations and values as a teacher, the PSTs exerted what Ruohotie-Lyhty (2018) calls *identity-agency*. In doing so, they found a constructive balance between their own aims, and the demands of STEM education, in turn authoring their STEM teacher identities (Ruohotie-Lyhty, 2018).

8.4.4 Theme 4: “I didn’t consider it ‘STEM’...I only thought of it the other day. I nearly forgot I’d done it”. Reflecting, rediscovering, and reevaluating STEM experiences through STEM identity graphing

Initially, the story-line approach (Beijaard et al., 1999; Bobis et al., 2021; Conway, 2001) was chosen as a reflective exercise to look back at participants’ STEM learning, and as a tool to capture key moments along this STEM journey. An unanticipated finding was the role the activity played in unearthing hidden STEM experiences. The process not only prompted participants to reflect, but triggered a re-discovery and re-evaluation of their experiences, with the benefit of increased knowledge for teaching STEM.

Perhaps the most discernible example was the uncovering of PSTs’ former engineering experiences. All participants reportedly struggled with the idea of engineering and claimed to have little to no experience of engineering at the beginning of the specialism (Fitzpatrick & Leavy, forthcoming). However, on reflection, they realised this was not entirely accurate. In fact, three participants studied *Technical Graphics (TG), Design and Communication Graphics (DCG),* and/or *Construction Studies* at second level, each holding the subjects in high regard. Aoife recognised her link with engineering during the graphing activity, while Evan and Shay state that they only realised it during the interview;

> Engineering? Yeah, reflecting back on it now, possibly started in secondary school… Ya, I suppose now that I'm thinking of it, we did it in secondary school. We had to do a project in construction studies... I did a construction model of a listed building...and you'd have to do things and then do them again cause they didn't work. So there's the redesign and the engineering design process. So yeah, I suppose really I should move that back to secondary. (Shay)

When asked if they considered this engineering prior to the specialism, there was a resounding "no".

> No, never. I never thought about it once. Literally just when I was reflecting on that... I nearly forgot I'd done it. (Evan)
>
> I didn't realise it was [STEM related]. I was like, oh that's TG, that DCG. Now, I think it is [STEM]… because you're designing with technology. The technology's CAD, yeah? And then engineering, you'd have to create something from a prototype. And the maths is just so intertwined into that. There was a lot of maths in that... So I suppose, behind it all I did actually have that experience before, but I never thought of it, which is weird. (Aoife)

Shay and Aoife both indicate that it was "never distinctly said to [them]" (Aoife) that such subjects were engineering based. "They didn't say 'we're doing engineering', but realistically there was engineering integrated in there" (Shay). The connections made through this reflective exercise were not lost on the participants themselves, with Aoife proposing that;

> I think it's even good doing this and like reflecting, because if I didn't do this, then I wouldn't have thought about those things. I've had the experiences in secondary school with STEM already. You know, so it's good to reflect in that way...I didn't even realise I was doing STEM back then, and then that's probably sparked the interest in it now... I don't think I'd have made the links myself.

Another notable outcome was the opportunity to re-evaluate previously taken for granted experiences, with a new, more knowledgeable lens. When speaking about particularly positive school experiences, Shay offers critiques of these same experiences through the eyes of a teacher. He notes that many approaches to mathematics, for example, although they may have suited him, may not have suited everyone. While Shay excelled at mathematics and managed well with traditional approaches, he now wonders how others in his class experienced it. He suggests that some must have struggled, raising his consciousness of the need for a variety of approaches and differentiation in his classroom as a teacher;

> In my piece [graph narrative] I mentioned that I felt I was good at maths... I enjoyed working things out or working towards an answer ... it was positive for me. Now, I'm looking back at my class and I'm thinking, people who found maths hard, you know, they must have hated maths time... looking back with my teacher eyes now... I don't know were the scaffolds there to help them. So it was achievable for me, but now as a teacher, I'm looking back, would others have that same perception? Maybe not. (Shay)

Reflection through graphing and storytelling provided participants the opportunity to interrogate the nature and quality of their prior experiences as learners using a new lens, thereby exemplifying an awareness of limitations in their earlier conceptualisations of STEM. These refection tools, therefore, offered participants new perspectives on the past (Kaasila, 2007). This is central to the development of participants' STEM *teacher selves* (Freese, 2006), as it is not the experiences themselves, but our *vision* of our own and other people's experiences that constitutes identities (Sfard & Prusak, 2005). Graphing and telling their narratives provided "historical signposts for meaningful encounters" which served as "important anchor points within the ongoing negotiation as participants re-narrated their relation with past events in the light of new experiences, in turn providing a means to re-envisage the future" (Ruohotie-Lyhty & Moate, 2016, p. 326).

8.4.5 Theme 5: "I want to be known as the teacher who does STEM". Future ready, but with cautious optimism.

All PSTs had a clear view of the type of STEM teacher they want to be in the future. They each refer to being creative and innovative, wanting to put what they have learned into action and "use it, not just know it's there" (Grace). Moreover, they want to be seen by others as 'the innovative guy', 'the creative fella', 'interactive', 'fun' and 'modern', someone who 'integrates' the disciplines and 'isn't afraid of a messy classroom'.

> I hope I have the confidence to experiment with my class and use inquiry-based learning. I don't want to fall into the cycle of teaching from the book all the time as it can be so boring and unmotivating. I hope I am known as a teacher who uses the STEM approach. (Aoife)

However, there are associated fears. While Aoife wants to be known as "the teacher who does STEM", viewing it as "brave and bold because no one else is doing it", she fears that others might see her as "not having control in the classroom". Although many of these concerns could be considered general concerns of a newly qualified teacher (such as planning and classroom management), others are STEM specific and relate to curriculum fit and timetabling issues, with some citing challenges of integrating non-subject disciplines such as engineering.

Participants also appear mindful of unforeseen challenges. Although Grace suggests that she "would be fairly autonomous" in her own classroom and confident that she could stand over her use of STEM, she worries that she doesn't "know yet about the running of a school". These sentiments are echoed by Aoife, who is worried about 'rocking the boat' as a newly qualified teacher;

> I think going out as a new teacher...you're supposed to, you know, just stay to the side and … don't be doing anything that will draw attention to you...But I don't want to do that, I don't want to assimilate into whatever.

Interestingly, Aoife had previously spoken about her difficulties in early professional placements, and how she abandoned her beliefs around the importance of developing understanding and active learning, as she had a fear of failure. Here we see a similar conflict between beliefs, value and enactment emerging again. While Aoife "hopes to have the confidence" to utilise STEM, she senses that in reality, this may be a challenge for her. The identification of challenges is an important aspect of future-oriented reflective discourse, providing a platform for teachers to voice their concerns. Muchnik-Rozanov and Tsybulsky (2021) also found that the PSTs in their study had similar concerns around meeting their own expectations and overcoming challenges. They suggest that such concerns "stemmed from the students' 'trying on' an identity of an ideal teacher and evaluating prospective difficulties they may encounter" (p. 317), thus highlighting their realistic understanding of what it means to be a STEM teacher and how their STEM teacher identity is emerging.

While overall self-reported STEM efficacy appears high, there is a recognition amongst the PSTs that becoming a STEM teacher is a process.

> I'm not *not* confident, if that makes sense. But I wouldn't say I'm super confident yet. But I feel like I'll feel a lot better say, this time next year, because I want to bring it into my classroom. (Donna)

While they feel more prepared than others, as outlined previously, there is a strong sense from all participants that it "will take time to find [their] feet" (Grace) and that they "need more practice" (Evan). Reflecting on their future selves allowed for reflection on their 'ideal identity', who they would like to become as teachers (Beauchamp & Thomas, 2010; Lauriala & Kekkonen, 2005), allowing them to move towards a positive vision of their future practice, with the intention of improving or change their current practice (Muchnik-Rozanov & Tsybulsky, 2021). Indeed, as "behaviour is cued by experience of discrepancy between one's current and planned outcomes" (Oyserman & James, 2009, p. 375), the recognition of this gap between PSTs' actual and possible identities is a necessary condition for identity development (Lutovac & Kaasila, 2019). Importantly, while they view *becoming* a STEM teacher as a process, their future identities described are proximal (usually within a year). Thus, the PSTs are perceiving their future self as connected to their current self and present action, which may cue identity-based motivational striving (Oyserman & James, 2011). In this way,

> The present can be seen as connecting fluidly to the future, and as such, as a time for setting the groundwork for what will become possible in the future. When the future begins now, current action is immediately necessary (Oyserman & James, 2011, p. 129).

Some PSTs reported that this practice has already begun. For example, Donna, who had taught a lesson of designing and building an earthquake resistant building, reported improvements in her STEM practice with more opportunities for classroom implementation. She believes that each time she teaches it, she "gets a bit better, a bit more clever about how to go about it. You tweak the lesson... use different [materials] or change the criteria". Shay and Aoife suggest that this comfort with "learning while doing" (Shay) stems from their STEM-related field experience during the specialism, in particular the emphasis placed on reflection and discussion of possible modifications in light of observations of the children's responses. Such dispositions are necessary to meet the demand for well-prepared STEM teachers, described by El Nagdi et al. (2018) as those who align their personal teaching philosophies to STEM requirements, acting as ongoing learners and problem- solvers, who see failure as an opportunity for learning, and are flexible and open to change.

