Teachers' Understandings of Lesson Study as a Professional Development Tool in a Primary Multi- Grade School

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Abstract

What are Teachers' Understandings of Lesson Study as a Professional Development Tool?

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With increasing focus on primary curricular reform in Ireland, growing understanding of the importance of education in the early years has led professional development organisations to consider the effectiveness of STEM (science, technology, engineering and maths) education for young children. This research seeks to explore the potential of lesson study as a vehicle to promote and support collaborative professional development in a rural, multi-grade primary school. Three teachers were introduced to and participated in four cycles of lesson study over the course of one school year. Lesson study was utilised to design and implement integrated STEM lessons in Junior and Senior Infants (ages 4–7 years). Through an action research methodology, qualitative data were generated from interviews, lesson plans, collaborative weekly meetings, observation sheets, and the researcher's reflective journal and field notes. Analysis suggests that teachers began to develop new pedagogical practices as a result of iterative and collaborative lesson study processes. Findings also reveal insights into the knowledge-related demands of designing and implementing STEM lessons. Successive and collaborative cycles enabled teachers to become more confident in their teaching of STEM education, and they believed they had a greater understanding of the children's learning. While teachers perceived lesson study to be a beneficial form of professional development, some factors constrained their engagement, including practical, cultural and sustainability challenges. The work concludes by contemplating the place of lesson study and STEM education in the current educational landscape, and makes recommendations to support their implementation nationally.

Declaration

I hereby declare that this thesis represents my own work and has not been submitted in whole or in part, by me or another for the purpose of obtaining any other qualification.

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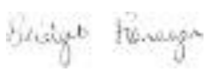

Date:

17th January 2021

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List of Abbreviations

BERA: British Educational Research Association

CPD: Continuous Professional Development

DES: Department of Education and Science

DPSM/ESERO: Discover Primary Science and Maths/ European Space Education Resource Office

DYCA: Department of Children and Youth Affairs

ESAI: Educational Studies Association of Ireland

ICT: Information and Communications Technology

INTO: Irish National Teachers' Organisation

KCT: Knowledge of Content and Teaching

KCS: Knowledge of Content and Students

LAOS: Looking at Our Schools 2016

LS: Lesson Study

MIREC: Mary Immaculate Research Ethics Committee

NCCA: National Council for Curriculum and Assessment

NEARI: Network of Educational Action Research Ireland

OECD: Organisation for Economic Cooperation and Development

PAR: Participatory Action Research

PCK: Pedagogical Content Knowledge

PD: Professional Development

PDST: PD Service for Teachers

PIRLS: Progress in International Reading Literacy Study

PISA: Programme for International Student Assessment

PSC: Primary School Curriculum

SCK: Specialised Content Knowledge

SEN: Special Educational Needs

SET: Special Education Teacher

SMK: Subject Matter Knowledge

SNA: Special Needs Assistant

SSE: School Self-Evaluation

STEAM: Science, Technology, Engineering, Arts and Maths

STEM: Science, Technology, Engineering and Maths

TIMSS: Trends in International Maths and Science Study

WALS: World Association of Lesson Study

Chapter 1: Introduction

1.1 Introduction

The principle purpose of this study is to improve the quality of teaching and learning through a collaborative, reflective and recursive process. The research has been designed to explore the potential of lesson study (LS) as a vehicle to promote and support collaborative professional learning between teachers in a primary school. The focus for LS is STEM (Science, Technology, Engineering and Maths) education with Junior and Senior Infants. The research reports on the impact that LS has on teachers' skills and knowledge.

The term *lesson study* is a translation of the Japanese words *jugyou* 'lesson' and *kenkyu* 'study' (Fernandez 2002; Lewis 2002a). LS is a model of professional development (PD) which encourages teacher collaboration in planning, conducting, observing and reflecting on teaching and learning practices. Firstly, teachers collaborate in carefully planning a research lesson. This requires time dedicated to intensive *kyozai kenkyu*, a process in which teachers collaboratively investigate all aspects of the content to be taught and instructional materials available (Takahashi 2005). The lesson is taught by one teacher while the rest of the group observe and note student learning, engagement and behaviour. Team members gather data on children's learning, perhaps studying selected children to observe how their thinking evolves (Lewis et al. 2012) and what barriers existed that prevented learning. All members reflect and conduct a post-lesson review, *jyugyo kentuikai* (Takahashi 2005). Teachers then discuss and revise the lesson based on their observations and re-teach the improved lesson to a different cohort of children. Participants observe as the lesson unfolds again. Teachers again meet to reflect and discuss the data gathered on child and teacher learning (Murata and Takahashi 2002). Teachers draw out implications for teaching and learning in the particular topic, but also for teaching and learning more broadly.

This chapter will outline the significance of this research by discussing the key features which led to its inception. First, it outlines the research question and embedded questions. It briefly summarises the national and international context regarding teachers' PD, with specific reference to Irish policy. It reviews current policies around STEM education to frame how this work is situated. It also presents the originality and the autobiographical context of the research. Lastly, it provides an organising framework for the thesis, outlining the purpose and structure of each chapter.

1.2 Research Question

The overarching question guiding the study is:

What are teachers' understandings of lesson study as a professional development tool?

The embedded questions associated with the overarching question are:

- In what ways does teachers' practice in STEM change (if at all) as a result of engaging with LS?
- What are teachers' learning experiences of STEM education?
- How can lesson study enhance the professional agency of teachers?
- What are the cultural adjustments made by teachers when implementing lesson study?

1.3 PD Practices

Since the 1980s, and as a result of changing economic, social and educational developments, teachers began to be expected to learn over the course of their careers (Hargreaves 2000). However, the courses offered to teachers by external agencies were most often fragmented, disconnected and irrelevant to the real problems of their classroom practice, and consequently did not lead to significant changes in teachers' practice (Hawley and Valli 1999). These traditional forms of PD have also been criticised for not including practice-based collaboration and research (Timperley et al. 2007; Conway et al. 2009; Banks and Smyth 2011). Borko concedes that despite billions being spent on teacher PD, it remains 'fragmented, intellectually superficial … and woefully inadequate' (2004, p. 3).

For the past thirty years there has been considerable research on effective PD for teacher and pupil outcomes. There is a gradual paradigm swing away from the view that PD is something done to teachers by external experts, to a view of professional learning as something done with and/or by a teacher (Loughran et al. 2008). De Vries (2016) writes that the current perspective of learning during PD draws on the cognitive psychological and adult learning approaches. These approaches have evolved into a situated, active, constructive and reflective perspective of learning. Effective PD is now seen as collaborative, situated in practice, sustained and focused on children's learning (Guskey 2002; Borko 2004; Desimone 2009; Borko et al. 2010).

There is an apparent discrepancy between teachers as passive recipients and teachers as professional learners. It is a distinction which separates traditional and contemporary models of PD. Currently, standard PD practices in Ireland are mostly short-term, one-shot workshops (Conway et al. 2009) which do not take the context of the teacher into account (Coolahan 2003; Sugrue 2003; Teaching Council 2010).

1.4 Irish Policy in PD

The context of PD in Ireland is complex. Traditionally, PD courses in Ireland have largely taken a top-down approach and have been implemented by external forces. PD was centrally mandated, focusing on circulating policies rather than enhancing teachers' aspirations or interests (Sugrue 2002). The main focus has traditionally been on cognitive knowledge rather than the development of competencies and skills (Sugrue et al. 2001).

The Teaching Council has introduced numerous initiatives and policies to improve teacher professionalism and autonomy (Lynch et al. 2013; Murray 2020). The Teaching Council is the professional standards body for the teaching profession and is responsible for policy development in teacher learning. Since its creation in 2006, the Council has advocated 'lifelong' learning (Conway et al. 2009). The *Draft Policy on the Continuum of Teacher Education* asserts that a robust, cohesive approach to PD is required 'to ensure the long-term capacity that is now needed in the system' (Teaching Council 2010, p. 22). The policy also introduces the idea of school-based PD, acknowledging that the teacher working alone 'isolated from peers is clearly obsolete' (2010, p. 22). Specific attention is paid to reflective practice and teacher enquiry, as these were areas that had previously received scant attention (O'Donoghue et al. 2017). The Teaching Council asserts that this requires a significant shift from traditional thinking on PD.

Following an extensive consultation period, the Teaching Council published its *Policy on the Continuum of Teacher Education* in 2011. This is considered a critical development, as it involves the revisioning of teacher education across the continuum (Teaching Council 2011). In this policy the Teaching Council notes the fragmentation of teacher education and the lack of coherence between the stages of the continuum. PD is conveyed as a mechanism to support autonomous and self-directed learning, rooted in the needs of the individual teachers (Teaching Council 2011, p. 19). The development of professional learning communities is encouraged, as clusters of schools collaborate through educational institutions or subject associations. The policy highlights collaboration, school-based enquiry and the links between policy, practice and research:

> Effective professional development, which is participative in nature, should encourage teachers to evaluate their pedagogical beliefs and practices, to critically reflect on their professional practice and working environments and to engage in professional collaboration.
>
> School-based collaborative enquiry carried out by teachers in teams or groups and supported by teacher education departments, is a valuable model for professional development.
>
> PD should involve teachers in sharing their expertise and experience more systematically while building cumulative knowledge across the profession by strengthening connections across research, policy and practice.
>
> (Teaching Council 2011, pp. 20–21)

This policy is welcome, as it recognises the various needs of teachers working in diverse contexts, and the value of professional collaboration and teachers designing PD for their learning needs. In their research, McMillan et al. (2016) found that Irish teachers were very open to and eager for the prospect of designing their own PD. However, Sugrue (2011) believes that school-based PD is mired with challenges, as schools do not receive a specific budget for PD and lack time for practitioner engagement. He believes that without a budget, release time or substitute cover, 'appealing to the good will of colleagues becomes the only basis on which collaboration and sharing expertise can occur, and a potential quagmire for principals whereby good will becomes the currency' (2011, p. 808).

Across the Teaching Council's initiatives, there is an emphasis on teacher collaboration as central to teacher PD (Walsh 2020). Collaboration is encouraged in initial teacher education as students partake in team teaching on school placement. It is also hoped that their student teachers' experience of collaboration in third level will be continued upon entry into their professional roles (Teaching Council 2017a). *Droichead: The Integrated Professional Induction Framework* was introduced in 2013 and was implemented on a phased basis in 2016. *Droichead* advocates for collaboration between newly qualified teachers and established teachers to identify areas of future learning (Teaching Council 2017b). However, implementation proved challenging, as this was a top-down policy which had not been agreed with teachers beforehand, and the Irish National Teachers' Organisation (INTO) directed members not to cooperate (O'Donoghue et al. 2017). A review of the pilot *Droichead* programme advised continuity and the establishment of complementary links between *Droichead* and further PD, to ensure high-quality learning (Smyth et al. 2016; Lynch et al. 2017).

Cosán: Framework for Teachers' Learning (Teaching Council 2016) aims to build on the *Droichead* programme. Its overall approach is based on several principles:

- recognises teachers as autonomous and responsible professionals
- facilitates teachers in pursuing relevant learning experiences
- facilitates teachers in identifying opportunities for quality learning
- recognises the importance of rich and varied learning opportunities
- facilitates teachers in valuing their learning and in prioritising learning that benefits them and their pupils

However, Lynch et al. (2017) state that *Cosán* does not outline outcomes associated with PD or the skills required for teachers to be change agents. They write that outcomes and skills for all stages of the continuum of teacher education would enable pedagogical connections to be made which would support teachers as change agents. Many of the Teaching Council's initiatives have not been embedded due to reform overload, poor communication and Ireland's cultural context (Murray 2020). Practical support is required for initiatives to take root (Walsh 2020). According to McMillan et al. (2016), Irish PD needs to develop a form of provision that will target teachers' choice, empower professional learning communities and implement a system of professional development.

This research aims to incorporate the values and principles espoused through the Teaching Council policies. By utilising LS and action research, this research affirms the active role of teachers in shaping their own PD. LS aspired to create a PD opportunity for the teachers to situate knowledge that was both socially and culturally constructed. Teachers gathered classroom data to reflect and to plan the best route ahead for children's learning. LS recognised teachers as researchers of their practice and highlighted the synergies between research, policy and practice. Collaboration was encouraged as teachers shared pedagogical knowledge and critically reflected to ensure a more sustainable form of professional development. This enabled the enhancement not only of individual teachers but of teachers' capacity-building across the school. Through LS, teachers were able to design their own PD, as LS was context-based and responsive to their individual learning needs. I argue that LS incorporated the characteristics of high-quality PD and can realise the visions of current educational policies.

1.5 Irish Policy in STEM

STEM is an acronym for science, technology, engineering and maths. STEM education is based on the idea of educating children in these four areas using an interdisciplinary approach, rather than teaching the four disciplines as separate subjects. This research was conducted at a time of considerable change in the policy landscape for STEM education in Ireland. In recent years, governments of progressive nations throughout the world have placed particular importance on advancing STEM policy and improving the quality of STEM education. STEM is deemed to be a solution to economic competitiveness, and many government strategies, policies and reports are flourishing. This competitiveness has resulted in many nations producing STEM policies to ensure quality education.

McClure et al. (2017) concur: 'just as the industrial revolution made it necessary for all children to learn to read, the technology revolution has made it critical for all children to understand STEM' (p. 4). Providing STEM education of the highest quality and aiming to foster creativity and innovation among young people are key priorities for governments worldwide. Reflecting international trends, the promotion of STEM learning has become more of a priority in Ireland in recent years. Richard Bruton, when Minister for Education, said that young children's 'ability to think critically and develop solutions in the digital world will be vital for their prospects in life. Digital technology is revolutionising our careers' (Irish Government News Service 2017).

In terms of policy, in recent years STEM education has slowly emerged from the shadow cast by the *Literacy and Numeracy for Learning for Life* (DES 2011b) strategy. This strategy presented a vision for literacy and numeracy. At the time of its development, Ireland was gripped by a recession; King and Nihall (2019) noted that the policy document emphasised literacy and numeracy skills as imperative for economic expansion. The document outlined a wide-ranging list of targets and actions required to improve literacy and numeracy standards, including increased teaching time for literacy and numeracy. Particular emphasis has also been placed on numeracy and digital skills for school children. Certainly, this policy has had better results than expected: many of the targets set out in the ten-year strategy by the Department of Education and Skills (DES) were met in little over half of its lifetime. While there is no mention of STEM in this document, there were concerns about the prospects of a STEM workforce. The STEM Education Review Group was subsequently established to conduct a review of

STEM education in Ireland (Leavy et al. 2020).

In recent years, there has been an increase in STEM policies, with the launch of *Innovation 2020*, the *Digital Strategy for Schools (2015–2020)* (DES 2015a), *Action Plan for Education* (2016b), *STEM Education in the Irish School System: Report of the STEM Education Review Group* (MacCraith 2016), the *STEM Education Policy Statement* (DES 2017a) and the *STEM Implementation Plan* (2017b). *Innovation 2020* was published in 2015 and encouraged the development of STEM at all levels of the education system as a way to attract foreign direct investment (Clarke 2019). There has also been greater importance attributed to digital technology. The *Digital Strategy for Schools* sets a clear five-year vision to embed technology in teaching, learning and assessment. It aims to invest €210 million over its lifetime and sets out a vision for the role of digital technologies in enhancing teaching, learning and assessment in schools (DES 2015a). The provision of technology infrastructure has come under sharp focus during the Covid-19 pandemic, as concerns were raised about a 'digital divide' and a 'digital use divide' (Hall et al. 2020). It was highlighted that not all children had equitable opportunities to access the technology required for their education.

2016 saw critical developments that cemented the STEM agenda in Ireland (Leavy et al. 2020). The *Action Plan for Education* (2016b), launched in 2016, took a stronger stance identifying STEM as a key area for development. The formation of a national STEM policy was prioritised, and recommendations outlined by the STEM Education Review Group were to be implemented. Specific attention was paid to the uptake of STEM disciplines by women and to measures to address skills gaps. Also published in 2016, *STEM Education in the Irish School System: Report of the STEM Education Review Group* outlined the vision for STEM education:

> Our vision is to provide students in Ireland with a STEM education experience of the highest international quality; this provision should underpin high levels of student engagement, enjoyment, and excellent performance in STEM disciplines.
>
> (MacCraith 2016, p. 54)

The report contains a number of recommendations for the development of STEM in primary schools. MacCraith believes teachers will require PD in STEM throughout their career, not just in response to curriculum change. Specifically, a robust PD programme in maths is seen as fundamental to STEM. The report advocates the creation of specialised 'STEM champions' among primary teachers and the use of technology to enhance STEM learning. MacCraith writes that a shift is needed in the type of PD offered in order to encourage teachers to embrace inquiry-based and problem-based learning.

Arising from this STEM Education Review Group report, the *STEM Education Policy Statement* (DES 2017a) was devised. The policy encompasses early childhood to post-primary education, which is quite significant, as traditionally these skills have not been taught in early childhood. Three principles reveal a vision of STEM learning:

> STEM is about igniting learners' curiosity so they participate in solving real-world problems and make informed career choices.
>
> STEM is interdisciplinary, enabling learners to build and apply knowledge, deepen their understanding and develop creative and critical thinking skills within authentic contexts.
>
> STEM education embodies creativity, art and design.
>
> (DES 2017a, p. 9)

The areas of policy development and actions are outlined in four pillars in the STEM policy. Of particular importance to this research is pillar 2: 'Enhance early years practitioner and teacher capacity' (DES 2017a, p. 14). High-quality PD in STEM is emphasised to support the development of teachers' pedagogical content knowledge (PCK), inquiry-based learning, digital technologies and a cross-disciplinary approach to STEM education. The *STEM Implementation Plan* (2017b) is the first of three such plans. Under each pillar of the implementation plan is a series of objectives, high-level actions, sub-actions, timeframes and organisations. Pillar 2 of the Implementation Plan (2017b) gives a detailed overview of the areas for improvement, again giving specific mention to enhancing the capacity of practitioners.

STEM is recognised globally as being central to economic prosperity and societal wellbeing. While a national STEM policy is very welcome, there is progress to be made in implementing the policy aspirations in reality. The aspirations and visions outlined in the various strategies need to be converted into education programmes and then into concrete practices. It is imperative that STEM remains an educational priority to advance it beyond policy and into practice.

1.6 Original Contribution of This Research

The PD policy context described above presents a growing imperative to understand the factors that facilitate teacher learning in primary school. As a result of changing conceptions of PD provision, methods such as LS are receiving attention as a strategy for PD. Much of the growing Irish research comprises of LS being implemented in third-level and second-level institutions. Additionally, LS research has concentrated on maths teaching and on single cycles of LS (Corcoran 2011). Literature searches point to a dearth of similar research on LS being implemented in Irish primary schools. The current research investigates the implications of implementing LS in a primary school. This illuminates the need to conduct research focusing with teachers in small Irish primary schools.

This research is timely, as STEM education is a priority for the Irish government. To date, research in Ireland has focused on science in primary education, and research on PD in science has focused predominantly on classrooms in upper primary school. Therefore, research in STEM education is in its preliminary stages, and this represents a gap in the knowledge base to be filled. PD is required to support teachers, so it is important to understand effective PD provision. There is currently no evidence of LS being implemented in STEM education PD in an Irish primary school. Nor is there Irish research available on what primary teachers think about LS and STEM education. This research aims to study LS as a PD vehicle in STEM education in a rural Irish primary school with children in Junior and Senior Infants.

1.7 Rationale

My professional background was a motivating factor in conducting this research. Many interests merged to culminate in the design of this study. I graduated in 2009 during the recession, which resulted in many years of teaching experience as a substitute teacher in rural, multi-grade schools with various cohorts of Junior Infants to Second Class (Kindergarten to Grade 2). This sparked my interest in early years education. Maths was a subject in which I lacked confidence as a child, and towards which I consequently developed an aversion and anxiety. As a teacher I was very focused on developing my maths teaching to avoid communicating this anxiety to the children. On a deeper level, I identified with children of lower ability, and I aimed to support them, as I recognised their struggle. This led me to attend many PD courses. I used the *Ready, Set, Go*[1] numeracy programme, which helped me to re-envision maths teaching and learning. When teaching, I was always drawn to methodologies that engaged children and enabled them to be active in their learning. I began teaching maths through concrete

[1] Ready, Set, Go is a numeracy programme designed to enable children to develop their number skills through concrete activities and interactive games.

activities, games and play, in direct contradiction to how I was taught as a child. I gradually became confident in my teaching of maths. When I became a permanent teacher, my duties were primarily in maths and science, which prompted my attendance at many PD courses in science. I especially identified science as a subject that facilitated children's natural curiosity, active learning and engagement. There was an increasing emphasis on STEM education in both policy and PD during my first year of the PhD, and this worked as an impetus to research STEM education. I became interested in STEM education, given the opportunities offered for child-centred learning and the merging of maths and science.

As deputy principal, I gained a diploma in educational leadership and management in 2015. As I engaged with the course, my interest was piqued in professional collaboration, reflective practice and teachers' professionalism. Before beginning the PhD, I was completely unfamiliar with LS. As I researched teachers' PD I recognised the potential for teacher collaboration, reflective practice and professionalism to be realised through the use of LS. I began to envision the effect that LS could have on collaboration and reflection in my classroom and school. The idea of teachers collaborating to develop themselves professionally appealed to me, as did the implications this would hold for teacher autonomy. I appreciated that my colleagues had built up a wealth of tacit knowledge, and I felt that LS could be a way to access this knowledge, share it and thereby improve children's learning experience. I envisioned LS as teachers building knowledge and practice together in a significant and meaningful way. I aimed to explore the potential of LS as a form of PD.

McNiff and Whitehead (2011) ask: Why is practitioner knowledge important? The decision to investigate LS and consequently action research as a methodology was motivated by a desire to raise awareness of the importance of practitioner research. 'Practitioner knowledge is central to practical and theoretical sustainability … action research has this self-transforming capacity,' write McNiff and Whitehead (2011, pp. 18–19). As teachers develop, test and create new knowledge, this process ensures a sustainable form of PD and builds capacity among teachers and schools. Action research combined with LS has enabled me to teach in the classroom, collaborate with my colleagues, research my practice and enhance my practice.

1.8 Structure of Thesis

Chapter 1 set out to briefly introduce this study. It outlined the research question and embedded questions, and it detailed the relevant policies that informed the research. Finally, it explained the unique contribution of the research and identified the rationale that motivated the research on LS and STEM. The literature review is divided into two chapters, analysing the literature on LS and STEM education. Chapter 2 discusses international and national LS practices and examines the factors required for LS to be supported in the Irish education system. Chapter 3 outlines existing literature on STEM education and explores the core concepts of science education in Ireland, inquiry-based learning and STEM education, specifically in early years education. Chapter 4 explains the research design, including the data collection methods and data analysis. Chapter 5 presents the research findings under five themes: LS and collaboration, teacher practice, teacher learning, increased focus on children's experience, and factors which affected teacher participation. Chapter 6 frames the findings within existing literature to ensure a deeper level of analysis. The final chapter concludes the thesis, summarises the findings, highlights the limitations of the study, and offers recommendations for policy, practice and future research.

Chapter 2: Literature Review on Lesson Study

This chapter contains a description of the literature review process and four sections which explore some of the literature pertinent to this study. The first section outlines literature relating to lesson study (LS) and effective professional development. This is followed by literature examining LS in Japan and the transferability of LS to other countries. As this research was conducted in Ireland, the third section will examine literature on the Irish educational context and the supports required for LS to grow.

2.1 Literature Review Process

This literature review was a continuous and iterative process, as there is research being conducted constantly, so there was a need to refresh and remould the chapter selections as more perspectives evolved (Easterby-Smith et al. 2008; Bryman 2012). The literature review involved a directed search of peer-reviewed journal articles from international journals and books written over the last thirty years approximately. Articles were selected from Academic Search Complete, British Education Index, ERIC, Education Source, and Education Full Text (H.W. Wilson). A selection was made of the journal articles most pertinent to this study. Firstly, my main selection criterion was literature that focused on understanding LS, teacher knowledge and practice.

Due to a shortage of Irish studies, articles were collected from around the world but mainly focused on Japan, the US and the UK. Using the same databases, it was decided to gain an overview of the main themes in STEM education literature. Particular attention was given to exploring science and STEM education in Ireland, effective PD practices in STEM, and STEM in early childhood. For both LS and STEM, the review had to be extended beyond peer-reviewed international journal articles to also identify and include seminal theorists or studies and relevant chapters in edited books to pursue various lines of interest. The literature review attempted to illuminate the major discourses of LS and STEM education, not just in Ireland but in a broader societal context. I could determine, with relative certainty, those topics and themes that were relevant to the inquiry. Furthermore, it guided further reading and examination of the themes identified.

2.2 Features and Principles of Effective PD

Current literature agrees that PD should be active, content focused, and sustained, and should include opportunities to reflect (Garet et al. 2001; Loucks-Horsley et al. 2009). Borko et al. (2010), reviewing contemporary approaches, believe there are seven features of effective PD:

1. PD is situated in practice and addresses problems of practice
2. It is focused on children's learning
3. The preferred instructional practices are modelled in PD
4. PD employs active learning and teacher inquiry
5. Professional learning communities and collaborative contexts are established
6. PD settings are appropriate to goals, often school-based
7. PD models are ongoing and sustainable (pp. 551–552)

In her conceptual framework, Desimone (2009) discusses five features of effective PD, many of which overlap with Borko et al. (2010):

1. content focus
2. active learning
3. coherence
4. duration
5. collective participation

The literature strongly encourages teachers being active in their learning (Loucks-Horsley and Matsumoto 1999; Garet et al. 2001; Desimone 2009; Borko et al. 2010). Bryk and Schneider (2003) and Desimone (2009) write that PD which highlights the focal position of the teacher makes teachers more receptive, thus providing more positive gains. Guskey (2002) believes the central role of professional learning is to cause teacher change. He believes that professional learning should have three areas of change: 'change in the classroom practices of teachers, in teachers' attitudes and beliefs, and in the learning outcomes of students' (p. 381). Desimone (2009) extends this, writing that changing teachers' beliefs about what constitutes effective teaching will cause a change in teacher practice. Changes to practices, routines or techniques are not sufficient. She believes there must be an exploration of the discourses that shape teachers' understanding of effective teaching.

There is a growing trend in global education towards developing professional learning communities. Yoshida (2012) writes that effective LS creates a robust professional community which will benefit teachers and children's learning. Teacher PD has been found to be more effective when it is sustained, local and supported by the school community (Cochran-Smith 2005b). A key aim of professional learning communities is that ongoing teacher learning will 'enhance teacher effectiveness as professionals, for students' ultimate benefit' (Stoll et al. 2006, p. 229). Schools as professional learning communities support the development of shared aims and effort (Leithwood and Riehl 2003). Educational aims shared by the professional learning community also provide an ongoing venue for teacher learning (Cochran-Smith and Lytle 1999). However, Timperley et al. (2008) point out that in professional learning communities, supportive relationships can be a double-edged sword, as dialogue can fail to challenge problematic beliefs, and the status quo is entrenched. They found that involving external expertise was more effective in this regard.

Lesson study merges many of these features of effective PD (Dudley 2013; Lewis and Perry 2014). In this research, it was hoped that using LS would have a positive effect on teachers' attitudes to STEM, and improve teachers' STEM professional knowledge for teaching as well as their classroom practice, thus creating a positive learning experience for children.

2.2.1 Lesson study in practice

LS originated as a practice in Japan in the late 1800s and has been the primary vehicle for PD for Japanese teachers since the beginning of the public education system (Lewis and Tsuchida 1998; Murata and Takahashi 2002; Takahashi and McDougal 2016). LS traditionally centred on maths instruction (Lewis et al. 2009a; Huang and Shimizu 2016) but is now integrated into various curricular areas. In 1999, the 'Teaching Gap' sparked worldwide interest in LS when it was highlighted as the critical feature responsible for enabling Japanese elementary teachers to improve science and maths instruction (Stigler and Hiebert 1999). Subsequently, in the US the concept of LS was presented in various state, national and international conferences in 2000–2001 (Lewis 2002a).

Since then, LS has seen a dramatic rise in international popularity. It is claimed to be the world's fastest-growing teacher learning approach (Dudley 2015). LS has been adopted by education systems across the US, Canada, England and parts of Asia and Europe. The World Association of Lesson Studies, established in 2005, has members from over 60 countries (Xu and Pedder 2014). This international rise in the popularity of LS has been matched by increased research documenting teacher learning in this model of PD (Lewis and Tsuchida 1998; Fernandez 2002; Lewis et al. 2009a). It is argued that LS builds the quality of teaching over time (Stigler and Hiebert 1999) and provides collaborative opportunities for capacity-building.

LS differs from others forms of PD, because the focus is on student learning as opposed to teacher performance (Cajkler et al. 2014). Its principle aim is to establish pupils' learning, participation and engagement as a central focus of teachers' learning and practice development (Dudley 2013). One of the main strengths of LS as a form of PD is the teaching of a live lesson (Murata and Takahashi 2002; Akiba et al. 2019). However, the purpose of LS is not to produce the perfect lesson but 'rather, to provide an avenue and focus for discussion on effective practices that bring about improvements in learning outcomes for students' (Leavy and Hourigan 2016, p. 162).

Lewis et al. (2009a) offer a clear model of the four steps of LS: teachers investigate their practice by studying, planning, conducting and reflecting.

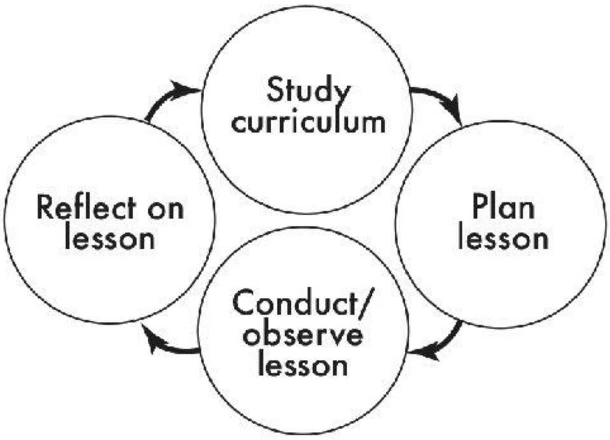

Figure 1: Lesson study cycle (Lewis et al. 2009a)

Step 1. Study curriculum and formulate goals
Step 2. Plan research lesson
Step 3. Conduct research lesson
Step 4. Reflect on research lesson and planning process

As LS has spread to numerous countries, there have been reinterpretations of the research cycle. Fujii (2014b) shows another conceptualisation of the LS cycle, highlighting goal-setting as phase one, at the beginning of the cycle. He also separates reflection into two phases, one devoted to discussion and the other focusing on broader reflection. Ní Shúilleabháin (2015) offers another conceptualisation and adds a fifth phase to Lewis's cycle, entitled revise and re-teach. This highlights the many forms of LS as it is reinterpreted in numerous PD programmes in various countries across the world (Lieberman 2009; Dudley 2013).

Building on Lewis et al. (2009a), Lewis (2016) analysed the impact of LS. Her model (Figure 2), which still includes four LS features (investigation, planning, research lesson, and reflection), is now extended into three pathways through which LS improves instruction. Lewis suggests that participating in LS improves four inputs of instruction: teacher knowledge, teacher beliefs and dispositions, teachers' learning community, and curriculum. Through participation in LS, teachers' dispositions to collaboration, reflective practice and researching the curriculum and their practice are integral.