In acknowledging that STEM is a nascent field, and that becoming a STEM teacher is a process, the PSTs appear comfortable with their own position on that continuum. For each of the PSTs on this journey, the future seems bright. They are optimistic about improving their own practice, and supporting the STEM learning of the children they will teach in the next year, while others, such as Shay, have set longer term goals, pointing to their potential for STEM leadership in the future;

> It's there. It's going to be part of the 2023 school year, and we're coming out with experience... We've just studied that for the last two years. So we're coming out with an advantage really... If a post came up for STEM in five years or whatever, I suppose I'd be kind of confident that I'd be able to lead a school in STEM. (Shay)

8.5 Conclusion

Integrated STEM education is fast becoming a core element of our Irish primary school curriculum. We are, in turn, compelled to reconsider how PSTs are prepared to implement such approaches in the classroom. A deficit discourse often exists around primary teachers' STEM knowledge (Galanti & Holincheck, 2022). As non-specialists, primary teachers are reported to lack the necessary efficacy and confidence to implement integrated STEM (Nadelson et al., 2013). This study, however, reveals the powerful impact of a STEM-focused specialism on preservice teachers' STEM development. It outlines the critical role played by *integrated* STEM learning and teaching experiences in leveraging key STEM literacies, beyond what can be achieved through disciplinary STEM experiences alone.

Using identity as a lens for teacher preparation illuminates the processes through which teachers learn and develop (Avraamidou, 2014; Luehmann, 2007). Participants' own experiences of the STEM disciplines in school contributed to their pedagogic perceptions and played a central role as they negotiated their emerging STEM teacher identities (Arvaja & Sarja, 2021; Flores & Day, 2006; Miller & Shifflet, 2016). By identifying what worked for them, and what did not, they recognised discrepancies between their experiences and the type of STEM teacher they want to be. Yet, despite the range of experiences of each participant throughout their own education and the varying comfort associated with each discipline, the specialism was seen as a turning point. It narrowed the comfort gaps between the disciplines by developing STEM knowledge, skills and competencies. The modules enriched their understanding of integration by providing opportunities to engage in STEM learning and STEM teaching experiences. Presenting opportunities for participatory experiences, rather than authoritative impositions, the specialism offered a persuasive ‘voice’ in the many ‘voices’ present when negotiating *who I am*, and *what kind of teacher do I want to be* (Ruohotie-Lyhty & Moate, 2016, p. 325). The specialism group acted as a community of practice, in which PSTs could safely co-navigate these new STEM experiences, all the while making sense of past and present experiences, in terms of the STEM teachers they want to be (Beijaard et al., 2022).

Preservice teachers develop their teacher identity as they interpret and reinterpret their experiences through reflective processes (Muchnik-Rozanov & Tsybulsky, 2019; Sutherland et al., 2010). Graphing and narrating *STEM story-lines* proved powerful sensemaking tools to re-examine the past with a fresh perspective in light of new experiences and increased STEM competencies. Buried memories and hidden STEM experiences were revealed to the preservice teachers, while previously accepted assumptions were reviewed through their emerging *teacher selves*. As Conway (2001) reminds us, however, reflection is not just about looking back. It is about “looking toward the future, with knowledge of the past, from the viewpoint of the present” (p. 90). Future oriented identities were strong, and although participants viewed becoming a STEM teacher as a process (a view in line with the theoretical underpinnings of teacher identity) they appeared confident in their ability to drive STEM in their future classrooms.

We must remain mindful, however, of some limitations in this study. While specific qualitative methods were chosen to generate the thick descriptions necessary for unpacking such a complex phenomenon as teacher identity (Hong & Cross Francis, 2020), the small sample size from one cohort of preservice teachers favours in-depth understandings over empirical generalisations (Patton, 2002). Exploring STEM teacher identity with a larger cohort of PSTs, thereby increasing generalisability, warrants further study. Also, despite the evident fervour for STEM amongst the participants in the study, Hong et al. (2017) remind us of the importance of moving "beyond the snapshot approach" and consider the longer-term perspective in relation to identity development (p. 95). It would be of interest, therefore, to follow up with participants into their early career, to consider how their STEM teacher identity is negotiated beyond the transition from ITE.

8.6 Declarations

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8.7 Chapter conclusion

This chapter reports on the emerging STEM teacher identity of five PSTs pre-graduation. It contributes to the field by offering STEM story-lines as an innovative approach to support STEM teacher identity work. By providing a space for retrospective reflection, it unveiled forgotten memories and unearthed unrealised experiences. By reflecting on their future, they envisioned their ideal teacher-selves and set out a path to achieve this. Regardless of prior disciplinary experiences, the specialism was recognised as a key turning point, particularly in relation to engineering and integrated approaches, and PSTs set themselves apart from their peers in terms of readiness to teach integrated STEM. This lies in stark contrast to the low confidence to teach STEM on entering the specialism, as highlighted in Chapter 4. Given that integrated STEM education is soon to become a curriculum mandate, this paper demonstrates the necessity for *all* PSTs to engage in integrated STEM education during ITE.

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Chapter 9

Discussion and conclusion

9.1 Introduction

The purpose of this dissertation was two-fold. Firstly, it sought to examine the evolving understandings and STEM teacher identities of primary PSTs undertaking STEM specialisms as part of their undergraduate studies. Secondly, it set out to identify characteristics of effective learning experiences that contribute to developing STEM-literate PSTs. Examining these experiences through an action inquiry lens resulted in an emergent focus on mathematics within integrated STEM tasks. The dissertation begins by setting out the current STEM policy landscape in Ireland and outlining the imminent changes in the primary curriculum. In doing so, Chapter 1 sets the research in context and lays out the objectives of each chapter's study. Chapter 2 synthesises the literature on integrated STEM education, while Chapter 3 offers an overview of the dissertation's methodological considerations.

Chapters 4 and 5 follow PSTs from *Cohort 1*, as they navigate this new area of teaching and learning. By journeying with them from the lecture room to the primary school classroom, we get an insight into the evolution of their conceptualisations of integrated STEM and witness a growing confidence in their ability to implement STEM as they bridge the theory-practice divide. However, as alluded to in Chapter 4, disciplinary confidences were traded over the course of the intervention, with new concerns being raised around the integration of mathematics in STEM classroom practice. This issue is the focus of Chapter 5. Taking a critical lens to the design and delivery of integrated STEM workshops with a local fifth class, this chapter explores the difficulty experienced by the PSTs in recognising opportunities for authentic mathematics teaching and learning within integrated STEM tasks, and discusses the possible causes of and potential solutions to this problem.

Chapters 6 and 7 introduce a new cohort of PSTs (*Cohort 2*) undertaking the same module the subsequent academic year. Seeking to capitalise on the learnings from *Cohort 1*, the revised module positions mathematics as the central discipline in an integrated STEM unit. Rooted in the sustainability context of the plight of the honeybee, Chapter 6 examines the roles of digital technology in supporting the statistical understanding of Emerging Bilingual Learners when engaging in a STEM inquiry. Using lesson study as a guiding framework, this study reports on PSTs' observations of children's conceptual understanding of big statistical ideas at primary level that was supported by the incorporation of inclusive pedagogies and the use of data analysis technologies. PSTs also noted the role of digital technologies in highlighting the relevance of statistics in understanding societal issues and in developing students' statistical agency. Chapter 7 focuses on PSTs' own attitudes towards statistics. PSTs report positive attitudinal change, citing the societally-relevant STEM context, the use of large local datasets supported through the use of conveyance and math action technology, as well as the collaborative and practical nature of the intervention, as influential factors.

Chapter 8 returns to the PSTs in *Cohort 1*. Having completed a STEM-focused, mathematics education specialism over two years, PSTs reflected on their emerging STEM teacher identities. Using *STEM story-lines* as an innovative graphing tool, PSTs took a retrospective view of prior experiences and anticipated their future teacher selves, as they negotiated becoming integrated STEM teachers.

This current chapter provides a critical synthesis of the overall findings of this study. It discusses the contribution of this study to the existing knowledge base and outlines the strengths and limitations of the study. This chapter also offers the study's implications for policy and practice and suggests directions for future research.

9.2 Contributions to evidence base

9.2.1 Purposefully designed, interdisciplinary STEM education experiences at ITE level can create informed, confident STEM teachers ready to take on new integrated teaching roles

Over the past year, we have witnessed a fast-paced shift in the primary curriculum landscape. The sector is moving towards a more integrated curriculum with broad curricular areas, as set out in the Primary Curriculum Framework (NCCA, 2023a). The Framework seeks to prepare our young children to "navigate a wide variety of contexts and situations... to interact and engage with the natural world around them and come to appreciate its value and their responsibilities as custodians of it" (2023, p. 8). STEM education has been positioned as one of the five broad curriculum areas, recognising the central role that integrated STEM can play in developing the essential skills, knowledge and dispositions needed both personally and professionally in the 21st century (Falloon et al., 2020; Leavy et al., 2023b), such as those espoused in the key competencies outlined in the Framework.

Yet, as we move towards this hopeful and integrated space, we must remain mindful that STEM education is still a nascent field (English, 2016; Goos, 2023). While the affordances and challenges of integrated STEM education have been laid out in the literature, we still have much to learn about how to promote authentic STEM learning in the classroom and support and prepare our teachers for the challenges it brings. Responding to the call from Corp et al. (2020), this study contributes to the field by identifying effective characteristics of course experiences that contribute to the development of STEM-literate PSTs. The experiences of two groups of PSTs are reported in this study. Chapters 4 and 5 report on key learning activities that influence *Cohort 1*'s evolving understandings of STEM across a 12-week integrated STEM elective module, while Chapter 8 takes a wider lens to experiences that contribute to their evolving teacher identities over the course of a STEM-focused specialism. Chapters 6 and 7 examine the impact of an 11-week STEM-focused Lesson Study intervention on the understandings and attitudes of *Cohort 2.*

Findings from both cohorts reveal more profound, critical understandings of STEM and STEM pedagogies. Central to this were opportunities provided to engage in activities as both STEM learners and STEM teachers. Findings reveal that integrated approaches were new to the PSTs, with most experiences of the disciplines to date, both at the school and ITE level, being predominantly siloed. PSTs also reported limited and impoverished experiences in their own STEM school learning, with many noting an absence of inquiry-based learning (Chapters 4 and 8) with an overreliance on the textbook (Chapters 4, 7 and 8), and a lack of connection to the real world (Chapters 7 and 8). Opportunities to engage in rich integrated tasks (Chapter 4), investigate local and societally relevant real-world problems and utilise innovative technologies (Chapter 7) as STEM learners supported the PSTs in identifying the natural links between the disciplines and develop their own STEM knowledge, skills and dispositions. Furthermore, engaging as STEM learners exposed them to the rich and ambitious pedagogies they would be expected to utilise in the classroom (Lesseig et al. 2016).

Built-in access to field practice provided the PSTs with an opportunity to apply this new knowledge, skills and dispositions in authentic settings. By witnessing this pedagogy in action, PSTs could observe first-hand how ambitious learning objectives play out in real time, authenticating the value of STEM for them. They were struck by the children's ability to complete complex designs, utilise 21st century skills (Chapters 4 and 5), and engage in challenging, higher order tasks, including advanced statistical reasoning (Chapters 6 and 7). It provided a safe space for PSTs to practice and develop their own content and pedagogical knowledge, make sense of new approaches and assume new roles as facilitators of STEM (DiFrancesca et al., 2014).

What is also evident across the findings, however, is that these specific integrated approaches to teacher education are essential. While some gaps in knowledge were to be expected (e.g. new content introduced for the first time, such as engineering practices), PSTs had difficulty in making explicit links between the knowledge and skills developed separately in discrete discipline education modules (as evident in Chapters 4, 5 and 8). Although PSTs from both cohorts had completed all compulsory mathematics, science and ICT modules before beginning elective modules, their disciplinary knowledge remained inert and they displayed significant difficulties in applying such knowledge in integrated settings. However, the interventions' integrated approach appeared to activate this inert knowledge, by spotlighting and exemplifying the opportunities for interdisciplinary connections. Furthermore, by making links explicit through a real-world context and driving STEM problem (such as colony collapse and the local honeybee in Chapters 6 and 7) not only did we observe an appreciation for the ties between the disciplines, but we can see a furthering of perceived competence and more positive attitudes towards individual disciplines.

Moreover, it is evident that PSTs themselves recognised the benefit of the interventions. PSTs in Chapter 8 set themselves apart from their peers in terms of 'readiness' for upcoming curricular change, and we see evidence of a group identity emerging (Feser & Haak, 2023) as they begin to recognise themselves and each other as 'STEM teachers' (El Nagdi et al., 2018; Galanti & Holincheck, 2022). They view themselves as STEM champions, ready to meet the demands of integrated STEM education as it unfolds through the new curriculum. This starkly contrasts the low levels of confidence reported for STEM teaching on entering the specialism (Chapter 4).

Therefore, this study sets a mandate for introducing integrated approaches for all PSTs during ITE. While it supports the case for maintaining a discrete disciplinary focus, it highlights the fundamental need to support PSTs in both identifying opportunities for meaningful integration, and in designing rich interdisciplinary learning experiences for students that meet the aims of our new curriculum and prepare our young children for 21st century life. It also contributes empirical evidence on the characteristics of effective learning experiences that contribute to the development of STEM teachers, thus providing recommendations for teacher educators and policy developers.

9.2.2 The role of collaborative journeying in developing STEM identity

Collaboration was a central theme in each of the studies. Collaborative experiences were structurally embedded in both module designs and also emerged as a powerful theme in the research findings. Both interventions were centred around collaborative experiences. PSTs in Chapter 7 credited the collaborative planning and teaching involved in Lesson Study with increased subject content and pedagogical content knowledge. For PSTs who were not confident in their knowledge of statistics, collaborating and sharing with peers introduced them to new ways of thinking about concepts that supported their development of conceptual understanding. Whereas for those who reported high confidence in their statistical content knowledge, hearing the struggles of others, and thinking about new ways to make content more accessible to all, built on their pedagogical content knowledge for statistics.

In Chapter 4, PSTs recognised the contribution of others in the development of richer, more critical understandings of STEM. As STEM learners, the PSTs initially struggled with group work during in-class design tasks, highlighting the soft skills needed to complete such activities, and pointing to the potential difficulties they may encounter in the classroom when facilitating such tasks with children. Communicating and collaborating with peers and their teacher educators during field preparation and practice gave them the support needed as they delved into the new role of STEM teacher, while post-teach discussions allowed for group reflection, leading to more comprehensive and critical understandings of STEM. In doing so, it mirrored the work of a community of practice (Lave & Wenger, 1991) and initiated an interest in collaborative inquiry. The feeling of collaborative journeying is reflected again in Chapter 8. PSTs in this study describe their collaborative experiences with a shared *'we',* and outline common goals for their specialism ‘social group’. Collaboration, therefore, appears to have aided the formation of a group identity (Feser & Haak, 2023; Rushton et al., 2023) as PSTs travel the road to becoming STEM teachers.

9.2.3 Positioning mathematics within integrated STEM

Initially, this study set out to examine the evolving understanding of integrated STEM education amongst a single cohort of PSTs undertaking a mathematics specialism. However, as outlined in Chapters 4 and 5, incorporating mathematics into integrated STEM lessons proved to be a real challenge for both the PSTs and the researcher, and one which steered the focus of this PhD study in a new but related direction.

The challenge of boundary crossing and maintaining disciplinary balance has been noted in the literature (English, 2016, 2017; Walker, 2017). Despite being positioned as the underpinning discipline, mathematics has been identified as underrepresented in STEM education (Fitzallen, 2015; Martín-Páez et al., 2019), often succumbing to the pressure of other disciplines and playing a service role in STEM tasks (Forde et al., 2023; Tytler et al., 2019). This study supports the findings of these previous studies and contributes to the field by serving as an example of the difficulties encountered in attempting to meaningfully integrate mathematics in STEM tasks and by investigating approaches to spotlighting mathematics within integrated STEM.

As noted in Chapter 4, PSTs participating in the study had, for the most part, positive experiences and success in their mathematics education modules, and had chosen to enrol in a mathematics specialism. PSTs, therefore, came into the module with confidence in their abilities as mathematics learners and teachers. As the teacher educator, I made assumptions about the ease with which the PSTs would apply the disciplinary knowledge and skills developed in their discrete disciplinary modules, to more integrated settings. By placing an emphasis on engineering design and practices (the discipline that PSTs were least familiar with, and reported least confidence in), I shifted my gaze from mathematics and failed to sufficiently support the PSTs in identifying meaningful opportunities for rich mathematics teaching and learning. This resulted in shifting disciplinary confidences. PSTs became quite enamoured with the engineering design process and 21st century skills espoused in the module, and by the conclusion of the intervention, their initial low confidence in engineering was reversed, while their confidence in teaching mathematics was called into question.

This became most evident in Chapter 5, which highlights the difficulty the PSTs in *Cohort 1* had in making connections with mathematics during STEM field placement. While it must be noted again at this point that not all integrated STEM lessons need to include mathematics as one of the disciplines, Chapter 5 highlights the misconceptions held by the PSTs around authentic integration, in which the integrity of the discipline is upheld and supported. Their difficulty was two-fold. Firstly, the PSTs failed to recognise the lack of appropriate mathematics learning within the integrated STEM task. They perceived lower order, incidental mathematical *activities* (which were far below the children's grade level) as mathematics integration. Subsequently, when this was pointed out and acknowledged, PSTs then had immense difficulty in recognising opportunities for meaningful integration of mathematics within the tasks taught, and required much scaffolding, through careful prompting and probing from the teacher educators to identify suitable inclusions. Chapter 5, therefore, contributes to the field, by providing planning prompts and a series of guided questions to support PSTs, and indeed novice teachers, in incorporating appropriate and meaningful mathematics into integrated STEM lessons and STEM inquiry cycles, i.e. to *Math*ify STEM.