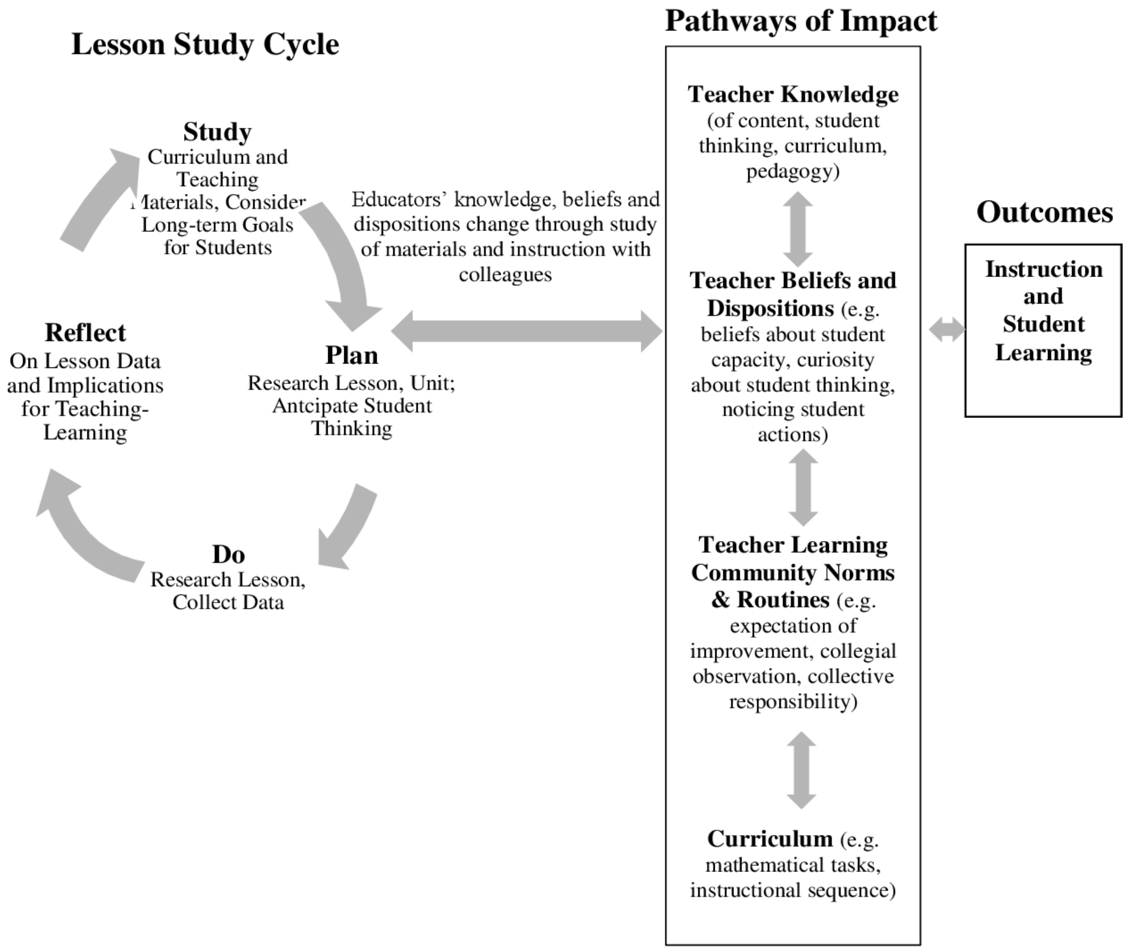

Figure 2: LS cycle and pathways of impact: a theoretical model (Lewis 2016)

Figure 1 (Lewis et al. 2009a) and Figure 2 (Lewis 2016) both link to the effective features of PD stated by Borko et al. (2010) and Desimone (2009). LS addresses problems of practice; it focuses on children's learning; preferred instructional practices are modelled in the research lessons; active learning and teacher inquiry are inherent throughout; collective participation through a professional learning community is encouraged; PD goals are school-based; coherence is apparent across teachers' beliefs and knowledge and wider policies/curricula; and, lastly, the LS cycle is spread over time to ensure it has a worthwhile impact on teacher learning (Desimone 2009; Borko et al. 2010).

Similar to Lewis's research (2016), Xu and Pedder (2014), in their international review of LS literature, found benefits to professional collaboration, development of knowledge, a renewed focus on children's learning, more awareness of the diverse needs of children, and improved classroom teaching and learning. Perry and Lewis (2011) state that their research on LS in the US has proven that when teachers are provided with high-quality instructional resources, practice-based opportunities to learn and collegial learning, they improve their knowledge, and children's learning is boosted. Cajkler et al.'s (2014) research in the UK asserts that the principle benefits of LS include increased teacher collaboration, enhanced teacher learning, enriched understanding of the children and improved classroom practice.

Borko et al. (2010) and Desimone (2009) both highlight the importance of the focus on children's learning during PD. LS particularly emphasises understanding and analysing children's learning during a research lesson (Murata 2011; Ylonen and Norwick 2012; Dudley 2013; Cajkler et al. 2015; Vermunt et al. 2019). Dudley believes that teachers participating in LS will discover 'unknowns' about children in their class. He writes that the joint planning of a lesson, predicting a case pupil's learning, and reviewing the learning observed after the lesson 'is one of the ways that LS reveals previously unseen aspects of the learning of case pupils and others in the class' (Dudley 2018).

The importance of PCK in LS has been highlighted (Ní Shúilleabháin 2015; Leavy and Hourigan 2018). Shulman (1987) proposed that PCK consists of the knowledge of content and students (KCS), knowledge of content and teaching (KCT) and the idea of curricular knowledge. Shulman's framework was later refined by Ball et al. (2008), Ball et al. subdivide Shulman's domain of subject matter knowledge into common content knowledge (CCK) and specialised content knowledge (SCK) as well as horizon content knowledge. Based on Ball et al. (2008) framework of knowledge for teaching, this research paid particular attention to how teachers employed their SMK and PCK during the LS cycles. During LS meetings, teachers engage in 'exploratory talk' as they design a lesson collaboratively; this involves teachers voicing parts of the lesson in order to understand how they might be interpreted by children (Dudley 2013). Dudley (2013) believes otherwise invisible, tacit PCK from LS members improves as teachers increase their responsiveness to children's needs (Dudley 2013). This is consistent with findings from Xu and Pedder (2014) that LS led to teachers developing a deeper understanding of children's diverse needs and a more acute responsiveness to those needs. Coenders and Verhoef (2019) believe that teachers assuming the role of observers supports them in noticing how children work, the different paces that children work at, and the habits they adopt when tackling problems. This leads to more effective class differentiation.

Vermunt et al. (2019) found that teachers' learning was of a higher quality when participating in LS. LS affected children's learning by developing teachers 'meaning-orientated' learning (Vermunt et al. 2019). This is supported by Desimone et al. (2013), who found that teachers discussing children's learning leads to higher-order instruction as teachers engage in problem-based learning. In a departure from research incorporating teachers' observations of children, Warwick et al. (2019) involved children directly in LS, using pupil voice as a trigger to improve teacher learning and teaching quality. They found that including pupil voice contributed to teachers' analysis of lessons and in some cases challenged teachers' assumptions about the pupils' experience of the lesson.

LS can also be beneficial for children with Special Educational Needs (SEN). Ylonen and Norwich (2015) found that LS had positive effects on teaching children with learning difficulties. Schipper et al. (2018) researched LS's effect on teachers' self-efficacy and adaptive teaching behaviour, evaluating whether teachers were competent in meeting the needs of all children in their class. They found that LS positively affected teachers' self-efficacy, but they found no significant differences in teachers' adaptive behaviour. In further research, Schipper et al. (2020) found that LS proved significant in changing teachers' perspectives about adaptive teaching, but again no intervention effects were found. Therefore, while LS places an emphasis on children's learning, and positive effects have been found, adaptive teaching requires further research.

2.2.2 Summary

Analysis of the literature outlines the tension that exists between traditional and contemporary approaches to professional development. The synergies of LS and effective PD such as those proposed by Desimone (2009) and Borko et al. (2010) were explored. LS is characterised by active collaboration and research; it is student-oriented, teacher-directed, context-based and reflective – characteristics that are very comparable to those of effective PD as recently identified in several review studies (Garet et al.

2001; Timperley et al. 2008; Darling-Hammond and Richardson 2009; Desimone 2009; Loucks-Horsley et al. 2009; Borko et al. 2010). Presently in Ireland, PD is largely concerned with meeting the needs of the system, 'with the purpose of implementing a DES-driven policy and it is about building teacher skills, rather than capacity' (O'Sullivan et al. 2011, p. 8). A more balanced approach is required where PD meets the needs of the system but also meets the needs of teachers; LS could be a way to achieve this aim.

2.3 LS in Japan and Worldwide

Now that we have examined the features of effective professional development, its parallels with LS, and the impact of LS on teachers and children's learning, it is necessary to examine LS in Japan. This section will briefly outline LS and its capacity to spread good practice in Japan, LS and its evolution in other countries, the challenges involved when adapting LS internationally, the transferability of LS to Ireland, and what LS practice is already evident in Ireland.

2.3.1 LS in Japan

In Japan, LS can occur at school, district and national level. There are four basic types of LS: school-based, district-level, university-attached laboratory schools, and LS sponsored by professional organisations (Murata 2011; Lewis and Takahashi 2013; Lewis 2016). Lewis (2016) believes there are links among the four types, though the purpose and focus change between them. The most common type of LS is a school-based PD programme in a single school (Yoshida 1999). Teachers may collaborate from different schools or subject areas, or teachers can meet who share similar professional interests (Murata and Takahashi 2002; Lewis et al. 2006a; Corcoran 2007). Lewis and Tsuchida (1998) have discussed the impact of research lessons and their potential to spread good practice; these seven points of impact will now be compared to LS research in other countries.

1. Improve classroom practice

Japanese research lessons improve classroom practice, from surface comments to more in-depth reflections on teaching, from simply giving feedback to a teacher on their lesson pacing to noting how many children contributed to the class discussion, and to broadening teachers' epistemological understand of teaching (Lewis and Tsuchida 1998). Cajkler et al. (2014) found that teachers engaged in pedagogic risk-taking, leading to less teacher-led instruction, as a result of their participation in LS. This evolving of teachers' beliefs and practices aligns with research conducted by Dudley (2013). He believes that LS supports the breaking down of self-consciousness between teachers, as they feel more comfortable to take pedagogic risks and improve their practice. He warns that new practice knowledge is fragile, but he maintains that passing on the new knowledge to colleagues can help cement it:

> LS then acts as a locus for co-construction of new knowledge between the LS group members and the imagining, observing, analysing and re-imagining of practice, and the effects of that practice help to distribute the cognition amongst the individual members.
> (Dudley 2013, p. 119)

Yoshida (2012) writes that Japanese teachers over a ten-year span usually observe and discuss a hundred research lessons. This supports teachers engaging in dialogue to critically discuss good practice. Yoshida believes this aids the sharing of good practice across the teaching community, as opposed to the American context, where 'good practice dies when a teacher retires' (2012, p. 149).

2. Spreading new content and approaches

LS allows teachers to collaborate on new topics, to question, problem-solve, and develop lessons, and this eases problems with teaching and learning. LS can be utilised to understand new pedagogical approaches, and it occupies a pivotal role in making new content accessible and adoptable in Japan (Lewis and Tsuchida 1998), thus connecting theory and practice (Murata 2011). Times of curriculum change create favourable conditions for LS (Takahashi and McDougal 2014; Ní Shúilleabháin and Seery 2018). LS enables teachers to collaborate and test out recent curriculum directions (Lewis et al. 2009a). Additionally, live public lessons enable practitioners to observe and question other practitioners' ideas on the application of curriculum reform (Lewis and Takahashi 2013). In Japan, LS has been used very successfully to facilitate teachers in times of major curriculum changes, from the inclusion of solar energy in the curriculum to the shift from 'teaching as telling' to 'teaching for understanding' in science (Lewis and Takashashi 2013). Similarly, in England, Vermunt et al. (2019) found that the collaborative learning during lesson design and reflection facilitates teachers as they encounter problems with new teaching approaches or learning methods. Likewise in Ireland, Ní Shúilleabháin and Seery (2018) found that LS supported the introduction of a new centralised maths curriculum, 'Project Maths', and the introduction of new practices.

3. Connecting classroom practice to broader goals

LS gives teachers the chance to discuss the big concepts and viewpoints dominating national educational debates (Lewis and Tsuchida 1998). Teachers have the opportunity to establish long-term goals for teaching and learning and to explore innovative approaches to their classroom practice (Lewis 2002b). Long-term goals may focus on broad ideals of children's motivation, children's ability to participate in group work, developing their love of a subject area, or developing their critical thinking or problem-solving skills. Dudley (2013) found that teachers working together towards the same goal had a unifying effect on participants. On a broader level, Lewis (2002b) believes the focus on long-term goals for academic and social development may stop teachers focusing on test results or other 'quick fixes'. Long-term aims also support teachers to reflect on the broader purpose of education, not the narrow aims of one lesson (McLaughlin and Talbert 2006).

4. Explore conflicting ideas

The collaboration inherent in LS enables each teacher to discuss their own philosophy, values, beliefs and understandings. When conflicting ideas arise, teachers can discuss and debate the implications and consequences (Lewis and Tsuchida 1998). During an LS cycle, teachers are more likely to observe the benefits of strategies that contrast with their own and to adjust their practice (Lewis and Tsuchida 1998). Dudley (2013) recognises the capacity of LS to alter teachers' long-held beliefs about pedagogical practices and children's learning revealed through research lessons. Lieberman (2009) notes, in her research of LS, that if an experienced teacher models openness and vulnerability about perceived weaknesses in their teaching, this creates the culture of openness.

Ireland's culture of collaboration is not as developed as Japan's, so teachers may be tentative in exploring conflicting ideas or exposing areas of practice they wish to improve. In his research with Irish primary teachers, Kitching (2009) recognises the discourse of the teacher as expert. He believes that in cultures of isolation and autonomy, teachers are more likely to solve problems independently rather than turn to colleagues to discuss possible solutions. Murray (2020) maintains that 'this culture of hiding difficulties can be linked to the construction of boundaries around a model of the "acceptable" teacher that does not permit the expression of vulnerability' (p. 10). Irish teachers may have to become more familiar with collaborative cultures before they are comfortable with dissonance or exposing vulnerabilities to their colleagues.

5. Creating demand

Research lessons broaden teachers' ideas of the potential of their teaching (Lewis and Tsuchida 1998). Teachers' appetite to improve their practice increases, as does the momentum for improvement (Lewis and Tsuchida 1998). LS helps teachers see their practice from a different perspective: 'teaching is not a one-way didactic path but a two-way integration of students' ideas and content exploration meaningfully facilitated by teachers, an endeavour that can be extremely challenging' (Murata 2011, p. 4). Through LS, teachers envisage the potential for improvement to their practice.

6. Shaping national policy

While all four types of LS provide unique learning opportunities and are responsive to the different needs of teachers (Murata 2011; Lewis and Takahashi 2013), live public research lessons are the heart of the process (Lewis 2002a). Lewis et al. (2012) believe that live public research lessons motivate teachers in their own practice and also enable them to adopt a learner's perspective. Live lessons:

> provide an opportunity to see, critique, and refine how the plans are actually brought to life, to meet colleagues who can be called on when questions arise, and to build a shared commitment to the ongoing work of changing one's practice.
>
> (Lewis et al. 2012, p. 369)

When conducting research lessons, outside commentators or more knowledgeable others (see section 2.4.5) can be invited to public research lessons. More knowledgeable others can include classroom teachers, principals, PD facilitators, third-level lecturers and policy makers. They are usually invited to support and guide the participants of the LS group. As teachers observe new approaches or practices being implemented, this can feed into the shaping of policy, allowing research to spread across the country (Lewis and Tsuchida 1998). Public lessons enable research to move from children in school-wide LS through district level, and it may influence national associations (Lewis and Takahashi 2013). Lewis and Takahashi (2013) compare Japan to the US in terms of the cooperation between macro and micro initiatives:

> the multiple forms of lesson study in Japan, and the synergistic relationships between government-sponsored inputs (such as national funding for designated research schools) and teacher-initiated inputs (such as choosing to focus school-wide lesson study on an upcoming curriculum change) greatly blur the dichotomies that are often clear in the US

> (grassroots vs government-sponsored; teacher ownership vs curriculum mandate).
> (Lewis and Takahashi 2013, p. 215)

In Ireland, the Professional Development Service for Teachers (PDST) has been instrumental in its support for LS. The PDST, funded by the Department of Education and Skills (DES), is Ireland's largest provider of PD to teachers and school leaders. In 2014, the PDST started an initiative in second-level schools, and LS is presently being adopted nationwide. As part of the PDST's post-primary 'Maths Counts' conference, it often invites an international expert on LS to conduct a live lesson. Live lessons may also be conducted by a small number of teachers. However, live research lessons have not become widespread practice in Ireland or the UK.

Additionally, since 2017 the PDST has been piloting LS in selected schools at primary level. In 2019, 19 schools participated, increasing to 21 schools in 2020. This usually culminates in a 'Lesson Study Shared Learning Day', with representatives from schools presenting posters on their experiences of LS. PD opportunities like these pave the way for teachers to affect policy. Another way that Irish teachers can influence national policy is through the National Council for Curriculum and Assessment (NCCA), a statutory body of the DES that develops curriculum and assessment at early childhood, primary, and post-primary levels. The NCCA is currently engaging in a consultation on the draft primary curriculum. Teachers are enabled to shape this curriculum through online questionnaires and focus group meetings. However, Irish teachers shaping national policy is not yet on the comprehensive systematic level that occurs in Japan.