Chapters 6 and 7, turn this idea of *Math*ifying a STEM lesson on its head and instead seeks to *STEM*ify mathematics. Responsive to the shortcomings of the initial intervention, Chapters 6 and 7 describe a statistical inquiry unit centred around a STEM problem in a sustainability context with PSTs in *Cohort 2.* Situated in the study of local honeybee data, statistics is the central discipline and the starting point in planning the STEM unit. With one eye firmly on the data at all times, PSTs were supported in creating a STEM inquiry around a societally relevant dataset. As outlined below, the authentic real-world problem drove the statistical analysis and engaged the students in age-appropriate, challenging statistical reasoning. Furthermore, close links and interdependence between the disciplines of science, technology and mathematics were evident. The science content provided the necessary background information needed to engage meaningfully with the data, by developing an understanding of the plight of the honeybee and highlighting the characteristics of a healthy beehive. Subsequent data analysis raised further scientific questions to be investigated by both PSTs and the children, questions such as, "what else might affect the rate of wing batting [and in turn, the production of sound] other than temperature?". Meanwhile, technology fostered interest in, and supported analysis of the data, while the data itself raised interest in the innovative technologies that captured it. This study adds to the field by offering an innovative example of mathematics-centred STEM, that promotes rich disciplinary learning, while also advancing other STEM literacies. Given that much of the literature on STEM classroom innovation comes from the field of science (English, 2016; Forde et al., 2023), evidence of classroom initiatives foregrounding mathematics in integrated STEM is greatly needed.

This dissertation, therefore, points to the ease with which mathematics can become lost in STEM, supporting Shaughnessy's caution of spotlighting the mathematics in STEM 'otherwise the M in STEM is silent' (2013, p. 324). When mathematics is accepted as the *underpinning* discipline in STEM, there is a danger of it being taken for granted, thus assuming a supporting role for science, technology, or engineering learning goals (Fitzallen, 2015). Despite having the support of at least three mathematics teacher educators, mathematically confident specialism students struggled to identify and design for meaningful mathematics experiences within integrated design tasks. Chapters 4 and 5 highlight that (while important) strong disciplinary knowledge alone is not enough for integrated STEM, calling for disciplinary balance and the careful positioning of mathematics within an integrated inquiry unit. Chapters 6 and 7 offer an example of a STEM unit that uses mathematics (statistics) as its starting point. Positioning statistics front and centre in the design of a STEM inquiry cycle upheld the integrity of the mathematics teaching and learning within STEM while also espousing STEM objectives. Given that the data set itself was the piece that tied the S-T and M together, it highlights the powerful role of statistics in driving STEM inquiry. While Chapter 5 identifies the difficulty of maintaining appropriate learning (beyond the service role) in other mathematics strands (such as measures, shape and space and number), the role of data and statistics education in Chapters 6 and 7 (re)positions mathematics in STEM as meaningful, challenging work, that is central to the overall project. This situates statistics as a fertile space for meaningful integration in STEM education.

9.2.4 The dynamic nature of STEM education: a challenge for all

The iterative features of the current study highlight the dynamic nature of STEM education. As noted earlier, STEM education is an embryonic field of research. The literature points to the many conceptualisations of STEM and integrated STEM, its accompanying frameworks and levels of integration. Breiner et al. (2012) argue that given the range of stakeholders in STEM education, an operational definition would not only be difficult but could also work against each STEM initiative's strengths. In a 2019 follow up editorial reflecting on that same study it would appear that little had changed, with Johnson (2019) stating that 'when we know what STEM is, it will be easy to enable change and be innovative in creating our future' (p. 368). This study also highlights the difficulty of conceptualising STEM, and like Breiner and colleagues (2012), advocates for a focus on shared STEM outcomes.

My own evolving conceptualisation of STEM education influenced the design of the interventions. In Chapters 4 and 5, STEM was conceptualised as integrating two or more disciplines centred around an engineering design task. Given the challenges posed in *Intervention 1* regarding the underrepresention of mathematics, Chapters 6 and 7 positioned mathematics as the primary discipline, with science and technology acting as supporting disciplines. This echoes the work of Tan et al. (2019) who position problem-solving as the overarching process, with complex real-world problems at its core (in this case, the plight of the honeybee and colony collapse disorder). In Tan et al.'s (2019) 'STEM Quartet', the disciplines must work harmoniously together, with one discipline taking the lead at a time, while others provide support.

While these may appear to be very different approaches, they had at their core some common characteristics that tied them. Firstly, both STEM conceptualisations had a shared focus on STEM goals and outcomes as outlined by Honey et al. (2014), in particular the development of STEM literacy, 21st century competencies, interest and engagement in STEM, the ability to transfer understanding across STEM disciplines and the development of STEM identity (in this particular case, STEM teacher identity). Secondly, STEM education in both iterations was centred around *driving questions,* and seeking solutions to real-world problems (Roehrig et al., 2021). In Chapters 4 and 5, driving questions sought engineering solutions, whereas in Chapters 6 and 7, a socio-scientific problem drove statistical analysis and technology use.

Despite these common attributes, however, this study highlights the ‘messiness’ of STEM education. While ill-structured problems may be valuable for learning (Cianca, 2020; Kloser et al., 2018; Smith et al., 2022), STEM’s blurry boundaries and many interpretations complicate the field. In a fast-paced and evolving research space, fuelled by emerging technologies, scientific invention and, indeed, ever-emerging problems, disciplinary lines are becoming more obscured, and the parameters of STEM education are shifting. One area of particular interest in this study relates to that of statistics education. As the proliferation of data in all aspects of our lives positions statistical literacy as a critical skill in today’s society, we need to perhaps consider: *Where does data science fit in the bigger STEM education picture?*

This dissertation also contributes to the field of teacher identity, an already dynamic construct complicated further by the newness and blurriness of STEM. Chapter 8 illustrates that part of the development of a STEM teacher identity is the ability to exist in the liminal space where disciplines blend, merge and shift positions, with individual disciplines being foregrounded at times and moving to the background at other times. Dealing with this constantly shifting landscape also requires being comfortable with the certainty that STEM may always remain undefined and malleable. The draft STE Curriculum Specification recognises primary education as a time of ‘being’ and ‘becoming’, a place where children can develop the appropriate knowledge, skills and dispositions through appropriately challenging experiences to empower them for STEM learning in the years ahead (NCCA, 2024, p.1). In a similar vein, ITE can offer a time of ‘being’ and ‘becoming’, a space for PSTs to *be* and *become* integrated STEM teachers, developing STEM literacy and in turn preparing them for future professional STEM teacher learning.

9.2.5 Authentic and local contexts serve as a catalyst for STEM

This study highlights the importance of utilising *authentic*, real-world problems. While each of the STEM tasks in Chapters 4 and 5 were set in a rich context, it could be argued that the ‘problems’ they posed were either fictional (designing a rollercoaster for Tayto Park) or somewhat removed from the lives of the children (building earthquake resistance buildings).

The driving questions posed concerning the plight of the honeybee (Chapter 5 and 6), were firmly embedded in a relevant sustainability issue. Utilising locally sourced, real-time data prompted optimum engagement by capturing the interest and buy-in of the students who were motivated by an obligation to social responsibility. A focus on local driving questions propelling STEM engagement in the classroom, echoes a quote from Galanti and Holincheck (2022, pp. 2-3),

> With this vision of a dynamic student-centered elementary classroom, STEM becomes more than its component content disciplines or even the intersections of content disciplines. STEM can be the way that teachers and students understand the changing world and its complexity.

Therefore, the driving questions, moulded from real-world problems and illuminated by data practices, advanced authentic STEM learning. Children were invested in the problems, impelling them to draw on disciplinary competencies to seek answers and solutions.

9.2.6 Integrated STEM can serve as an *equaliser,* providing high quality learning experiences for all

A growing body of research within the field aims to support under-represented and minority groups in STEM. Chapter 6 contributes to these studies by providing an example of a classroom initiative aimed at supporting the STEM engagement of Emerging Bilingual (EB) learners. It outlines a series of inclusive features that aid all learners to engage with big statistical ideas and tackle STEM problems. It also highlights the potential of conveyance and math action technologies to support learners in engaging with large authentic data sets. Free-to-use CODAP fostered inclusivity by carrying the procedural load (thus removing the unnecessary procedural and drill work that impedes advancement) and freeing up instructional time to engage in cognitively challenging tasks. Consequently, it opens up here-to-fore unrealised possibilities for young learners to grapple with and actively engage in meaning making about real (adult) world issues and problems. The provision of such tools allows children to participate as knowledge creators and experience what it means to ‘do’ STEM. Integrated STEM activities, such as those enabled by CODAP-supported data practices, armed PSTs with the tools to scaffold learners and accelerate their learning trajectory, facilitating them to engage in the types of thinking and reasoning (e.g. justifying, conjecturing etc.) that were traditionally only accessible to more able learners.

The role of the teacher was also highlighted in enabling EB learners to access appropriate statistical experiences. This supports calls for teachers to maintain a non-deficit view of bilingual learners, and to develop strategies, norms and processes (Ní Ríordáin, 2018; Planas & Setati-Phakeng, 2014) necessary to support all learners in the classroom. Indeed, STEM was recognised as an inclusive activity by both cohorts, who spoke about the potential for each child in the group to bring individual strengths, skills and abilities to the task. PSTs referred to their ‘surprise’ in relation to children’s capabilities across the papers. They shared unexpected observations about children’s resilience and their positive dispositions towards failure, which were fostered by child-led nature of STEM tasks and their multiple solution paths. This supported the creativity of students and the uniqueness of their designs. Indeed, PST observed that the open-ended engineering tasks (Chapters 4 and 5), supported EB learners to showcase their understanding through working on and producing a physical prototype (Suh et al., 2020). PSTs remarked on children’s responses and their potential for deep reasoning and critical thinking, connecting such skills with children’s deep engagement in the STEM context. Some PSTs were surprised that primary school children would develop such skills and competencies at this age, as this was something they had previously associated with post-primary education. Thus, STEM was viewed as a vehicle for driving engagement, inclusion and higher order thinking.

9.2.7 Formative assessment tools in STEM teacher education

The paucity of research on teachers and teaching in STEM (Li & Anderson, 2020; Margot & Kettler, 2019) and the call for more research into effective integrated STEM education for primary PSTs, raises other questions in relation to how we assess their development during such initiatives. As discussed in Chapter 2, the assessment of integrated STEM at all levels is an ongoing challenge in the field (Fang & Hsu, 2019; Gao et al., 2020; Roehrig et al., 2021). A key contribution of this dissertation is the development of two assessment tools. Chapter 4 describes a pre-/post- intervention *STEM Task Analysis* activity. The task analysis documents allowed for the examination of changes in the PSTs’ understandings and conceptualisations of STEM education. It also revealed changes in their

STEM knowledge. While PSTs' disciplinary STEM knowledge is assessed in during discrete subject education modules as part of their undergraduate programme (i.e. mathematics education, ICT/digital technologies education), the pre/post- task analysis activity captured their ability to apply this knowledge in integrated practice. It highlighted PSTs' ability to design meaningful integrated STEM tasks, by comparing pre-/post- intervention task modifications, as well as the PSTs' justifications for their modifications. The pre-test provided data to benchmark, while the post-test data revealed their knowledge development and the evolution of their understandings. During intial task modifications in Week 1, PSTs generally added 'more' mathematics to the lesson, or 'extended' the science within the task. However, when drawing from the literature on high-quality STEM education, it was evident that the PSTs did little to enhance the 'STEM' nature of the task. Post-intervention modifications however, incorporated many features of the published STEM frameworks examined throughout the intervention, such as setting the task in a real-world context and incorporating an inquiry-based approach to the problem. PSTs were also more critical of the STEM nature of the task, suggesting in the post- intervention data that they no longer agreed that this task involved engineering, as the build was prescriptive and did not allow children to engage in design thinking or the engineering design process. Furthermore, the STEM task analysis activity provided the PSTs themselves with a self-assessment tool by affording them the opportunity to reflect on their changing conceptualisations, knowledge and skills, and to identify key learning events that triggered such changes.

Chapter 8 offers *STEM story-lines* as both a data generating tool and a self-assessment activity for the PSTs. Adapting an existing approach proved successful in capturing STEM journeys and supporting the identity work of the PSTs in *Cohort 1.* Furthermore, by highlighting the ups, downs and turning points across each of the STEM disciplines and reflecting on the experiences and interactions associated with each, the PSTs recognised their own dynamic relationships with the disciplines across time, revealing to them that becoming a STEM teacher is a process. By anticipating their future selves, PSTs were prompted to create an image of their *ideal* teacher self, thus setting a target to work towards.

9.3 Strengths and limitations

Limitations have been outlined in sections 6.7, 7.6 and 8.5. While the small sample size in individual papers may be regarded as a limitation of each study, the examination of two separate cohorts of PSTs across multiple modules adds to the strength of this dissertation's research. The iterative nature of the design allowed us to be responsive. The issues and concerns raised in Chapters 4 and 5 (*Cohort 1*) were used to inform the design of the intervention in Chapters 6 and 7 (*Cohort 2*), while retaining successful features of the initial design.

In addition to the limitations noted in previous chapters, it could be argued that the relatively homogenous nature of both groups (Year 3 and Year 4 mathematics education specialism PSTs from the same institution) limits the findings. It should also be noted however, that as the PSTs were all mathematics specialism students, who opted-in to each module, they largely represented a cohort of students with high confidence in mathematics, both in terms of content knowledge and pedagogical content knowledge. Most self-identified as strong mathematics educators. Therefore, the problems that we encountered, as outlined in the papers' findings, represent a picture of the best-expected outcomes. The findings from this sample, therefore, represent the minimum challenges we could expect to find from the larger population of primary PSTs who do not consider themselves as 'mathematics experts'. Nonetheless, working with this specialist sample also has its affordances. It allows us to draw comparisons at post-primary level, and identify the obstacles that may be encountered by specialised mathematics teachers, who would have strong mathematics disciplinary knowledge, but also face the same challenges in terms of applying such competencies in integrated settings.

Another strength of this study is that it followed the two cohorts closely over a prolonged period of time (*Cohort 1*: three semesters; *Cohort 2*: one semester). This allowed the researcher to observe their journey closely as they moved from the lecture room to primary school classrooms and back. The research therefore, provides more than just a snapshot of pre-/ post-conceptual changes, but examines their evolving understandings over time. This is captured through a variety of approaches and data collection tools, adding to the methodological integrity of this research. Joining the PSTs on the transition to the classroom, revealed rich insights into how the PSTs' evolving understandings and theoretical knowledge played out in practice. This research therefore addresses the complex landscape of ITE, in which PSTs must make sense of theory and practice, activating critical knowledge in terms of the design of STEM tasks and curriculum, and the pedagogical decisions they must make. The complex design of this research captures key moments as the PSTs move between these spaces.

That being said, however, my closeness to the research could also be perceived as a limitation of the study. Given my dual role as researcher and teacher educator, I may have inadvertently presented more positive findings from the study, while PSTs may have been conservative in reporting negative aspects of the intervention. I remained mindful of my assumptions and biases throughout the research process, and through memo writing and journaling pushed myself "deeper into reflexivity", to note my "responses to things, but also interrogate those" (Braun & Clarke, 2022, p. 19).

Finally, writing this dissertation as an article-based thesis also presents some challenges. Journals' publishing requirements, editors' requests and peer review feedback set the direction for chapters 4-8. Therefore, each chapter is somewhat limited to the scope of the paper which has been prepared for publication. For example, as each paper presents a fine grained study on a particular aspect of the overall research, they are each presented for publication as individual studies (with their own specific methodology) and do not address their location within an overall action research study (eg. Chapter 8 refers to the use of *case-study*). To offset this limitation, each chapters' *preamble* and *chapter conclusion* attempt to place each paper in context and discuss the paper's contribution to the overall dissertation. Another challenge of an article-based PhD relates to the statement of claims made. Claims made in the published manuscripts may need caveating in the broader scope of the overall dissertation. For example, casual claims and claims about children's development are made in Chapter 6. As outlined in section 6.9, however, the scope of the paper and reviewer comments encouraged a focus on such claims based on the data. However, Chapter 3 (which allows for more detail in terms of description of experiences) and this final chapter, Chapter 9 (which attempts to synthesise the findings and their contribution to the existing knowledge base) attempt to mediate these claims somewhat in terms of the overall dissertation findings.

9.4 Implications for policy and practice

We have witnessed a steady increase in STEM and STEM education policy over the past two decades. As curriculum reform aligns with this discourse at primary level, we need to ensure that teacher education and classroom practices are research-informed. With the Primary Mathematics Curriculum set for implementation in September 2024, and the newest curriculum specification, the *Draft Science, Technology, Engineering Education Specification* recently released for consultation in March 2024, the findings of this dissertation have timely relevance and implications for both policy and practice. Recommendations arising from this dissertation relating to policy and practice include:

- To incorporate integrated STEM education as part of compulsory modules for all PSTs during ITE. As curriculum policy moves towards an integrated model, our teachers must be prepared for the new demands that this brings. This dissertation highlights the difficulties experienced by PSTs in applying disciplinary knowledge and skills to interdisciplinary tasks and lessons, offering examples of the types of experiences that contribute to the development of STEM literate PSTs.
- To identify opportunities for embedding integrated curriculum in action during ITE. The increasing nature of integrated curricula in the new Primary Curriculum Framework and accompanying specifications, places new demands on ITE institutes. The need for PSTs to experience integrated curriculum in action (in this case integrated STEM) following discrete disciplinary experiences, creates an impetus for faculty conversations around how best to achieve a disciplinary/interdisciplinary balance during ITE, both in terms of taught modules and school placement.
- To provide professional development for in-service teachers specifically related to interdisciplinary education and integrated STEM. Given that STEM is becoming an entirely new specification in our curriculum, it is likely that even more experienced teachers will encounter challenges in integration, similar to those met by the PSTs in

this study. Professional development opportunities should include options for sustained and bespoke support closely tied to their classroom practice, allowing for critical perspectives of STEM to be developed. Lesson Study is one such professional development approach that would scaffold groups of teachers when collaboratively developing expertise in integrated STEM teacher.