7. Honouring the role of classroom teaching

LS enables classroom teachers to have ownership over their PD. LS acknowledges the autonomous role of teachers, who are best placed to understand their students' needs and to develop their own course to shape their practice. Some of these teachers can also receive national recognition (Lewis and Tuschida 1998).

> Improving something as complex and culturally embedded as teaching requires the efforts of all the players, including students, parents and politicians. But teachers must be the primary driving force behind change. They are best positioned to understand the problems that children face and to generate possible solutions.
> (Stigler and Hiebert 1999, p. 135)

LS respects the role of teachers, as they are not expected to be passive recipients of curriculum reform (Lewis and Tuschida 1998). Through LS, some teachers write research articles, contribute to curriculum textbooks and conduct research lessons; this provides avenues for teachers to become known nationally (Lewis and Tuschida 1998). This is not common practice in the US (Lewis et al. 2009a) or in Ireland.

2.3.2 The evolving nature of LS outside Japan

Teaching is a cultural activity (Stigler and Hiebert 1999), and throughout the years different forms of LS have developed as it has been adopted and adapted in different countries (Murata 2011). Learning study (Lo and Marton 2012), Chinese LS (Huang and Bao 2006), and British LS (Dudley 2013) are all variations of traditional Japanese LS (Table 1). Elliott (2019) maintains that learning study is a combination of LS and variation theory, focusing on children's experience of learning and not solely on teaching methods or approaches. Huang and Shimizu (2016) write that Chinese LS differs from traditional Japanese LS in three ways: Chinese LS culminates in the development of a model lesson; the knowledgeable other may be involved in the whole process; and teachers repeat the teaching until they feel satisfied that teaching goals are achieved.

	Focus on children's learning	Classroom based	Building a collaborative community	Repeated teaching of the same lesson	Involvement of case pupils	Involvement of MKO
Japanese LS	X	X	X			X
Learning Study	X	X	X	X		X
Chinese LS	X	X	X	X		X
British LS	X	X	X		X	

Table 1: Comparison table comparing Japanese LS, Learning Study, Chinese LS and British LS

Elliott (2019) believes that the US's improving test scores in the Programme for International Student Assessment (PISA) and Trends in International Maths and Science Studies (TIMSS) assessment were the catalyst for the UK and many other western countries to adopt LS. LS is in the preliminary stages in the UK, so there is a growing number of studies conducted to date. LS has been used in initial teacher education

(Cajkler et al. 2013), second-level (Ylonen and Norwich 2012; Cajkler et al. 2014; Warwick et al. 2019) and primary-level education (Dudley 2013; Vrikki et al. 2017). Research LS (see Figure 3) was developed by Dudley (Warwick et al. 2019). LS in the UK is different from that implemented elsewhere because of its focus on 'case pupils' in planning and analysing research lessons. The case pupils (typically three) are interviewed after the lesson. After three cycles, the teachers reflect on their learning and may invite colleagues to an 'open house' (Dudley 2013).

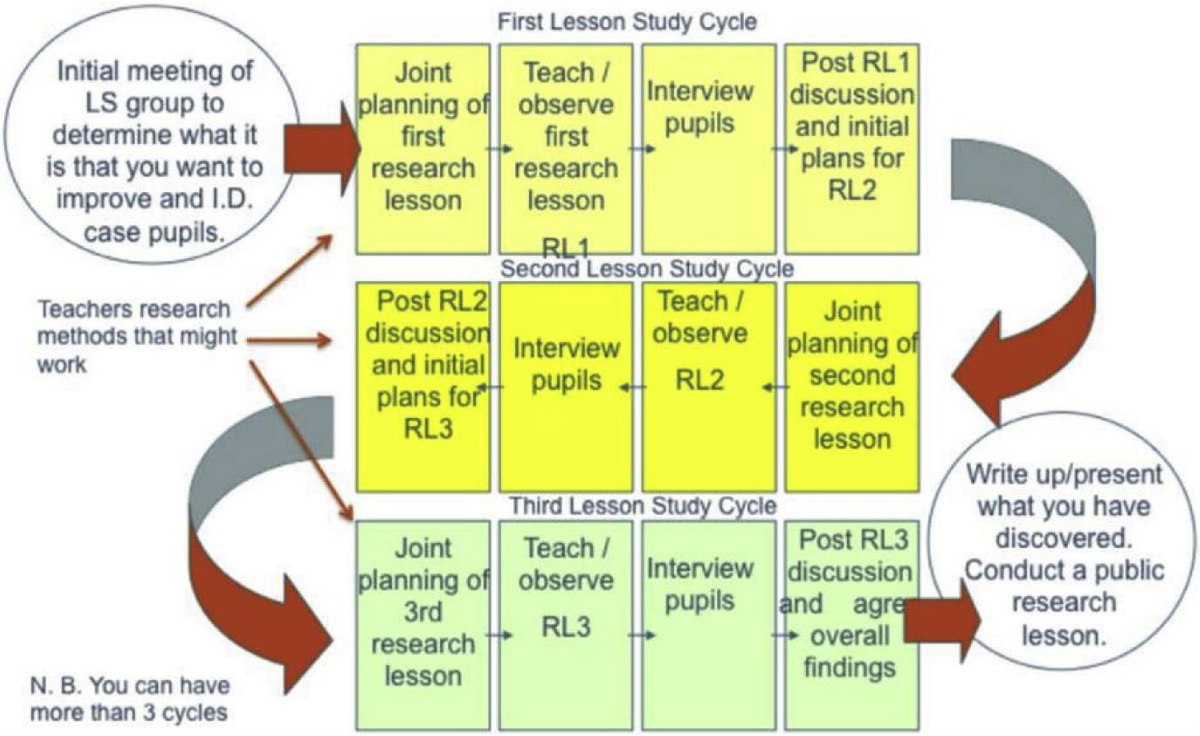

Figure 3: Lesson study process used in the UK, according to Dudley (2013)

Acknowledging critics who are sceptical that LS can be implemented as a form of PD because of existing school structures, indications are that it is possible and can be successful (James and Pollard 2008).

2.3.3 Adapting cultural practices in other countries

LS is essentially 'like the air' in Japan (Fujii 2014a), institutionalised through support by robust networks of schools and universities (Lewis and Takashashi 2013). Strong teacher leadership provides the foundation for LS, as it is not mandated by policy makers (Akiba and Wilkinson 2016). Lewis et al. (2006) recognise that LS is relatively simple to do but difficult to do effectively. LS has not always been successful outside of Japan (Murata 2011; Fujii 2014a; Takahashi 2014; Wolthuis et al. 2020). Generating local knowledge of practice in one context and making it applicable and accessible to other contexts is complex (Corcoran and Pepperell 2011; Stigler and Hiebert 2016). Researchers and authors have been open about LS's limitations and potential pitfalls. Lewis (2020) writes: 'LS cannot be borrowed but just be thoughtfully adapted to our own very different educational system and culture' (p. 20). Similarly, Murata (2011) believes that modifications are to be expected and are vital, as teaching is a localised activity. However, she warns that too many adjustments could make LS ineffective.

Takahashi (2014) notes many differences between the implementation of LS inside and outside Japan. Takahashi and McDougal (2016) believe that some aspects have been lost in translation and that the purpose of LS has been misinterpreted. They write that crucial practices are identified that are omitted from LS as it moves westwards. These include the initial step of LS *kyouzai kenkyuu*, which should involve significant time input; the timeframe for LS should cover a number of weeks rather than hours; the objective of LS is not to design the perfect lesson but to learn something new or improve practice; and, lastly, more knowledgeable others offer valuable insights during the planning phases and reflection meetings (Takahashi and McDougal 2016). Given these changes, they sometimes use the term *collaborative lesson research* (CLR) instead of *lesson study* in the US (Takahashi and McDougal 2016).

Numerous other challenges to LS have been cited concerning the cultural contexts of settings and the structure of schools. Obstacles to LS include the cost of implementation, sustainability, insufficient teacher content knowledge and connection to student learning, teachers' lack of familiarity with the research process, lack of resources, teachers' already hectic work schedules, lack of strong leadership, extra stress for teachers to refine their practice, and problems in collaboration (Murata 2011; Akiba and Wilkinson 2016; Schipper et al. 2017; Wolthuis et al. 2020). Professional learning is not embedded into teachers' work schedules, and essentially teachers are accustomed to autonomy in their daily practice (Akiba et al. 2019). Similarly, participants in a study by Wolthuis et al. (2020) felt that the LS process was too time-consuming for what it yielded: 'one lesson plan or a one-time insight into student responses' (p. 10). Wolthuis et al. (2020) believe that if long-term, school-based PD is to become the norm, a cultural shift is required involving teachers changing their perspective of professional development. This may take time to develop (Murata 2011; Yoshida 2012; Wolthuis et al. 2020).

Considering the various challenges faced by schools in adopting and adapting LS, it is unsurprising that its sustainability has been challenging in some countries (Wolthuis et al. 2020). Murata (2011) adds that teachers are not accustomed to PD being sustained from year to year; she believes that teachers may practise LS for one year and then expect to move on to their next PD experience. Mulcahy-O'Mahony (2013), in her PhD research, carried out a model of PD based on the principles of the Japanese system of *jugyou kenkyuu* (lesson study) in two Irish primary schools. Like Murata (2011), she found that while teachers preferred PD that was in-school and during term time, they were reluctant to give up their one-shot workshop: 'it would seem that teachers have been enculturated into a model of professional development which removes them from their places of practice' (2013, p. 323).

In their research in the UK, Cajkler et al. (2014) found that LS was not sustained after the research, despite enhanced teacher community and improvements to student learning with the introduction of LS. They identified challenges and questioned the 'feasibility of including LS in a school's PD programme' and enticing teachers and leaders to invest their time (Cajkler et al. 2014, p. 527). They also found that strong leadership is required for LS to be a sustainable change in the school, because it requires cultural and structural changes. They warn that sustainability of LS in schools could be resisted by teachers if immediate changes are expected in results.

Akiba and Wilkinson (2016) discuss the importance of incentives to encourage teachers to devote extra time to embracing a new form of professional development, added to an already busy schedule and numerous obligations. They believe that district authorities should be required to support capacity-building at district, school and teacher level. They offer numerous suggestions for ways that districts can support LS: introducing new routines for PD, working with external experts, providing training for administrators and teachers, assigning a facilitator specifically for LS, and substituting some PD programmes with LS. Akiba and Wilkinson (2016) also envisage districts providing LS training for teachers, and once they begin an LS cycle, the districts should continue to offer guidance throughout the LS stages. Murata (2011) recognises the significant cost as schools implement LS. Because it requires extensive time from teachers, she believes substitute teachers are required for shared observations; payment may also be required for facilitators and more knowledgeable others. Additional reimbursement for teachers participating in after-school LS meetings would also give teachers a significant incentive (Murata 2011).

2.3.4 Transferability of LS to Ireland

LS has been adopted in the US, Canada, Britain, Europe and parts of Asia. The question then arises: How will LS be adapted to fit into various countries' cultures? Considering the concerns and challenges mentioned, it would be understandable to question LS's potential adaptability to the Irish primary-school setting. Using Lewis's (2002b) seven supporting conditions, the education practices of Japan and Ireland will now be discussed and compared, to identify existing practices that would support LS, and equally practices that are required to be developed.

1. A shared frugal curriculum

Japan has a very sparse curriculum. Japanese teachers usually teach their classes for two years and then rotate to other class levels. In Ireland, there are no conditions for teachers teaching different class levels; many teachers may teach one class repeatedly, and it is left to individual schools to decide these practices. Japanese textbook publishers often include teachers' lesson plans that have been discussed at district level, because they will contain good-quality, realistic maths content (Murata and Takahashi 2002). Irish research suggests that teachers rely heavily on textbooks. There is heavy dependence on science textbooks in particular (DES 2012), and teachers have been found to adopt traditional, didactic approaches (Murphy, Neil and Beggs 2007; Murphy et al. 2012). It has also been noted that Irish maths textbooks do not align with the curriculum, do not address differentiation, and limit creativity, active learning and critical thinking (INTO 2015).

2. Established collaboration

Japanese educational culture is one of established collaboration. In recent years the Irish education system has been promoting teacher collaboration, with the introduction of School Self-Evaluation and *Literacy and Numeracy for Learning and Life* (DES 2011b) and several policies from the Teaching Council. In 2016 the DES developed *Looking at Our School* (LAOS), whose domain 4, 'Teachers' Collective/Collaborative Practice', contains the following statements of effective practice:

- Teachers value and engage in professional development and professional collaboration
- Teachers work together to devise learning opportunities for pupils across and beyond the curriculum
- Teachers contribute to building whole staff capacity by sharing their expertise

(DES 2016a, pp. 20–21)

Relative to Japan, however, Ireland does not have a long history of collaborative culture in schools. Murray (2020) argues that ‘in the Irish context, the teaching profession, accustomed to isolation and a lack of collegiality, is particularly susceptible to current discourses of competitive individualism’ (p. 14). The individual nature of classroom teaching and PD can impede collaborative culture (Lewis et al. 2009a; Brosnan 2014). Brosnan (2014) found that a requirement for successful LS in Irish second-level schools is a shared professional culture with mutual trust. Schools with scant experience of collaboration would therefore require considerable coaching in the practice and may even be reluctant and dubious about LS.

3. A belief that teaching can be improved through collective effort

Japanese teachers have an established teacher community (Lewis 2002b). Therefore, the culture of the school largely dictates the belief that teaching can be improved through collective effort. However, LS is quite different from the type of PD to which Irish teachers are accustomed. Traditionally, practice-based professional learning is not common in Ireland (Jeffers 2006). However, recent studies have found that teachers wished for PD to reflect their personal and school needs (Guiden and Brennan 2017) and that PD should be collaborative and part of a professional team (Foley 2017). These studies reflect Irish teachers’ current views on PD and their wish for its future to be more school-based and collaborative.

4. Self-critical reflection

While self-critical reflection is entrenched in Japanese school culture, this is helped by broader Japanese culture (Lewis 2002a). External evaluations are understated in Japan. In Ireland, the Teaching Council is introducing initiatives to promote teachers as reflective practitioners (Murray 2020), but it could not be said that teachers have a strong culture of self-reflection. Walsh (2020) writes that it is problematic for leaders to schedule time for teachers to engage in collaborative planning and reflection, as teachers are teaching for most of the day. But current research indicates that a high level of reflection is integral to effective PD (Wasik et al. 2006; Grimmett 2014).

5. Stability of educational policy

The Japanese Ministry of Education accepts the time it takes for real educational change to take root. Hence, it usually allows two decades for major educational change to occur. Similarly, Ireland has seen the introduction of the 1971 Curriculum and the 1999

Curriculum, and the new language curriculum is currently being implemented. Sugrue (2004) highlights that curriculum planning at national level has gone from ‘being a highly centralised and sometimes mysterious process within the state Department of Education to adopting more open and participative procedures’ (p. 68). Although the new primary maths curriculum was due to be introduced in 2020/21, it is being delayed in recognition of the present scale of curricular change. In addition, the NCCA is currently reviewing and redeveloping the entire primary curriculum. This is very welcome, given reports of various constraints including time and curriculum overload (NCCA 2010; Banks and Smyth 2011; Sugrue 2011; INTO 2015; Murray 2020).

6. Class time focused on instruction

Although Japanese and American children spend the same amount of time studying science, Japanese children focus on a smaller number of topics (Lewis and Tsuchida 1998). Japanese children seem to have fewer topics and to study topics in depth, and many of these topics have objectives focused on children’s interest (ibid.). It is reassuring to note that there are plans to address curriculum overload in the new Irish primary curriculum (McCoy et al. 2012; NCCA 2012). The proposed framework aims to move away from eleven subjects to five broad curriculum areas in the first four years of primary school. A redeveloped primary curriculum would align early years and primary education (Moloney 2017). Aistear (NCCA 2009) would be a focal point of this newly aligned curriculum.[2] This redeveloped curriculum would espouse the principles and themes of Aistear and would have an integrated approach to learning. This would help children’s transition from the early years setting to the primary school setting, ease curriculum overload and promote a play-based pedagogy (Moloney 2017).

7. Focus on the whole child

In their research, Lewis and Tsuchida (1998) acknowledge the Japanese education system’s focus on children’s holistic development. Japan seeks to develop the emotional, intellectual, physical, social, ethical and aesthetic sides of the child (ibid.). Establishing a positive connection towards school and developing children’s character are a focus of the curriculum (ibid.). Elementary schools aim to develop friendships and

[2] Aistear (NCCA 2009) is the curriculum framework for children from birth to six years. This age span incorporates children in their first two years of primary school. Aistear focuses on the development of values and learning dispositions, reflecting the most current research in how young children develop and learn.

a sense of belonging by giving children a say in the running of their class and school. Moral education is integral and is focused on through Japan's national *Course of Study for Elementary Schools* (ibid.). Classes are expected to work together to form class goals and personal goals, encouraging the children to reflect on their behaviour and to be responsible for their actions (ibid.). Japan holds high expectations for students: that 'all, or very nearly all, children can learn to high standards. In many Western countries … the assumption is that student achievement is a function of inherited learning capacity' (Janes 2010, p. 151). Ireland can also be commended for emphasising children's holistic development (Aistear, 2009; Primary School Curriculum, 1999; Action Plan for Education 2016–2019). However, O'Flaherty and McCormack (2019) found that children's holistic development was largely catered for in extracurricular settings and was heavily reliant on teachers' goodwill.

In Japan, there is no ability grouping or tracking (Lewis and Tsuchida 1998). In her research of Irish second-level schools, Smyth (2018) found that ability grouping was present in some schools in maths, Irish and English. Many researchers disagree with ability groupings in maths, believing that the message this sends is very negative and damaging for children (Boaler 2009). Boaler (2009) believes that ability groupings imply that teachers have lower expectations for children and focus on low-level, cognitive activities, stifling children's achievement and in turn affecting children's view of themselves.

Lewis's seven supporting conditions (2002) outline the type of education system in which LS has grown. It indicates that while there are notable differences between the Japanese and Irish educational systems, there is potential in the Irish system. The Teaching Council, PDST and NCCA are introducing initiatives that would complement the use of LS in schools. Additionally, the roll-out of the primary curriculum could whet teachers' appetite to engage in collaborative PD.

2.3.5 LS in Ireland

LS is a relatively new phenomenon in Ireland. But it has now been included in several initial teacher education programmes, with researchers examining the benefits for pre-service teachers (Corcoran and Pepperell 2011; Leavy 2010, 2015; Hourigan and Leavy 2016; 2019, Leavy and Hourigan 2018; Ní Shúilleabháin and Bjuland 2019). LS in initial teacher training in Ireland consists of pre-service primary teachers in Mary Immaculate College and Dublin City University, while pre-service secondary teachers conduct LS in University College Dublin. All three institutions focus on maths teaching, with the maths educators acting as members of the LS group or more knowledgeable others. There is minimal involvement of the classroom teacher.

In Mary Immaculate College, Leavy and Hourigan have carried out extensive research on LS, having spent ten years implementing LS with over 225 children in 45 cases (Hourigan and Leavy 2019). Their work has greatly contributed to the research base on Irish LS and initial teacher education. They have found that LS deepened pre-service teachers' maths content knowledge in conjunction with their PCK (Leavy 2010, 2015; Leavy and Hourigan 2016, 2018). LS encouraged pre-service teachers' reflective practice and increased their comprehension of children's thinking (Leavy and Hourigan 2016). LS improved pre-service teachers' observation skills and consequently their confidence in the classroom (Hourigan and Leavy 2019). As well as researching initial teacher education, the authors' focus has varied widely, with research investigating LS cycles focusing on a range of maths concepts across the primary school (Leavy and Hourigan 2018; Hourigan and Leavy 2019), LS in the Irish immersion setting (Leavy et al. 2018) and LS in integrated STEM education (Hourigan and Leavy 2020).

LS was also used in second-level schooling to support the implementation of the new Project Maths curriculum in 2013. Brosnan (2014) used LS in 24 post-primary schools. In this study, schools were provided with substitution (two full school days). Although LS 'partially failed in the first instance (2008–2009)', years later Brosnan found:

> There was a growing appetite to engage in ongoing collaboration and effective teamwork. This may be one of the progressive gains of introducing LS in the first year (2008–2009). A culture of sharing had grown slowly.
>
> (Brosnan 2014, p. 246)

Brosnan found that a professional school culture and dedicated leadership are required to provide impetus to the LS groups. Additionally, Ní Shúilleabháin and Seery (2018) investigated how teachers' pedagogical practices and beliefs about student learning were impacted as a result of their participation in LS. The findings showed a change in teachers' pedagogical approaches and attitudes to supporting students in communicating their mathematical thinking; teachers' enhanced awareness of themselves as facilitators; and providing students with a context for their learning. Furthermore, findings suggest that teachers facilitated students' inquiry, engaging them in a productive struggle, thereby increasing their engagement. The authors acknowledge that external funding and school leadership encouraged the teachers' participation in this case study. The teachers also highlighted that their voluntary participation was an important factor to aid their willingness to participate. Because LS requires time for teacher planning, dialogue and reflection, it is perhaps not surprising that the teachers expressed their wish for LS to be scheduled into their 'Croke Park' hours.[3] These recommendations provide insight into the possible factors necessary for implementation of LS at primary level.

Ní Shúilleabháin's (2016) research investigated the development of second-level maths teachers' PCK over successive cycles of LS. It highlighted that the different collaborative cultures in schools affect the implementation of LS. School culture was decidedly different in each of the two schools studied, Crannog and Doone. Crannog practised collaboration regularly; it held teacher and departmental meetings and shared resources. In contrast, Doone did not share resources and had no physical space for teachers to collaborate. In contrast to Doone, teachers in Crannog 'did not see LS as an "add-on" but rather as a model which benefitted their practice, knowledge, and collaboration' (ibid. p. 223). In Crannog, the support of school leadership enabled LS to be sustained for the next academic year, but LS was not continued in Doone. This research highlights the benefits and intricacies of collaboration and collegial support. This is a challenge for LS in Irish schools, because many schools do not have the structures and frameworks for teacher collaboration and dialogue.

2.3.6 Summary

When LS is adopted outside of Japan, it usually does not retain the same structure as the Japanese model. How LS can become embedded and sustained in different contexts, while preserving the features that make it effective, is a challenging question. LS is integral to the education system in Japan, where it is nurtured by a culture of collaboration, reflection and research. Ireland, by contrast, does not have a long tradition of those features, making the adoption and adaptation of LS daunting. Ireland has made significant progress in including LS in initial teacher education and second-level education, but development is still required in implementing LS across primary education.

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[3] Under the Croke Park Agreement, teachers are required to work an additional 36 non-contact hours per year (DES 2011a).

2.4 What Supports Are Required for LS to Grow in Ireland?

Lewis has written comprehensively on LS, and in 2002 she raised questions regarding the transfer of LS to the United States. In 2020, those questions can be directed to the development of LS in the Irish education system:

- What are the essential features of LS that must be honoured when LS is conducted in the US (and what are the non-essential features that can be changed)?
- How do educators improve instruction through LS?
- What supports will be needed for LS in the US, given its educational system and culture? (Lewis 2002b, p. 5)

Since we have explored the first two questions, the current section will discuss the final question: What supports are required to be further developed in Irish schools, given its educational system and culture? In order to understand this question, a comprehensive review of the literature was necessary. This resulted in important supports for LS being revealed: collaboration, school leadership, teacher agency, the teacher as researcher, the more knowledgeable other, and reflective practice. These features will now be discussed with a view to the implementation of LS in the Irish education context.

2.4.1 Collaboration

Elliott believes that the main challenge to LS being adopted in other countries is to create the culture of collaboration:

> One of the most neglected features of the globalisation of the lesson study phenomenon has been a lack of serious attention to the problems of effecting change in the dominant organisational culture of individualism that shapes schooling.
>
> (Elliott 2019, p. 183)

Literature indicates that the Irish education system has traditionally endured low levels of collaboration (Coolahan 2003; Hogan et al. 2007; O'Sullivan 2011; Murray 2020). In their research, Hogan et al. found that teachers 'highlight the prevalence of professional insulation and isolation, as distinct from proactive professional co-operation, in the inherited cultures of post-primary education in Ireland' (2007, p. 34). They report that teachers rarely partook in collaboration on learning issues, peer reviews or self-evaluations or had any involvement in school planning. This correlates to later findings by O'Donovan:

> a significant finding, and meriting further research and discussion, is that the isolationist

> culture continues to pertain. Traditionally in Ireland, the teacher has had virtual autonomy in the classroom, operating behind a 'closed door' culture. Across the case-study schools, the principals express a reticence to counter that culture, in deference to staff sensibilities and micro-politics and to remnants of a culture where the powerful teacher unions vehemently supported the 'closed door' system. From a distributed instructional leadership perspective, this presents challenges to principals and school communities to negotiate meaning anew.
>
> (O'Donovan 2015, p. 263)

In her research O'Sullivan states that Irish culture and practice is that of 'a national teaching environment where isolated practice still predominates' (2011, p. 112). She shares a conceptual model for learning collaborative practice.

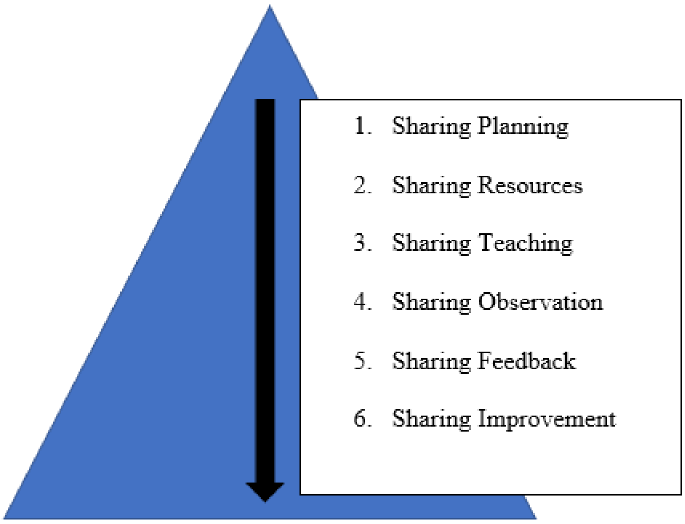

Figure 4: Conceptual Model for Learning Collaborative Practice (O'Sullivan 2010)

O'Sullivan (2010) suggests that level one, sharing planning, is where Irish teachers are more comfortable however this 'is only the tip of the iceberg' (p. 18). Similarly, Murray's research revealed that collegiality was irregular, and instead teachers were focused on 'coping' with isolation (2020, p. 14). Jeffers (2006) associates teacher isolation with noteworthy drawbacks for teachers' professional development, including a lack of support and feedback being inhibited.

While recent policy documents and Teaching Council initiatives have emphasised professional collaboration (see section 1.4), teachers are effectively being asked to collaborate without a strong history of it in the profession. When looking at Brosnan's research (2014) of LS in Irish schools, Posch (2015) acknowledges that the collaborative culture amongst teachers was not yet developed. Teachers did not seem to be ready for the level of collaboration LS required, and Brosnan comments, ‘for many teachers the cultural shift from their insulation and isolation proved a step too far, too quickly’ (2014, p. 242). As Yoshida asserts, ‘isolation is the enemy of lesson study’ (2012, p. 149).

While teacher collaboration is a prerequisite for LS, it is no easy feat to move from teaching as an isolated practitioner and working under conditions of relative autonomy to being a member of an educational community. Hargreaves (2001) believes that the changing role of the teacher necessitates letting go of the culture of individuality. Schipper et al. (2017) caution that if teachers are accustomed to working individually or competitively, it is very difficult for a culture of collaboration to take hold. Different forms of collegiality can evolve in schools, dependent on the prevailing culture and context (Murray 2020). Murray (2020) points out that the idea of collaboration may be perceived as surrendering one’s autonomy, therefore it may not be welcomed by all. Furthermore, some educational cultures aiming to enhance collaboration have turned out to be weak, with teachers exchanging resources and ‘tricks of the trade’ rather than scrutinising practice together (Little 1990; Fullan and Hargreaves 1996).

LS is heavily dependent on rich collaboration between educational practitioners and a team spirit permeating throughout the process. Corcoran and Pepperell (2011) write that LS gives teachers an opportunity to deepen their learning and discover how to engage children in meaningful learning. While the focus is on collaboration, it must also involve a critique of practice (Corcoran and Pepperell 2011). Collaboration helps teachers to reflect on their practice, trial new ideas and observe the effects on children’s learning (Lieberman 2009; Dudley 2013). By participating in LS, teachers have the time and space to experiment with new strategies and opportunities to learn from each other. However, when considering Ireland’s position, it seems to have a tentative hold on a truly collaborative culture. The practical logistics and the culture of collaboration in a school would heavily impact on LS’s adoption and success. Given Brosnan’s (2014) finding that the development of a collaborative culture is a slow process, it should not be rushed as teachers negotiate productive, professional relationships.

2.4.1.1 Professional capital

Cajkler et al. (2014) and Dudley (2013) link increased collaboration during LS to teachers developing professional capital (Hargreaves and Fullan 2012). Hargreaves and

Fullan (2012) argue that for successful development of the teaching profession instead of focusing on individual performance, there must be a focus on capacity-building amongst the whole teaching profession. The power of professional capital lies in uniting teachers in collaborative efforts. Elemental to the development of professional capital are three other types of capital: human, social and decisional. Human capital describes the individual capability of each teacher, and social capital refers to how teachers collaborate. Dudley believes that LS unites its participants in a learning community as they collaborate to improve children's learning, thus building social capital:

> The features of interaction and collaboration in the work of these LS groups reveal how important is the building and use of social capital tools and resources amongst group members for creating conditions for teacher learning and also how powerful the ontogenetic will to improve pupils' learning adds momentum to this.
>
> (Dudley 2013, p. 118)

Human and social capital equip teachers with enhanced decisional capital, that is, their capacity to make effective judgements about their practice. Teachers' collaborative reflection is a core underpinning of Hargreaves and Fullan's theory on professional capital: 'you learn more and improve more if you are able to work, plan, and make decisions with other teachers rather than having to make everything up or bear every burden by yourself' (2012, p. 102). However, Murray (2020) concedes it can be difficult for professional capital to develop in a school with a weak collaborative culture. She believes that structured collaboration or mentoring initiatives are 'a necessary first step to developing professional capital in these contexts' (2020, p. 14).

2.4.1.2 Trust

Relatively little research is devoted to the building of trust between participants in the initial stages of LS, but trust between colleagues is pivotal to the creation and flourishing of collaborative relationships during LS. Educational success is a function of high social capital. According to Field (2003), the theory of social capital is encapsulated in the words 'relationships matter'. The foundations of social capital models include trust, collaborative action, shared identity and engagement. Trust is the springboard for the other three components. Developing these values brings the school community together, enriches social capital and maximises the school's capacity to learn. Dudley (2013) found that as teachers participated in LS, social capital was built amongst the group as they became accustomed to dissonance and challenge and became more flexible to resolve disagreements.

Bryk and Schneider (2003) found strong relationships between social trust amongst teachers, parents and school leaders and a school's capacity to improve and reform. Schools with strong levels of trust at the outset of a programme to improve maths and reading had a one in two chance of improving, while schools with weak relationships had only a one in seven chance of improving. Similarly, Barth believes that if relationships among the adults in education are trusting and cooperative, this has greater effect than anything else on the quality of the school and on children's learning: 'teachers demonstrate all too well a capacity to either enrich or diminish one another's lives and thereby enrich or diminish their schools' (Barth 2006, p. 9). Positive relationships between colleagues promote valuable teaching and learning experiences. Positive colleagues are willing to collaborate with one another, engage in productive dialogue and offer advice and encouragement if needed. Lencioni describes the five dysfunctions of team collaboration, warning that they are interrelated, 'making

Figure 5:Five Dysfunctions of a Team

susceptibility to even one of them potentially lethal for the success of the team' (2002 p. 187). As the diagram shows, trust is the building block.

School leaders are pivotal when steering their team towards a culture of collaboration, as they are critical when cultivating trust and empathy through professional relationships amongst colleagues. In O'Donovan's (2015) research, many Irish principals cited the importance of developing a culture of trust, but she found there were differences in how trust was enacted in schools. Some principals referred to the importance of empowering teachers, developing a risk-taking culture and distributing leadership (ibid.).

There is a challenge for Irish principals in creating and sustaining a collaborative culture, because many features have to combine to ensure success. The school leader must inspire trust among their colleagues, create a space of safety and respect for productive conflict, and drive teachers to commit: 'effective school leaders help develop school cultures that embody shared norms, values, beliefs and attitudes and that promote mutual caring and trust among all members' (Leithwood and Riehl 2003, p. 7).