- To use formative assessment to support teacher learning during STEM education programmes. The *STEM task analysis* activity (Chapter 4) and *STEM story-lines* (Chapter 8) could serve as powerful formative assessment tools, offering important insights into STEM teacher development, and supporting teachers' learning during preservice and in-service teacher education programmes.
- To devise clear guidelines and supports for teacher planning in relation to integrated STEM tasks. In particular, guidance should be provided on ways to meaningfully incorporate appropriately challenging mathematics teaching and learning in STEM. The recommendations in Chapter 5 could be useful in this regard.
- To establish a national repository of large, societally relevant datasets for use in the primary classroom. Given the effectiveness of CODAP as a free math action tool, this combination (accompanied by focused PD in this regard) could support teachers in facilitating rich statistical inquiries in the classroom to enhance their students' statistical reasoning. As well as promoting statistics education, such datasets could support the aims of the Primary Curriculum Framework, by exposing students to authentic contexts on climate and sustainability, wellbeing and active citizenship.

9.5 Further research

- While this study has begun a conversation about the development of STEM literate PSTs, additional studies are needed. Furthermore, there is a need to scale up this research to examine how we can prepare large cohorts of PSTs for integrated STEM.
- The studies in this dissertation adopted an action inquiry approach, in which the second intervention sought to build upon the successes and improve the shortcomings of the initial module. While this inquiry has highlighted many possibilities and challenges for integrated STEM during ITE, it is merely a starting point. There is an opportunity and

need for design research in this area, to establish key principles of effective STEM ITE and support the development of STEM education curriculum during ITE.

- This dissertation outlines evolving understandings, knowledge and skills of PSTs during ITE. Although positive changes have been noted at the end of the interventions, follow-up studies are needed to re-examine these changes after the transition to professional practice. Longitudinal studies following teachers from ITE through their professional life cycles are needed to explore how STEM conceptualisations, STEM literacies and STEM teacher identity evolve over time.
- Additional research is needed to investigate effective incorporation of mathematics in integrated STEM tasks. While the recommendations in Chapter 5 hope to provide guidance for teacher planning, further research could examine the mathematical content of STEM tasks. Moreover, studies into how these tasks are then enacted in practice is needed, for example, through classroom observation.
- *STEM story-lines* have potential to capitalise on prior experiences, identifying strengths and needs, self-evaluating areas for improvement. Their potential for use with in-service teachers appears promising and warrants future study.
- While Chapter 6 offers some insight into STEM learning in the classroom, future research should expand the grain size and examine the impact of these integrated STEM experiences on the learning and dispositions of children in school.

9.6 Conclusion

The series of studies presented in this dissertation outline an action research inquiry into the development of preservice primary STEM teachers. The papers demonstrate the powerful interplay in becoming STEM learners and STEM teachers, and highlight the potential of collaborative and reflective experiences in supporting the evolution of STEM knowledge, skills and STEM teacher identity. However, the studies also unearthed some challenges of integrated STEM education, notably the incorporation of authentic, interdisciplinary mathematics. Findings indicate that strong disciplinary knowledge alone is not enough to support meaningful integration. This dissertation points to the importance of careful task design, offering examples of how rich STEM units can be created using mathematics as the central discipline. The papers illustrate the value of driving questions to stimulate and integrate

STEM teaching and learning, and point to the critical role societally-relevant, local datasets can play in this regard. Overall dissertation findings indicate that purposefully designed integrated STEM interventions during ITE can nurture the development of informed, critical STEM teachers, ready to take on integrated roles. Given the imminent changes in the primary STEM curriculum landscape, this dissertation sets a mandate for the provision of integrated STEM education for all PSTs during initial teacher education.

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Appendices

Appendix A: Systematic Literature Review: STEM and the Arts (Leavy et al., 2022)

Link to this report: f05f7b2f-e175-442e-85e9-4a2264391843.pdf (www.gov.ie)

Full citation details for this report:

Leavy, A., Carroll, C., Corry, E., **Fitzpatrick, M.**, Hamilton, M., Hourigan, M., LaCumbre, G., McGann, R. & O'Dwyer, A. (2022). *Review of Literature to Identify a Set of Effective Interventions for Addressing STEM and the Arts in Early Years, Primary and Post Primary Education Settings*. A report commissioned by the Department of Education. Available at https://www.gov.ie/pdf/?file=https://assets.gov.ie/96986/f05f7b2f-e175-442e-85e9-4a2264391843.pdf#page=null

Appendix B: Report on Consultation with Children on the Draft Primary Mathematics Curriculum (Leavy et al., 2023)

Link to this report: consultation_with_children_pmc.pdf (ncca.ie)

Full citation details for this report:

Leavy, A.M., Hourigan, M., Harmon, M. Treacy, M. & **Fitzpatrick, M.** (2023). *Report on the consultation with children on the Draft Primary Mathematics Curriculum*. A report commissioned by the National Council for Curriculum and Assessment. Available at https://ncca.ie/media/5938/consultation_with_children_pmc.pdf

Appendix C. MEI9 Conference paper (Fitzpatrick, 2023)

Mathematics *for* and *from* STEM: Conceptualising successful mathematics integration in STEM education

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The pace of STEM policy and curricular change in Ireland gives impetus to exploring more integrated approaches to STEM education. In turn, it challenges traditional, disciplinary approaches to teacher education, forcing us to reimagine how we prepare our future teachers for integrated STEM. This paper presents an effort to support 27 pre-service primary teachers in unearthing productive mathematical learning opportunities within integrated STEM tasks. It reports on pre-service teachers' experiences across two modules over two years. We outline the challenges experienced by both the pre-service teachers and teacher educators, before suggesting and trialling a framework for meaningful mathematics integration in STEM tasks. Preliminary findings suggest that the framework has potential to capitalise on mathematical opportunities across a STEM inquiry cycle. This study has implications for mathematics education in initial teacher education, where recent developments demand a balance of both disciplinary and interdisciplinary approaches.

Keywords: Mathematics education, integrated STEM, primary pre-service teachers

Introduction

There has been a recognised need for more integrated approaches to STEM (Honey et al., 2014). Although this has been met with enthusiasm from teachers (Hourigan et al., 2022), challenges abound which impede effective implementation (Margot & Kettler, 2019). One challenge is in maintaining a balance between the disciplines, with the underrepresentation of mathematics being particularly evident (English, 2016; Maass et al., 2019). Despite being generally accepted as the underpinning discipline in STEM, mathematics is often reduced to a service role in STEM tasks with little opportunity for genuine mathematical learning (Tytler et al., 2019; Forde et al., 2023). Meanwhile, teachers have reportedly struggled to identify opportunities for authentic mathematics teaching and learning within STEM tasks (Tytler et al., 2019). In this paper, we demonstrate how primary pre-service teachers (PSTs) can be supported in maintaining the spotlight on mathematics in integrated STEM tasks, by examining the role of mathematics teaching and learning *for* STEM and mathematics teaching and learning *from* STEM.

Background and study context

STEM education continues to attract global attention. The Irish policy landscape is no exception. Ambitious goals were set by the *STEM Education Policy Statement 2017-2026* (DES, 2017) mapping out a vision for STEM education engagement across the sectors. STEM policy is now aligning with curricular change at primary level. While mathematics and science are currently treated as isolated subjects, the new Primary Curriculum Framework (NCCA, 2023) sees the introduction of STEM education as one of five new broad curriculum areas. A STEM education development group has also recently been assembled, to prepare for the design of a national primary STEM curriculum.

Traditional teacher education programmes have focused on developing skills and knowledge in the individual disciplines. Pre-service teachers, therefore, are rarely provided with opportunities to develop pedagogical approaches to integrated STEM. Given the increased emphasis on interdisciplinary approaches, practices need to be reimagined, as teachers feel unprepared to teach in integrated ways (Shernoff et al., 2017).

Methodology

Participants were 27 primary pre-service teachers undertaking a mathematics specialism course as part of their Bachelor of Education programme. As part of a larger study investigating PSTs' evolving understanding of integrated STEM education, this paper follows the PSTs across two elective modules and reports on their experiences of integrating meaningful and authentic mathematics in STEM tasks. In the second semester of their third year (*Phase 1*), PSTs worked with three teacher educators across a 12-week integrated STEM intervention. As part of this module, PSTs designed and taught five STEM tasks to a fifth class in a partner school. PSTs and teacher educators then reflected on field practice, with a particular focus on the positioning of mathematics within each lesson. In the second semester of their fourth year (*Phase 2*), the same PSTs returned to the role of mathematics within STEM. Over five weeks, PSTs reconsidered the positioning of mathematics in STEM task design. They examined the role of mathematics during a STEM inquiry cycle, seeking out opportunities for rich mathematical teaching and learning at each stage of the process.

Data collection methods include pre-post intervention surveys, field notes, reflective journal entries, video recordings of lessons, post-teaching focus groups (*Phase 1*) and group-designed STEM tasks and interviews (*Phase 2*). Data from *Phase 1* were analysed using a grounded theory approach. Codes were generated and a constant comparison method was used to examine the data within and across each participant's data corpus. Data collected in *Phase 2* were deductively analysed based on the findings from *Phase 1*. Ethical approval was granted by the institution's research ethics committee and all considerations were adhered to.