2.4.2 School leadership

Current educational policy from the Teaching Council reflects the merging of collaboration, PD and leadership. Building a collaborative culture and the opportunities for teachers' PD depends on the leadership of the school; the Teaching Council states, 'the intensity of this cooperation and learning among staff also depends on leadership within the school and the degree to which opportunities are created for teachers' professional learning' (Banks and Smyth 2011, p. 10). In the first domain of leading teaching and learning, *Looking at Our School* (2016) states that the principal must promote a culture of collaboration and the PD of staff.

> Domain 1: Leading Learning and Teaching
>
> - Promote a culture of improvement, collaboration, innovation and creativity in learning, teaching, and
> - Foster teacher professional development that enriches teachers' and pupils' learning
>
> (DES 2016a, pp 22–23)

In broader terms, school leaders have a responsibility to create a learning culture and the optimum conditions for teachers to learn (Stoll et al. 2006). McLaughlin and Talbert write that 'because of their positional authority and control over school resources, principals are in a strategic position to promote or inhibit the development of a teacher learning community in their school' (2006, p. 56).

The important role of leadership is therefore understandable if LS is to take root in a school (Dudley 2013; Mulcahy-O'Mahony 2013; Ní Shúilleabháin 2016; Takahashi and McDougal 2016; Schipper et al. 2017). Dudley (2013) believes that many school leaders are discouraged from LS due to timetabling, staff buy-in and the school budget. For LS to be introduced to Ireland, principals and teachers would be required to learn about the process. LS would have to be led and organised by a leadership team in the school. Analysing the demographics, however, we find that three quarters of principals in small rural schools teach full-time, while one quarter of principals in large urban schools take up full-time administrative posts (Stynes and McNamara 2018). LS in rural schools would be challenging to introduce, given principals' current hectic workload. Distributed leadership is therefore vital if LS is to be sustained (Perry and Lewis 2009).

2.4.3 Teacher agency

Traditionally, teacher agency in PD has been practically invisible. Teachers have become accustomed to choosing from a range of predetermined PD courses. These courses, usually supplied by the DES, offer little prominence to teachers recognising and addressing their own PD requirements. This raises questions about power and who is exercising it. Halliday finds that 'technicism dominates current policy and practice' (1998, p. 597). He defines technicism as 'the notion that good teaching is equivalent to efficient performance which achieves ends that are prescribed for teachers' (ibid.). Since knowledge is to be transmitted efficiently to pupils, and then teachers are trained in effective instruction, such an approach renders their reflective consciousnesses redundant. Kraft agrees that teachers need to engage in research so that they become 'more than mere technicians who apply initiatives handed to them by others (2002, p. 175)'. Stenhouse highlights the importance of teachers as researchers and autonomous professionals:

> the outstanding characteristics of the extended professional is a capacity for autonomous professional self-development through systematic self-study, through the study of the work of other teachers and through the testing of ideas by classroom research procedures.
>
> (Stenhouse 1975, p. 144)

Admittedly, School Self-Evaluation could be viewed as a means of addressing teacher agency, as it is a process of internal school review.[4] The Inspectorate aims to empower school development, but it is mandatory. The language of the document *Literacy and Numeracy for Learning and Life* (DES 2011b) describes target-setting, and this raises the issue of power, which is reminiscent of Foucault. Each school must monitor its progress and set goals and deadlines, which again raises concerns about teacher voice. Brown et al. (2017) highlight the current debate on the correct balance between School Self-Evaluations and inspections and whether schools should be adopting more responsibility for their evaluations. Instead of inspiring and urging teachers to exercise their agency, the DES seeks to enforce collaboration into a system that is traditionally individualistic.

[4] School Self-Evaluation (SSE) is a reflective process of internal school review.

Dudley believes that LS may be seen as a motivator for schools in the UK and US to compete in the international comparisons PISA and TIMSS. In this case, Elliott warns that 'LS becomes part of a system for "managing the performance" of teachers to secure "good grades" … LS will be "cherry picked" and forged to fit an organisational culture that is driven by test data' (2019, p. 76). Elliott (2019) warns that as LS has been globalised, teachers may not be seen as curriculum developers but instead as curriculum implementers. He believes that teachers should be working with more knowledgeable others to construct professional knowledge platforms; as the platform develops over time, rich pedagogical knowledge will be available to all teachers. He notes that most LS research is authored by academics and advises that teachers should be co-authors and authors of research. Similarly, Vermunt et al. (2019) recognise LS as a vehicle to promote teachers' agency in their PD. They praise it as an approach that enables teachers to assume ownership of their learning. In Ireland, as teachers and PDST facilitators co-author posters on their findings at the Lesson Study Shared Learning Day, this could be viewed as teachers writing research. However, the teaching culture has significant progress to make before this becomes common practice amongst the teaching profession.

2.4.4 Teacher as researcher

Over the past decades, McGee and Lawrence write, 'the trend in teacher research has shifted from research on teachers to research with and by teachers' (2009, p. 139). This is not a new phenomenon: in 1975, Stenhouse argued that teachers should be classroom researchers and play an active part in curriculum development. Yet in 1996 this was not the case, and Hargreaves noted the 'yawning gap between theory and practice and the low value of research as a guide to the solution of practical problems' (1996, p. 2). This has not changed significantly in 2020.

Presently in Ireland, School Self-Evaluation expects teachers to gather and analyse data and implement strategies to improve instruction. School Self-Evaluation and LS have some similarities. Both require a collaborative, inclusive and reflective process of internal school review. Both employ an evidence-based approach and require gathering information and making judgements all with the aim of improving instruction. As schools are accustomed to School Self-Evaluation, therefore, the enquiry, reflection and collaboration skills that teachers have developed could form a solid basis for LS.

However, some researchers (Murata 2011; Akiba and Wilkinson 2016; Akiba et al.

2019; Wolthuis et al. 2020) caution about teachers' unfamiliarity with the research process. In Ireland, one of the main concerns expressed by educators in the 1990s was how PD and teacher education did not produce teachers with the capabilities necessary to improve themselves and their schools (Sugrue 1999). Akiba et al. (2019) write that teachers may also be unaware of the inquiry process that requires them to research their practice and the curriculum. They pinpoint teachers' unfamiliarity with collecting classroom data, analysing this data, interpreting findings and drawing conclusions for future teaching and learning. According to Akiba and Wilkinson:

> This shift from a traditional role of teachers who utilize externally generated knowledge to the new role of generating professional knowledge to inform their practice requires capacity building of teachers through ample resources and leadership support.
>
> (Akiba and Wilkinson 2016, pp. 76–77)

Wolthuis et al. (2020) found that teachers sometimes omitted the research elements of LS because they did not consider it necessary. Teachers did not perceive LS as a form of research; instead they saw it as a form of lesson planning or observing children.

Kraft envisages a more autonomous, empowered teacher. He believes that teachers need to engage in research so they become 'more than mere technicians who apply initiatives handed to them by others' (2002 p. 175). Teachers should no longer be passive participants, but encouraged to research and reflect on practice and construct their own personal educational theories. Similarly, Cochran-Smith (2005b) believes in the role of the educator as practitioner researcher in educational change and promotes 'inquiry communities'. She believes teachers should be smart consumers of research, conduct good research, pose and explore important questions, collect multiple data sources and analyse data.

These findings make the case for school-based PD and for teachers to become inquiring practitioners for their school (Cochran-Smith 2005b). Murata (2011) concedes that teachers new to LS may initially find it challenging to adopt a critical researcher stance. But she believes that with subsequent cycles, teachers will develop enquiry dispositions, while 'in the meantime, the sense of community and new professionalism will sustain their motivation to participate (2011, p. 8).

2.4.5 The more knowledgeable other

Takahashi and McDougal (2016) define 'the more knowledgeable other' (MKO) role as an experienced LS practitioner and content expert from outside the LS team who is able to link content to the wider curriculum and provide a different perspective. Takahashi (2014) noted that LS has not been adopted in other countries with the success it has had in Japan, which he believes is partly due to omitting the MKO in LS collaborations. In Japan the MKO is always involved, whereas in the US they are often absent (Takahashi 2014). Similarly, Perry and Lewis (2009), examining the modification of LS to the US, report how an absence of support and guidance for teachers in the initial phases of LS meant that teacher outcomes varied considerably.

Corcoran (2011) believes the MKO holds a vital role in supporting and developing the reflective practices of teachers. This is echoed by Gutierez (2015), who also found that the MKO helped teachers to engage in critical dialogue and make attempts to self-evaluate. Akiba et al. (2019) found that the MKO's focus on children's thinking was most strongly associated with perceived changes in teachers' perception of knowledge, growth and self-efficacy. The MKO's presence in LS ensures that professional learning is rooted in the teachers' setting and that it supports them throughout the cycles of LS.

2.4.6 Reflective practice

The belief that teachers should be reflective about their practice is not new. It is based on the ideas of Dewey, who defined reflection as 'active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends' (1933, p. 9). Schön (1983) took this further and advocated the notion of the 'reflective practitioner'. Reflection on-action and reflection in-action enable teachers to adopt a critical lens in their practice. Critical reflection on instructional practice is essential in any teacher PD activity, because it enables teachers to 'reconstruct local knowledge while working within a dynamic research community' (Cochran-Smith and Lytle 1993, p. 68). If educational reform is being undertaken, research suggests that teachers' values, beliefs, skills and behaviours are more likely to change if teachers are reflective and if they receive support that enables them to cope with the uncertainty and difficulty of learning and change (Schön 1987; Fullan 2008).

Reflective meetings are part of each cycle of LS (Amador and Carter 2018). Pre-lesson planning and post-lesson meetings provide expansive openings for thorough planning and in-depth reflection about the quality of teaching and learning (Lewis 2009). Dudley (2013) believes that post-lesson meetings preferably should occur after the lesson:

> Caught moments, snatched snippets of dialogue – not all of which can be recorded – are critical if an analysis is to be sufficiently accountable to the level of detail that generated finely grained cognitive dissonance, group resolution and consequent learning points. Such detail is rapidly lost.
>
> (Dudley 2013, p. 119)

LS as a method of PD encourages a culture of reflection (Gutierez 2015). Studies report that after engaging in LS, participants realised the central role of reflection in teaching (Cajkler et al. 2013; Hourigan and Leavy 2019). Fernandez (2005) writes that as teachers adopt more of an inquiry stance through their engagement in LS, they become more reflective. Loucks-Horsley et al. writes that LS can promote collective reflection, ‘a catalyst for school-wide reflection on the goals and the vision for developing a more collegial faculty and encourage teachers and administrators to take steps toward achieving those goals’ (2009, p. 191). Incorporating pupil voice has also aided teachers’ reflections and influenced their future lessons (Warwick et al. 2019).

Currently, allocating time and space for reflection on education practice is difficult, as there are many other demands (Walsh 2020). O’Donovan (2015) believes that the challenge is for principals to create cultures that enable teachers to become reflective practitioners to facilitate discussions that reflect on the meaning of knowledge and learning. PD is required for principals to support them in creating a culture which empowers teachers to reflect on teaching and learning (ibid.).

2.4.7 Summary

There are influences both within and external to schools that can either inhibit or support the effective implementation of LS. Traditional forms of PD have been majorly top-down, and the Irish education system has tended to be insulated. These factors make it challenging for teachers to adapt to a vehicle of PD like LS. LS diverges from the type of PD to which teachers are accustomed, instead emphasising collaboration, teacher agency, the role of teachers as researchers in their own classrooms, and reflection. Irish policy recognises the importance of developing teacher professionalism with themes of collaboration, agency, the teacher as researcher, and reflective practice. All of these features are important for implementing LS, and this creates a hopeful platform on which PD forms like LS can flourish.

2.5 Conclusion

The literature has identified the features of effective PD. These features were examined to position LS and to outline its merits. LS has long been identified as an effective model of teacher PD and influences change in a slow and steady way (Stigler and Hiebert 1999). However, as LS is very different to the type of PD teachers are accustomed with it ‘requires a paradigm shift in thinking about what best practice professional development looks like…’ (Loucks- Horsley 2009, p. 191). Ultimately, there is a need for contemporary PD to be collaborative, sustained, active, reflective, focusing on the teacher as researcher and children’s learning. LS presents a structure that can integrate these facets and build on an excellence of learning for teachers and children.

Notwithstanding the Irish studies outlined (Corcoran 2007, 2011; Leavy 2010, 2015; Ní Shúilleabháin 2016, Ní Shúilleabháin and Seery 2018), there is a dearth of studies in the literature that examine the implementation of LS in an Irish context. The real opportunity that LS presents is to broaden the opportunities of teachers to become inquirers, researchers and collaborators. LS encourages the collective capacity of a team while also increasing personal knowledge and agency. The pervading culture in schools can support or inhibit LS. Creative resolutions are needed to the obstacles described earlier. The question of leadership inevitably rises in relation to LS. Strong, supportive leadership is necessary to establish a common vision of school goals and an acceptance of collaborative PD. Frameworks need to be devised to facilitate such diffusion.

Chapter 3: Literature Review on STEM

3.1 Introduction

STEM has played a prominent role in international educational and policy agendas in recent years. It is viewed as central to the knowledge economy, global competitiveness and ultimately future national and individual prosperity. The National Research Council (2011) states that although there is an understandable economic argument for implementing STEM education as countries pursue global competitiveness, the importance of early childhood STEM education should extend beyond this. An education in STEM is not just for those children who will pursue third-level education or careers in STEM. Children with a STEM education will be better prepared to face the challenges and opportunities of a science and technology driven society. STEM is a means of empowering children in their lives, helping them to understand the world and increasing their scientific literacy, leading to well-informed citizens for global issues and to economic competitiveness. Increasing the STEM literacy of all children is an important aim, because STEM literacy is required for environmental issues, social problems, individual decision-making and cultural progress (Park et al. 2017). Claymier (2014) believes that STEM naturally promotes the four Cs of 21st-century skills: critical thinking, communication, collaboration and creativity. STEM and the four Cs provide an all-embracing framework for creating citizens prepared to address the challenges of the 21st century.

This chapter begins with an exploration of the science curriculum in Ireland. It outlines reviews of the science curriculum and relevant reports, then identifies challenges faced by teachers and discusses an appropriate approach to STEM professional development. Specifically, it identifies effective features of PD in STEM education through a review of the literature. Finally, it explores STEM in early years education with reference to Aistear and the importance of early experiences of science and maths.

3.2 Primary Science in Ireland

To give a comprehensive picture of STEM in Ireland, it is necessary first to review the science curriculum. It is important to note at the outset of the research that the view at our school was that STEM was heavily science based. Our views aligned with Akerson et al. (2018, p. 5) as they debated the meaning of STEM: 'teaching STEM is to most of us teaching science while making connections as we can to the other disciplines composing STEM'. In the initial stages of the research, we used the maths and science curricula, but we acknowledged feeling confused about how to include engineering for four to six year olds. This again mirrors Akerson et al.'s comments:

> We also acknowledge a struggle making connections to engineering through science or technology lessons. … But we are not sure what that really means, as it means something different for each of us, and depending on which letter of STEM a person is most aligned with, the focus is different.
>
> (Akerson et al. 2018, p. 6)

At the outset of the research, we acknowledged that our conception of STEM was in its infancy and would evolve with the research.

It is necessary initially to examine the context of science education in Ireland to fully assess the type of foundation laid for the introduction of STEM education. Science education in Ireland highlights a complex, multifaceted issue which will have a bearing on the implementation of STEM education. Over the last decade, science education has been reformed in Ireland, with development at primary and post-primary level (Smith 2014). Murphy et al. (2016) note the resurgence of interest in science in the 1990s and link this to economic development, as eight of the world's top ten pharmaceutical companies had locations in Ireland. The authors note there was a drive at that time to make science more enticing to pupils at school level.

This section offers an in-depth analysis of primary school science education in Ireland. First, I review the official guidance on the teaching of science in the 1999 primary science curriculum. The NCCA commissioned two reports on science in primary and post-primary school (Varley et al. 2008a, 2008b), and I discuss these in conjunction with other pertinent Irish research (Murphy et al. 2012). I also refer to pupil performance in science and maths at primary and post-primary level. I then explore Irish primary teachers' relationship with science, and discuss concerns about classroom practice, specifically inquiry-based learning and the instructional time given to science.

3.2.1 1999 primary science curriculum

The first formal introduction of science into the primary curriculum was with the 1971 curriculum. Science and geography were encompassed under social and environmental studies, but it is notable that elementary science appears only on the fifth and sixth class syllabus (O'Dwyer and Hamilton 2020). The 1999 primary school curriculum (PSC) was the first completely revised curriculum since the 1971 curriculum. It made science a mandatory subject for all primary classes. A revised science curriculum was introduced in September 2003. It is intended for pupils aged 4–12 years (DES 1999a). Science is one component in a three-component strand of the curriculum called social, environmental and scientific education (SESE), consisting of three disciplines: science, geography and history. The curriculum intends that through engagement, children will be enabled to create and develop scientific ideas and concepts. It also says that 'science education equips children to live in a world that is increasingly scientifically and technologically oriented' (DES 1999a, p.6).

Amongst the aims of the primary science curriculum are:

- To develop knowledge and understanding of scientific and technological concepts through the exploration of human, natural and physical aspects of the environment
- To develop a scientific approach to problem-solving which emphasises understanding and constructive thinking
- To encourage the child to explore, develop and apply scientific ideas and concepts through designing and making activities
- To foster the child's natural curiosity, so encouraging independent enquiry and creative action
- To help the child to appreciate the contribution of science and technology to the social, economic, cultural and other dimensions of society

(DES 1999a, p. 11)

The PSC introduced considerable changes to science at primary school level (Varley et al. 2013). A key focus was an emphasis on inquiry-based learning (Varley et al. 2013; Murphy et al. 2016). While the curriculum does not overtly refer to inquiry-based science education (IBSE) methodologies, it underlines an IBSE approach embedded in a social constructivist epistemology (Murphy et al. 2015). The science curriculum suggests that teachers employ a variety of methodologies, including discovery learning, guided discovery, open-ended investigations, teacher-guided learning, free exploration of materials, whole-class teaching, small groups and individual work when addressing chosen topics or projects (DES 1999b). It highlights the development of pupils' scientific conceptual understanding and skill. The primary science curriculum also wishes to encourage pupils to develop a scientific approach to problem-solving, emphasising understanding (Varley et al. 2008a; Murphy et al. 2015). The PSC assumes that these skills will be developed at each class level as children engage with open-ended problems (DES 1999a).

The PSC advocates a child-centred curriculum as an approach to science (DES 1999b). There is a strong emphasis on active, hands-on learning, with the primary science curriculum guidelines specifically stating: '*science lessons should not be workcard or textbook based*' (ibid., p. 27; emphasis in original). It also advocates the development of children's values and attitudes towards a sense of responsibility for the environment (ibid., pp. 2–5). The primary science curriculum encourages the development of pupils' scientific knowledge in physics, chemistry and biology through the skills of working scientifically and designing and making. The skills intended for children to develop are outlined as follows:

- Questioning
- Observing
- Predicting
- Investigating and experimenting
- Estimating and measuring
- Analysing
- Sorting and classifying
- Recognising patterns
- Interpreting
- Recording and communicating
- Evaluating (fifth and sixth class only).

Children focus on strands and strand units as they explore the world around them. These are arranged to ensure that children have equal access to a range of topics. All strands should be taught with equal emphasis (DES 1999b).

Living Things	Energy and Forces	Materials	Environmental Awareness and Care
Myself / Human life Plants and animals	Light Sound Heat Magnetism and electricity Forces	Properties and characteristics Materials and change	Caring for my locality Environmental awareness Science and the environment Caring for the environment

Table 2: Strands and strand units of science curriculum

Science has evolved extensively since the 1999 curriculum, specifically with the move towards STEM. Literature on the progress of primary science in Irish schools is growing, and challenges have been identified in the research (Murphy et al. 2007).

3.2.2 Research reports of primary science education

This section explores pertinent Irish reports and research to obtain an overall picture of primary level science education in Ireland. The main study from which results will be discussed is Varley et al. (2008a). They conducted a primary science review on behalf of the NCCA, gathering data from eleven primary schools, including observation of science lessons, interviews of pupils and questionnaires completed by 1,030 children from third to sixth class. These findings will be supplemented by Murphy et al. (2012), who present findings from a large-scale national study that examined the views and experiences of school science among third to sixth class pupils (aged 8–12 years). Fifteen primary classrooms were observed, 1,149 children completed questionnaires, and eleven group interviews were conducted. The second NCCA commissioned research report by Varley et al. (2008b) is briefly referred to. This research focused on students in their first year of post-primary; 234 students across eight schools were interviewed and completed questionnaires. The report aimed to ascertain the impact of past and present experiences of science on students. Smaller scale Irish studies will also be referenced.

Irish primary school children are generally very enthusiastic towards science (Varley et al. 2008a; Murphy et al. 2012; Smith 2015; Clerkin et al. 2016; Shiel 2018). Children are also positively disposed towards group work (Murphy et al. 2012), and this seemed to be a frequent feature of the Irish science classroom (Varley et al. 2008a). Varley et al. (2008a) found significant evidence to suggest that children are engaging in lessons that cover scientific-subject content in the strands Living Things, Energy and Forces, and Materials.

However, areas of concern include the strand unit of Forces and Environmental Awareness and Care. Floating and sinking experiments seemed to dominate the strand, with little evidence of students engaging with other forces experiments. Researchers found that despite children being very positively disposed to the environment, there was a lack of experience in the strand Environmental Awareness and Care, with field trips and children working outdoors reported only intermittently.

There was also concern at the lack of apparent design and make activities. This is especially worrying as these provide children with opportunities to exercise scientific skills and opportunities for problem-solving. Children were particularly positive towards hands-on science (Murphy et al. 2012), but the researchers were unclear of the frequency of this in classrooms. It was found that many hands-on investigations seemed to be teacher-led as opposed to child-led (Varley et al. 2008a; Murphy et al. 2012). Murphy et al. wrote: 'for some pupils, hands-on science was perhaps infrequent, and for a few, it was not happening at all' (2012, p. 432).

Other concerns mentioned in the reports were limited interaction and didactic methods in classrooms. Children reported that teacher explanation and demonstration were the leading characteristics of some science classes (Murphy et al. 2012). Children in primary school complained of repetition and lack of continuity (Varley et al. 2008a). They displayed very positive attitudes towards ICT, but there was very little evidence of its use. Relatively few comments were gleaned from children on the 'relevance' of the science they were learning or on the overall importance of the subject (Varley et al. 2008a).

The skills that children had opportunities to develop most frequently were questioning, observing and predicting (Varley et al. 2008a). The skills of investigating and experimenting, analysing (sorting and classifying), estimating and measuring were not frequently explored in Irish classrooms. The researchers suggested that higher-order thinking skills in children was an area that required improvement: 'the application of different scientific skills would appear to be uneven in comparison with the ideals suggested in the curriculum' (2008a, p. 180). Similarly, Murphy et al. expressed concern that there appeared to be little skill development as children moved up through the primary classes: 'older pupils appeared to have been operating at skill levels similar to those seen in much younger classes' (Murphy et al. 2012, p. 432).

Varley et al. confirm that there are 'challenges with the implementation of the primary curriculum' (2008b, p.142). More recent research found that many problems persisted in primary science: limited use of inquiry-based learning, inadequate challenge in science tasks for children in senior classes, and limited development of skills and concepts (Roycroft 2018). Varley et al. (2008a) concluded that large class size inhibited practical tasks, hands-on activities, and outdoor environments investigations and made it challenging to teach certain strands of the curriculum.

In the second phase of their research, Varley et al. (2008b) found that almost a third of students said they did not intend to study a science subject for their Leaving Cert. The most common reasons were the difficulty of the subject and its apparent irrelevance for their future occupations. Murphy et al. (2016) observe:

> Research shows a global trend that many children lose interest in science as they reach the end of primary school and during the post-primary phase, resulting in fewer pupils studying science at senior levels.
>
> (Murphy et al. 2016, p. 55)

Roycroft (2018) cautions that if children are not adequately challenged in senior classes in primary school, they may be over-stretched by science content in post-primary school, which could result in 'the breakdown of meaningful learning' (p. 80). The performance of primary and post-primary children in PISA and TIMSS will now be reviewed.

3.2.3 Pupil performance in science and maths

Developing positive STEM related classroom experiences, attitudes and competencies in children is a pressing goal for many educational systems globally. This is partly due to shortages in the STEM workforce and also to outcomes from international assessments (English 2016). Performance in science and maths is critical to evaluate the platform on which STEM is to grow. MacCraith (2016) is critical of Ireland's average performance:

> The situation is far from 'great' if we consider STEM subjects. Our performance has

> been consistently average, hovering just above, or below in some instances, according to a series of reports on the TIMSS and PISA. … These levels of performance in STEM subjects are not good enough if we aim to provide the best for our nation's children and if we wish to sustain our economic ambitions for the future.
>
> (MacCraith 2016, p. 20)

Looking at performance at primary level, Irish pupils in fourth class participated in TIMSS in 1995, 2011, 2015 and 2019. In contrast to PISA, children have improved in maths and science since 1995, with most improvements occurring between 2011 and 2015 (Clerkin et al. 2016). There were increases in maths and science, more noticeably in maths. Shiel (2018) attributes this to the increased time for numeracy under the *Literacy and Numeracy for Learning and Life* strategy (DES 2011b). Analysis of the results shows that Irish pupils in national assessments and TIMSS and PISA find higher-order thinking skills (problem solving, applying knowledge) challenging in both subjects (MacCraith 2016). Difficulties in maths strands among Irish pupils included reasoning, measures, shape and space, which are the areas shown as weak in our national assessments at primary (Shiel 2018) and post-primary level (Leahy 2015). Eivers and Clerkin (2013) noted the heavy emphasis on number in Irish classrooms.

At post-primary level, Irish fifteen-year-olds continually perform better at reading than at maths (e.g. PISA 2000, 2003, 2006, 2009, 2012, 2015). In PISA 2015, out of thirty-five OECD countries, Irish pupils' performance ranked third in reading but only thirteenth in maths and science; having improved their position in reading, there was a noteworthy fall in science. This was attributed to the introduction of computer-based assessments. The gap in performance between boys and girls has widened in science and maths, with boys outperforming girls. Irish students' use of ICT in school and for homework is significantly less than across OECD countries. Irish second-year and fifth-year students ranked 26th out of 27 OECD countries for ICT-based activities (Cosgrove et al. 2014).

Results in 2018 proved similar: Ireland ranked 4th in reading, 16th in maths and 17th in science out of thirty-seven OECD countries. There is concern that the number of higher-achieving pupils in science and maths is lower than in other developed countries. This decline has been occurring since 2012, and there is concern about whether higher-achieving pupils are being given challenging-enough learning activities. Girls significantly overtook boys in reading, but there is no statistical difference between the genders in maths and science. Irish children are again less likely to use technology in school or at home. Given the global importance of pupils' STEM performance in international assessments, it is not unexpected that many countries are looking at their educational systems and their teachers' PD needs in order to improve their provision of STEM education (English 2016).

3.2.4 Teachers' relationship with primary school science

In order to assess primary teachers' PD requirements, it is important to understand the nature of Irish primary teachers' relationship with science. Many Irish primary teachers, according to Murphy and Smith (2012), have inadequate content and pedagogical knowledge of science, and this impedes their confidence and competence. Lack of confidence in science affects teachers in STEM education: 'if teachers are not confident in teaching maths and/or science as standalone subjects then the integration of STEM subjects may be even more difficult' (Rosicka 2016, p. 8).

Eivers and Clerkin (2013) note that in a report containing results of Progress in International Reading Study (PIRLS) and TIMSS tests, teachers' confidence was particularly low in answering pupils' questions and providing appropriately challenging activities for high achieving pupils in their class. Teachers also complained of a lack of resources for investigative work and a lack of time for learning how to use resources. Varley et al. (2008a) found that 72% of teachers surveyed were using science textbooks in their teaching. Dunne et al. (2013) write that this entirely contradicts the DES's '*science lessons should not be workcard or textbook based*' (1999b, p. 27; emphasis in original). Teachers welcomed textbooks and manuals, perhaps due to topic-based knowledge and lesson ideas, as the curriculum contains inadequate scientific information; this may explain their unpopularity as planning aids (Varley et al. 2008a).

Teachers also appear to have didactic approaches to using textbooks (Murphy and Beggs 2002). An Inspectorate report in 2008, collecting data from forty primary schools on the implementation of science, indicated an overemphasis on textbooks and said that in one third of classrooms, the pupil textbook had an excessive effect on the teacher's planning of the science programme (DES 2012). This reliance on textbooks implies a lack of PCK (Shulman 1987). Teachers with low levels of PCK have low confidence and therefore more restricted teaching (Shulman 1987; Murphy, Neil and Beggs 2007; Varley et al. 2008a, 2008b). Teachers' low confidence levels in primary science can be linked to weaknesses in PD in the Irish education system (Harlen et al. 1995; Murphy, Neil and Beggs 2007; Varley et al. 2008a, 2008b; Eivers and Clerkin 2013). Smith (2014) believes that during the recession in Ireland, the government limited teachers' PD opportunities in primary science, and he warns of the effect of this on pupils.

Given the various issues with primary science education, as outlined here, Shiel (2018) writes that there are significant challenges to incorporating STEM at primary level. He advises that instructional time should be extended, STEM should be integrated through cross-disciplinary approaches, open-ended activities should be included, and activities should be built on children's natural curiosity. He encourages a move away from the explicit specification of content, towards more inquiry and problem-based learning and teaching the critical skills for the 21st century. Shiel (2018) understands that this has implications for teachers' PD as they focus on developing these skills in children. Likewise, MacCraith writes that one of the biggest challenges for teachers is the 'extent of the change in their professional lives' (2016, p. 25). Teaching through inquiry is a challenge that teachers' PD in STEM will have to address, as this has been problematic for the primary science curriculum.

3.2.4.1 Inquiry-based learning

Inquiry-based education receives much attention in STEM literature, and policy is clear that this is the preferred approach to science and STEM teaching and learning (Rocard et al. 2007; Varley et al. 2008b; Nadelson et al. 2013; Tippett and Milford 2017; Roycroft 2018; Beswick and Fraser 2019). In 2007, the European Commission's report *Science Education NOW: A Renewed Pedagogy for the Future of Europe* recommended a transformation of the pedagogical approach used to teach science to encompass more IBSE approaches (Rocard et al. 2007). Again, in 2017, both the Irish *STEM Implementation Plan* (2017b) and the *STEM Education Policy* (2017a) call for 'an inquiry orientated approach to teaching and learning' (DES 2017a, p. 15).

Inquiry-based science education receives widespread attention in educational research, as it enables teachers and children to collaborate in co-constructing knowledge (Dobber et al. 2017). Inquiry-based learning is praised for having many positive effects on student outcomes (Rocard et al. 2007; Minner et al. 2010; Murphy et al. 2011; Murphy et al. 2015). The IBSE approach has been commended as vital to science, because it motivates children and allows key scientific skills to be developed (Rocard et al. 2007). IBSE maximises children's natural curiosity, uses a child-centred approach, enables children to conduct their own investigations, elicits predictions from children, and questions and tests their predictions (Driver et al. 1996; Harlen 2000; Murphy and Beggs 2002; Rocard et al. 2007). Rocard et al. (2007) also suggest that the IBSE approach positively affects children's attainment and confidence, especially among those from disadvantaged backgrounds:

> Inquiry-based science education (IBSE) has proved its efficacy at both primary and secondary levels in increasing children's and students' interest and attainments levels while at the same time stimulating teacher motivation. IBSE is effective with all kinds of students from the weakest to the most able and is fully compatible with the ambition of excellence.
>
> (Rocard et al. 2007, p. 3)

IBSE is also suited to children in the early years of primary school, as this is what Rocard et al. call the 'curiosity golden age' (2007, p. 12).

Regardless of curricular and policy developments, the literature suggests that IBSE approaches to science are problematic and are not being practised in many classrooms (Rocard et al. 2007; Minner et al. 2010; Dobber et al. 2017; Roycroft 2018). While IBSE seems to include many approaches, 'there is no one definition of what inquiry-based instructional practices encompass. This has given rise to confusion among educators about how best to carry it out' (Smith 2014, p. 216). Banchi and Bell (2008) write that there are four levels of inquiry: confirmation inquiry, structured inquiry, guided inquiry and open inquiry. They say it is challenging for a teacher to design a task that supports high levels of inquiry. There is also little agreement on how different levels of inquiry should be implemented in the classroom (Bunterm et al. 2014). IBSE has caused uncertainty for teachers regarding the appropriate teaching methodologies (Nadelson et al. 2013).