Findings and conclusions

Phase 1

The pre-intervention data reflects high levels of confidence amongst the PSTs in their ability to teach mathematics. Participants attributed this confidence to success and enjoyment in their mathematics education modules, as well as in their professional school placement. Following the integrated STEM education intervention, however, there was concern amongst the PSTs relating to how mathematics could be meaningfully integrated in STEM. This was particularly evident following field practice. While video analysis and post-teaching focus group discussions suggest that the tasks were successful in promoting some STEM learning (notably science, engineering and 21st century skills), there was no evidence of planned, age-appropriate mathematical teaching and learning across the five lessons. Furthermore, the PSTs initially viewed the unambitious and incidental mathematical activities that were present (such as lower-order computation and measurement) as authentic mathematics integration and had significant difficulty in recognising opportunities to explore rich mathematical content and promote mathematical thinking.

We have detailed elsewhere (Authors, *under review*) some possible reasons for the lack of mathematical learning in these STEM tasks. Firstly, by prioritising engineering practices (the initial source of concerns for PSTs), we, as teacher educators, underestimated the need to maintain the spotlight on mathematics in STEM and made assumptions about the ease with which PSTs would apply their experiences in mathematics education to more integrated approaches. Secondly, no curriculum-based learning outcomes were identified that would focus on the mathematical skills and understanding to be developed. Finally, the task parameters did not stimulate mathematical thinking or reasoning. Given the difficulties in realising productive mathematics within integrated STEM tasks, we suggest that conscious decisions must be made about *where* and *when* we position mathematics and STEM in our teaching. We argue that reflecting on mathematics learning opportunities before, during and after STEM tasks in the planning process, would support PSTs in recognising rich opportunities for mathematics in STEM inquiry cycles, allowing discrete disciplinary learning to inform meaningful integrated work and vice versa. In turn, we offer the terms **mathematics learning *for* STEM** and **mathematics learning *from* STEM** (Authors, *under review*).

Mathematics learning for STEM. Specific disciplinary knowledge and skills, developed in preceding discrete mathematics lessons, to be utilised and developed in new ways during the STEM task.

Mathematics learning *from* STEM. New mathematical knowledge and skills developed during the STEM task. Furthermore, it may also refer to new mathematical concepts that the STEM task presents, whereby the STEM tasks act as both a rich context and a springboard for future mathematical inquiries.

Phase 2

Phase 2 of this study utilises the findings from Phase 1 as a framework for designing a mathematics-focused integrated STEM task. Attention was focused on the potential for spotlighting the 'M' in integrated STEM, by: ensuring tasks contain reference to relevant *explicit mathematics disciplinary content*; identifying *curriculum-based mathematics learning objectives*; setting *task criteria and parameters* that stimulate mathematical reasoning; and providing *mathematical materials* that promote mathematical thinking. PSTs were also guided to consider meaningful opportunities for discrete mathematical learning *for* and *from* STEM. Emerging findings suggest that the PSTs successfully used the framework to uncover potential for rich mathematical learning at different stages of the inquiry cycle. In their groups (5-6 PSTs), pre-service teachers were required to design integrated STEM tasks (based on *the honeybee*) that positioned mathematics as the central discipline. The groups each identified appropriate mathematical concepts and skills to be developed while remaining attentive to the characteristics of an integrated STEM lesson. Two lessons focused on the honeycomb structure, exploring geometry (shape and tessellation) and measures (capacity and volume). A third lesson also explored volume, this time presenting a Fermi problem to estimate the number of bees that would fit in a given area. The fourth lesson was centred around statistics, using data sets and maps to determine the best location for bee populations. The final lesson set children the task of designing a school 'pollinator garden', offering a series of dimension parameters to investigate measurement. While aspects of the tasks needed further development, there was a striking difference in terms of mathematical engagement, age-appropriate content, as well as an increase in mathematical cognitive demand, compared to earlier tasks designed. These preliminary findings, while limited, suggest that this framework has potential to support PSTs in foregrounding mathematics in integrated STEM tasks, and warrants further investigation. Data collection is ongoing.

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Appendix D: STEM Survey (*Intervention 1*)

Appendix D.1: Pre-intervention survey

Student Details

1. **Student ID** (First letter of first name, first letter of surname and the last three digits of phone number e.g. MF123) ___________________
2. **Gender:** Male ______ Female ______ other _______
3. **Are you doing a specialism in Mathematics?** Yes _________ No ________
4. **Was the mathematics education elective /specialism your first choice?** Yes __ No __

   If no, which choice was it? __________

Your understanding of STEM

5. What is STEM?

____
____
____

6. How do you understand STEM Education?

____
____
____
____

7. a). How related to one another do you perceive the STEM disciplines to be?

1 (not connected) → 10 (very connected)

1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

b). Explain your answer

____
____
____

8. Draw a diagram of how you visualize STEM using the letters S-T-E-M and illustrate how they are connected overleaf.

9. How would you teach STEM Education in the primary setting?

____
____
____
____
____
____

10. What are the benefits for children, if any, of engaging in a STEM lesson?

____
____
____
____
____
____

11. What challenges exist when teaching STEM?

____
____
____
____
____
____

12. At this moment, my biggest concerns about teaching STEM are:

____
____
____

13. How confident do you feel about teaching STEM? (Rank 1-10 below)

1 (not confident) → 10 (very confident)

1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why did you give yourself this rating?

____
____
____
____
____

Appendix D.2: Post-Intervention Survey

Student Details (First letter of first name, first letter of surname and the last three digits of phone number e.g. MF123) ___________________

Your understanding of STEM

1. What is STEM?

____
____
____
____

2. How do you understand STEM Education?

____
____
____
____
____
____
____

3. a). How related to one another do you perceive the STEM disciplines to be?

1 (not connected) → 10 (very connected)

1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

b). Explain your answer

____
____
____
____
____
____

4. Draw a diagram of how you visualize STEM using the letters S-T-E-M and illustrate how they are connected overleaf.

5. How would you teach STEM Education in the primary setting?
____
____
____

6. What are the benefits for children, if any, of engaging in a STEM lesson?

7. What challenges exist when teaching STEM?

8. At this moment, my biggest concerns about teaching STEM are:

9. How confident do you feel about teaching STEM? (Rank 1-10 below)

1 (not confident) → 10 (very confident)

1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why did you give yourself this rating?

10. If you were giving advice to the next group of specialism students, what advice would you give for designing and teaching a good STEM Lesson?

Appendix E: STEM Task Analysis Template

Reflections on Task (Week 1)

I.D: ______________________________

1. Is this a STEM Task? ______ Explain your response:
____
____
____
____
____
____
____
____
____

2. How do you rate this as a STEM task?

1 (poor) → **10 (excellent)**

1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Explain your response:
____
____
____
____
____
____
____

3. What disciplinary areas are targeted in this task?
____
____
____
____
____

4. Is there potential for skills and dispositions to be developed through the use of this task? (give detail)

5. Outline one or more potential modifications that could be made to enhance this task. Justify.

Modification(s):

Justification:

Appendix F: Sample of completed annotation sheet for *STEM Story-lines*

Science

· Within science ed. my experience in primary school was quite limited. We engaged only with textbooks. Therefore, my enjoyment and comfort within the subject was very low.

1. As I started secondary school, I began to realise what "real science" was and this was a turning point for my enjoyment.

· As I engaged with science + experiments throughout secondary school my enjoyment and comfort within the subject continued to grow as it became one

Technology

1) I had no experience with technology in school until I reached TY in secondary school.

· In primary school and Junior Cycle technology was kept to a minimum + the extent of my experience was some powerpoint presentations in secondary school.

2) In TY we began to have "computers" classes. At this point my understanding + confidence was still quite low and I dreaded having to attend these classes. However, they marked a

Engineering

· Within primary ed. & the majority of secondary ed. I had little-no experience within engineering, other than 1-2 short experiments within late secondary school when teachers realised the importance of STEM. This meant that my understanding + enjoyment of engineering was v. low

Mathematics

1) - I remember doing a lot of maths in primary school. It was the main focus of our primary school day + I quite enjoyed it I felt confident in my ability.

- Going into JC I felt confident in my abilities still.

2) As I moved into leaving cert maths got much more difficult + engaging with the higher level decreased my confidence.

3) This began to turn as I entered college + started learning about the intricacies of teaching primary mathematics. At this point my enjoyment began to return.

Appendix G: Sample participant information letter and consent form

An investigation into preservice teachers' understanding of STEM Education

Participant Information Letter

Investigators: Michelle Fitzpatrick, Dr. Aisling Leavy, Dr. Mairéad Hourigan, Clodagh Cleary

Department: Department of STEM Education, Mary Immaculate College, Limerick.

This module will explore key components of STEM Education**.** Opportunities are given for student teachers to reflect on their personal learning experiences and conceptualisations of STEM and its teaching. Specific theories and approaches to STEM Education will be interrogated to facilitate student teachers to experience and use teaching strategies which promote children's conceptual understanding and develop STEM skills. Student teachers will engage in the process of planning and preparing research informed inquiry-based STEM tasks for implementation and analysis during field-based experience. Student teachers will also explore the incorporation of the arts into STEM (STEAM) and examine opportunities for innovative integration that fosters creative and critical inquiry.

The lecturers on this course (listed as investigators above) would also like to use the information you provide in the context of EDU363 in their evaluation research. The research concerns students' conceptualisations of STEM. It will focus on changes in preservice teachers' understanding of STEM during the course of this module, and their development as a STEM educator.

Rights to Anonymity & Rights to Withdraw from the research

Your anonymity is assured and you are free to withdraw from this research study at any time without giving a reason and without consequence. You can participate and be part of EDE363 without involvement in this research study.

How will the information be used / disseminated?

Qualitative data (from field notes, transcribed focus group recordings, teacher surveys, video recording, graphical and written responses, participant journals, and artifacts) will be used by the investigators (named above). The data will be analysed to investigate the effectiveness of the STEM Education module in supporting and facilitating STEM education and understanding. Any data used in dissemination or publications will be anonymised.

How will confidentiality be kept?

All information gathered will remain confidential and will not be released to any third party. A random ID number will be generated for each participant and it is this number rather than the participant's name which will be held with their data to maintain their anonymity.

What will happen to the data after research has been completed?

In accordance with the MIC Data Retention Policy, anonymised data may be retained indefinitely. All data with identifiers will be destroyed once it is anonymised.

Contact details for project investigator, and MIREC Administrator:

If at any time you have any queries / issues with regard to this study, my contact details are as follows: Michelle Fitzpatrick (Michelle.Fitzpatrick@mic.ul.ie) .

If you have concerns about this study and wish to contact someone independent, you may contact: MIREC Administrator, Research and Graduate School, Mary Immaculate College, South Circular Road, Limerick. Telephone: 061-204980 E-mail: mirec@mic.ul.ie

An investigation into preservice primary teachers' understanding of STEM Education

Consent Form

You are under ***no*** obligation to participate in this study. If you agree to participate, but at a later stage wish to withdraw, you are free to do so, without consequence.

Please answer all of the following by ticking the appropriate box.	**Yes**	**No**
▪ I have read and understood the **information letter**.	☐	☐
▪ I understand the **particulars of the research study** for which I am volunteering as a participant and what the findings will be used for.	☐	☐
▪ I know that participation is voluntary and that I can **withdraw** from the project at any stage.	☐	☐
▪ I understand that my identity will be **anonymous** in any reporting of the findings.	☐	☐
▪ I give permission for the data gathered to be used for reporting of the findings.	☐	☐
▪ I give permission for the data gathered to be used for research purposes.	☐	☐

Participant Signature (PRINTED): ____

Date: ____

Investigator (Signature): ____

Appendix H: Statements of Authorship

H.1 Statement of Authorship Chapter 4:

Fitzpatrick, M. & Leavy, A. (accepted for publication). Reciprocal interplays in becoming STEM learners and teachers: preservice teachers' evolving understandings of integrated STEM education. *International Journal of Mathematical Education in Science and Technology.*

Statement of authorship:

We hereby declare that Michelle Fitzpatrick (Ph.D. candidate) is the principal author of this article. The following statements outline her contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; AND

• Drafting the work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Signed:

(Ph.D. candidate)

Signed:

(Supervisor & Co-author)

H.2 Statement of Authorship Chapter 5:

Fitzpatrick, M., Cleary, C. & Leavy, A. (in press). Mathifying STEM or STEMifying Math? Challenges and possibilities for mathematics learning within integrated STEM contexts. In J. Anderson & K. Makar. (Eds.). *The Contribution of Mathematics to School STEM Education: Current Understandings* (pp. XX). Springer.

Statement of authorship:

We hereby declare that Michelle Fitzpatrick (Ph.D. candidate) is the principal author of this book chapter. The following statements outline her contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; AND

• Drafting the work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Signed:

(Ph.D. candidate)

Signed:

(Supervisor & Co-author)

Signed:

(Co-author)

H.3 Statement of Authorship Chapter 6:

Leavy, A., Hourigan, M. & **Fitzpatrick, M.** (in press). Exploring the plight of the honeybee: Using data sensors and CODAP to support emerging bilingual learners in reasoning about big statistical ideas. *Statistics Education Research Journal*

Statement of authorship:

We hereby declare that Michelle Fitzpatrick (Ph.D. candidate) is a co-author of this article. The following statements outline her contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; AND

• Drafting the work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Signed:

(Ph.D. candidate)

Signed:

(Supervisor & Co-author)

Signed:

(Co-author)

H.4 Statement of Authorship Chapter 7:

Fitzpatrick, M., Leavy, A. & Hourigan, M. (under review). “Rather than simply learning statistics, we aimed to learn about the bees, from the bees”: An exploration of the factors influencing the development of positive teacher attitudes towards statistics. *Journal of Statistics and Data Science Education*

Statement of authorship:

We hereby declare that Michelle Fitzpatrick (Ph.D. candidate) is the principal author of this article. The following statements outline her contributions to the work:

• Substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work; AND

• Drafting the work and revising it critically for important intellectual content; AND

• Final approval of the version to be published; AND

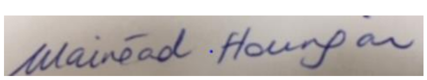
• Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Signed: 

(Ph.D. candidate)

Signed: 

(Supervisor & Co-author)

Signed: 

(Co-author)

Appendix I: Letters from Editors confirming status of peer-reviewed article/ book chapter

I .1 : Signed letter confirming status of article from the Editor-in-Chief of IJMEST

IJMEST **International Journal of Mathematical Education in Science and Technology**

Dr Colin Foster
Editor-in-Chief
International Journal of Mathematical Education in Science and Technology
Department of Mathematics Education
Loughborough University
Schofield Building
Loughborough LE11 3TU, UK
http://www.tandfonline.com/tmes
Ijmest@lboro.ac.uk

28 March 2024

Dear Michelle Fitzpatrick

Your article: "Reciprocal interplays in becoming STEM learners and teachers: preservice teachers' evolving understandings of integrated STEM education"

This letter confirms that your above article (submission number: 231268504) has received favourable reviews and has been accepted by *International Journal of Mathematical Education in Science and Technology* subject to minor revisions.

With best wishes,

C Foster

Colin Foster

Editor-in-Chief

International Journal of Mathematical Education in Science and Technology

I.2: Signed letter confirming status of book chapter from the book's co-editor

THE UNIVERSITY OF SYDNEY

Judy Anderson PhD
Honorary Associate Professor, Mathematics Education
Sydney School of Education and Social Work

2 April 2024

Ms Michelle Fitzpatrick
Limerick
Ireland

Dear Michelle,

We are delighted that you and your co-authors, Aisling Leavy and Clodagh Cleary, have submitted your final, revised chapter, "Mathifying STEM or STEMifying Math? Challenges and possibilities for mathematics learning within integrated STEM contexts", for the book *The Contribution of Mathematics to School STEM Education: Current Understandings*.

This letter is to advise that the book is now complete and will be published by Springer in July 2024.

Thank you again for your valuable contribution to the research in this field and we look forward to further collaborations in the future.

Yours sincerely,

Judy Anderson

Assoc. Prof. Judy Anderson
(on behalf of the co-editors Judy Anderson and Professor Katie Makar)

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I.3: Signed letter confirming status of article from the Editor of Special Issues at SERJ

Universität Münster

gimb

Institut für grundlegende und inklusive mathematische Bildung

Universität Münster | Institut für grundlegende inklusive und mathematische Bildung
Prof. Dr. D. Frischemeier | Johann-Krane-Weg 39 | 48149 Münster

Prof. Dr. Daniel Frischemeier

Johann-Krane-Weg 39
48149 Münster

dfrische@uni-muenster.de

To whom it may concern

26.03.24

Datum

Ihr Zeichen | Ihre Nachricht vom | mein Zeichen | meine Nachricht vom

Confirmation: Manuscript is accepted for publication in Statistics Education Research Journal

Dear Sir or Madam,

Hereby I confirm that the manuscript (authors: Aisling M. Leavy, Mairéad Hourigan and Michelle Fitzpatrick) "Exploring the plight of the honeybee: Using data sensors and CODAP to support Emerging Bilingual Learners in reasoning about big statistical ideas" has been accepted for publication in the Special Issue of the Statistics Education Research Journal (SERJ, see: https://iase-web.org/ojs/SERJ) on *Inclusive Statistics Education with Digital Resources*. The Special Issue is expected to be published in July 2024.

Daniel Frischemeier

Prof. Dr. Daniel Frischemeier, Editor of Special Issues, Statistics Education Research Journal

I.4: Signed letter confirming status of article from the General Editor of IES

##EXTERNAL EMAIL##: Article Acceptance in Irish Educational Studies

Audrey Bryan <Audrey.bryan@dcu.ie>

Fri 12 Apr 2024 1:52 PM

To:Michelle Fitzpatrick <Michelle.Fitzpatrick@mic.ul.ie>

CAUTION: This email originated from outside of the organization. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Dear Michelle,

I am writing to you in my capacity of General Editor of Irish Educational Studies (IES).
I understand that you are completing a PhD by publication and that your recent submission to IES forms part of the examination process at your institution.
I hereby confirm that your article entitled "Drawing the past to envision the future: Supporting the development of STEM teacher identity" has been accepted for publication in IES, pending minor revisions, and will be published online in the coming weeks upon receipt of same.

Thank you for your important contribution to Irish Educational Studies.

Wishing you the very best of luck on your upcoming Viva Voce.

I can be reached at audrey.bryan@dcu.ie if any further confirmation is required.

Sincerely,
Audrey Bryan
General Editor, Irish Educational Studies

--

Audrey Bryan

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