Traditionally, behaviourist theories have influenced teaching, leading to 'traditional' or 'deductive' teaching methodologies. These methodologies are often linked with whole-class teaching, and Rocard et al. (2007) refer to it as 'top-down' transmission of knowledge. IBSE requires teachers to be facilitators of knowledge, but research has found that some teachers are more traditional in their lesson delivery and find the shift to a facilitative role challenging (Lesseig et al. 2016; Sias et al. 2017; Margot and Kettler 2019). Cremin et al. (2015) explored the teaching and learning of science in early years settings, drawing on data from nine EU countries and practices in exemplary primary settings in the EU project *Creative Little Scientists (CLS)* (2011–2014). Preschool teachers were found to be more likely to offer a more facilitative role to investigations and experiments. Findings suggest that inquiry-based and creative approaches are more plentiful in preschool, with more instances of play and exploration. Preschools tend to be more collaborative, interactive and explorative. In contrast, primary teachers' knowledge is framed and delivered by the teachers without the children generating their own questions or inquiries. Broadening this to other subject areas, moving from a didactic to a facilitative role has been documented as a challenge in Irish maths classrooms (Treacy 2017; Nic Mhuirí 2012). O'Shea and Leavy (2013) found teachers to be unfamiliar with constructivist approaches, and they had difficulty shifting to a more facilitative role.

McClure writes that the role of the teacher in STEM 'is often to resist directly answering children's questions' (2017, p. 96). Schoenfeld (2017) recognises teachers' struggle to adopt a facilitator role and their inclination to decrease a task's cognitive demand when children appear to be struggling. He discusses this in relation to maths and defines a productive struggle as:

> The extent to which students have opportunities to grapple with and make sense of important disciplinary ideas and their use. Students learn best when they are challenged in ways that provide room and support for growth, with task difficulty ranging from moderate to demanding. The level of challenge should be conducive to what has been called 'productive struggle'.
>
> (Schoenfeld 2017, p. 5)

Dobber et al. attest that the facilitator role of the teacher is 'complex, multi-faceted and demanding' (2017, p. 212); they write that teachers are not guided sufficiently on how to implement this approach in their classrooms. Nadelson (2009) argues that teachers require support, feedback, and adequate time for reflection when adopting an inquiry-based approach. Dobber et al. (2017) elaborate on this and argue that teachers need sufficient subject content knowledge to enable them to change their practice and adopt an inquiry-based approach. Discussing Irish practitioners specifically, Roycroft (2018) believes that teachers require a deeper understanding of inquiry-based education and why it is important. She believes that teachers require knowledge and skills to adopt inquiry-based learning, especially as they are not familiar with this approach and do not know how to successfully adopt it into their practice. Teachers require 'early and consistent exposure to inquiry' (Nadelson et al. 2013, p. 159). Similarly, Rocard et al. (2007) recommend providing PD for teachers which promotes IBSE approaches. Regarding PD, Rocard et al. (2007) are quite specific, suggesting that professional networks should be introduced. These would allow collaboration between schools, allow reflection, exchange ideas and support motivation (Rocard et al. 2007).

It is clear, across research sources, that this is a significant challenge and that teachers need support in developing the skills of inquiry-based education as well as time to embed this approach into practice.

3.2.4.2 Instructional Time

Another challenge that hinders teachers' relationship with science is the lack of instructional time. In a primary curriculum perceived to be overloaded (INTO 2015), what has the increased time for literacy and numeracy, under the *Literacy and Numeracy for Learning and Life* strategy (DES 2011b), meant for the other subject areas? Circular 0056/2011 (DES 2012) stated that schools should use their discretionary curriculum time and reallocate time for other subjects to literacy and numeracy. Teachers were left in no doubt about the prominence of literacy and numeracy, perhaps to the detriment of other subject areas:

> We have to acknowledge that understanding and using literacy and numeracy are such core skills that time for their development must be safeguarded, sometimes by delaying the introduction of some curriculum areas and always by ensuring that teaching literacy and numeracy is integrated across the curriculum. We have to say clearly to teachers that we want them to emphasise the development of literacy and numeracy above all other aspects of the curriculum.
>
> (DES 2011b, p. 25)

In 2008, before this strategy was introduced, primary teachers 'highlighted the inadequacy of one hour per week allocated to the Science Curriculum, given the practical, process-oriented (and therefore time-consuming) nature of the subject'

(Varley et al. 2008a, p. 196). Subsequently, with the introduction of the strategy, science time allocation has suffered, and more teachers find there is insufficient time to cover everything in the curriculum, to the detriment of subjects such as science (Varley et al. 2008a; Murphy et al. 2011; McCoy et al. 2012).

This focus on literacy and numeracy is reflected in the time allocation reported in various studies. Data from PIRLS compares the instructional time devoted to reading, writing and science. Science is allocated 4% of teacher instructional time: far lower than in other countries (Lewis and Archer 2013). In Ireland, 159 hours were devoted to reading, 150 hours to maths and 63 hours to science; the TIMSS average is 85 hours for science (ibid.).

Shiel (2018) criticises the time allocated to science and insists this is a concern going forward; he believes there is scope for more time to be allocated to STEM. Many researchers provide a solution, stating that literacy – particularly oral language and stories – should be integrated into science, thereby providing the recommended teaching time for science (Murphy et al. 2015; Liston 2015). Tanna (2016) found that the use of fairy tales promoted the engagement and motivation of young girls, as the stories provide 'the narrative hook that contextualizes that engineering activity' (p. 22). This is important for the engagement of some girls, as they are initially excited by the fairy tale aspect and remain engaged for the STEM learning; this is a feature missing from many STEM programmes (Tanna 2016). Therefore, setting the context for learning was found to be particularly important for girls (Tanna 2016; Cunningham 2018).

Another solution is provided by the DES, who suggest integrating Visual Arts, recognising its strong role in fostering creativity (DES 2017a). It is vital that a solution be found, because 'against a background of limited and reducing resources and with increasing class sizes, the teaching of primary science is coming under increasing strain in Ireland' (Murphy et al. 2016, p. 59). A possible solution could be apparent in the proposed Draft Primary Curriculum Framework for consultation (NCCA 2020), where science is aligned with maths and technology in 'Maths, Science and Technology Education':

> The overarching aim of maths is the development of mathematical proficiency. Science and technology are intrinsically linked and enable children to benefit from learning about, and working with traditional, contemporary and emerging technologies.
>
> (NCCA 2020, p. 13)

Time allocation will be on a monthly basis for Science and Technology Education, Social and Environmental Education, and Arts Education. This aims to give greater flexibility to teachers and schools (NCCA 2020).

3.2.5 Summary

Curriculum reform at primary level has been relatively low-scale since the introduction of the 1999 PSC. Since then, reform has taken place at subject level, largely in literacy and maths. Significant reform is imminent, with the proposed introduction of the draft primary curriculum (NCCA 2020). Currently, science is being realigned in the proposed curriculum with other STEM disciplines maths and technology. This realignment is vital for the future of STEM instead of the 1999 PSC, which had only science and maths curricula, but there is no mention of engineering in the draft primary curriculum framework. The issues highlighted here through the research reports, international assessments and research of classroom practice are important because they contextualise the foundation on which STEM is growing. They will also influence and inform STEM policy, and this will have implications for STEM PD.

3.3 STEM and PD

Across the globe, education systems have turned towards STEM, designing policies and creating initiatives with implications for schools and teachers. The PD accompanying STEM education affects the dissemination and implementation of STEM education. PD in STEM is complex, as there is presently no curriculum in Ireland. Additionally, some STEM terms are ambiguous and interpreted differently by the various stakeholders. It is therefore important that all PD providers hold a united philosophy of STEM education in order to communicate a shared understanding to teachers. Educational stakeholders must then decide on the most effective form of PD for the successful implementation of STEM education.

3.3.1 International STEM policy

STEM comprises science, technology, engineering and maths. But there has been significant confusion over its definition worldwide (Sanders 2009; Honey et al. 2014; Bell 2016; Rosicka 2016; Lawrenz et al. 2017; Tippett and Milford 2017; Liston 2018; Beswick and Fraser 2019; Margot and Kettler 2019). In many countries, STEM education reports have many similarities, and there is a prominent pattern in the hierarchies of STEM subjects (McGarr and Lynch 2017). Traditionally, science and maths have dominated teaching in primary school (Bybee 2010; Bell 2016; Lindeman and Anderson 2015; Rosicka 2016), with little consideration given to how children make connections between the subjects (Honey et al. 2014). The *STEM Education in the Irish School System* report states: 'Maths is viewed as a fundamental discipline since it underpins all the other STEM disciplines' (MacCraith 2016, p. 13). Similarly, McGarr and Lynch (2017) believe that science and maths have a distinct advantage, having previously enjoyed status and power in Irish education. They argue that these subjects are linked to increased cultural capital in the Irish education system, compared to technology and engineering, which seem to occupy a lowlier position. They point out that when the uptake of STEM subjects in Irish third-level institutions is discussed, concern centres on the uptake of science and maths, with little or no mention of technology or engineering.

Again, international STEM policies seem to favour science and maths. In her report *Must try harder: An evaluation of the UK government's policy directions in STEM education*, Hoyle (2016) writes that while the implementation of England's STEM strategy 2004–2010 was initially successful, the recession and changes to policy have slowed progress. When observing the emphasis on STEM subjects, 'policy is unequal and frequently negates to consider the importance of technology and engineering's fundamental role in STEM education' (Bell 2016, p. 63). The *UK STEM Education Landscape* report (2016) states that 95% of students at 16 years pick subjects that close off engineering careers in universities. It recommends specialist STEM teachers and incentives at school and university level, to ensure that teachers have access to PD at all stages of their careers.

In Europe, like the UK, there is significant emphasis on promoting STEM careers. Rocard et al. (2007) found that despite curriculum revisions in various countries, there remained an alarming decline of young people studying science and maths. ‘Despite the numerous projects and actions that are being implemented to reverse this trend,’ they wrote, ‘the signs of improvement are still modest’ (p. 2). The authors recommended that policy makers revise and prioritise science teaching in Europe. The European Commission currently has many initiatives to boost the attractiveness of STEM-related careers and market needs. The *New Skills Agenda* (2016) focuses on STEM skills development, promoting STEM careers and teachers’ PD. The *Education Policies in Europe* report (European Schoolnet 2018) is a study of 14 EU countries which summarises national initiatives aimed at tackling STEM challenges. Again, prominence is given to maths: ‘Maths is the key lever to transform STEM teaching and learning’ (p. 7). The report’s main motivations for improving STEM are to create a digital culture for the future and to entice students into STEM careers. It outlines ways that teachers can be supported, suggesting collaboration with universities and companies, PD for teachers in new methodologies, and new resources.

In the US, because of concern over the poor performance in international maths and science assessments, Obama pressed STEM forward with the *Educate to Innovate* plan (Obama 2009). The innovative report *Rising Above the Gathering Storm* (Augustine et al. 2005) placed a spotlight on the importance of a STEM workforce, but *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5* (National Academies of Sciences 2010) highlights that the situation in 2010 had worsened since 2005 (Education Commission of the States 2011). Maths and science in public schooling showed few signs of improvement (National Academies of Sciences 2010).

Sullivan and Bers write that the ‘T’ of technology and the ‘E’ of engineering ‘are the most neglected in early childhood STEM education’ (2016, p. 18). Resnick believes ‘there are troubling trends – focus on delivering literacy instruction and less time for playful exploration’ (2017, p. 9). Sanders (2009) believes the T can be commonly linked to technology, which gives a very narrow focus. Similarly, Sharapan (2012) writes that adults associate technology with digital equipment and machines, but crayons, rulers and pencils are tools also. Sanders, however, believes the emphasis has moved from science and maths to technology and engineering, as ‘the realisation that the T and E will play a critical role with regard to our welfare in the twenty-first century, the call for support has shifted from "science and maths " to "STEM and STEM education" ' (2009, p. 25).

Australia is also mindful of improving STEM skills for future social and economic challenges and has invested significantly in early years STEM education. Australia initially became concerned about the state of STEM education when the project *STEM: Country Comparisons* outlined its positioning in relation to America, Western Europe and East Asia (Marginson et al. 2013). It showed that Australia ran the risk 'of being left behind' (ibid., p. 12). The report mentions the promotion of maths and science extensively, with specific mention of a meritocratic career structure of maths and science teachers. It also discusses giving maths and science teachers higher rates of pay (Marginson et al. 2013). The Australian government invested fourteen million Australian dollars in three initiatives to develop STEM skills in young children. The Australian Academy of Science aims for world-class science and maths education for every student in every school and third-level institution: 'science is the engine room for innovation' (Australian Academy of Science 2015).

It is interesting to observe how STEM education evolves internationally and the interplay between educational policy and the economy. Variability is evident across policies and countries, with some focusing on children's engagement, establishing a STEM workforce, enhancing performance in science and maths, or increasing the participation of women and minority groups (Freeman et al. 2019). It is important to be mindful that educational policies can be used as mechanisms (Ball 1999). As Hoeg and Bencze (2017) point out, there may be hidden agendas in some STEM policies as they exploit STEM to further their country's economy rather than progressing their citizens and educating them for pressing social problems. Ball (1999) recognises this as the emphasis on human capital theory, with economic competitiveness linked to education.

3.3.2 STEM integration

Defining the acronym for STEM is simple, but it is not an easy task to support children to see the connections between the disciplines, how they interact with and complement each other (Honey et al. 2014). Sanders warns of the challenges of integrated STEM: 'for a century, science, technology, engineering, and maths education have established and steadfastly defended their sovereign territories. It will take a lot more than a four-letter word to bring them together' (Sanders 2009, p. 21). Integrated STEM instruction is encouraged by workforce needs, but STEM instruction in schools appears to be segregated (Nadelson and Seifert 2017). While science and maths seem to hold a prominent position, there is confusion over the level of integration of science, technology, engineering and maths when STEM education is discussed (Lawrenz et al. 2017).

> The meaning or significance of STEM is not clear and distinct. There is reference to four disciplines, but sometimes the meaning and emphasis only include one discipline. In some cases, the four disciplines are presumed to be separate but equal. Other definitions identify STEM education as an integration of the four disciplines.
> (Bybee 2013, p. x)

Many different perspectives on STEM education and integration are prevalent in the literature (English 2016). Vasquez (2015) believes that not all of the four STEM disciplines need to be present in every STEM lesson, nor does it need to centre on a problem or a project. Brown and Bogiages (2019), however, believe that STEM means combining two of the STEM disciplines. Shaughnessy (2013) advocates problem-solving as a means to draw on maths and science while incorporating technology and engineering. Lesseig et al. (2016) and Margot and Kettler (2019) propose that all of the STEM subjects could be integrated by teaching through the Engineering Design Process, which offers children the opportunity to problem-solve. Hobbs et al. (2018) outline five models of STEM teaching being used in Australian schools, from level one, where each discipline is taught separately, to level five, which is a STEM curriculum.

Many policies are calling for an interdisciplinary, multidisciplinary or transdisciplinary approach to STEM education. Lederman and Niess (1997) distinguish between multidisciplinary and interdisciplinary approaches by using chicken soup as a metaphor to define multidisciplinary, as its ingredients are easily definable and the differences between the disciplines are accommodated (Lederman and Niess 1997). Lederman and Niess (1997) describe interdisciplinary as tomato soup: the components are indistinguishable when they are mixed together. Similarly, Redman (2017) calls for STEM areas to be 'defined and distinguishable for their associated discipline similarities and differences, it then becomes easier to reassemble them, recognizing and accounting for each, when planning for STEM learning experiences' (p. 322). In Ireland, the DES advocates for an interdisciplinary approach to STEM, as this enables 'learners to build and apply knowledge, deepen their understanding and develop creative and critical thinking skills within authentic contexts' (DES 2017a, p. 9). Vasquez et al. (2013) give a more comprehensive account of the levels of integration. Their continuum begins with disciplinary and extends to multidisciplinary, interdisciplinary and transdisciplinary integration. With increasing levels of integration there is increased interconnection and interdependence of the STEM disciplines. Vasquez (2015) believes that transdisciplinary is the most advanced level of STEM education, but it is the hardest for teachers to implement due to the advanced planning and time.

As was evident as a challenge in science education (see section 3.2.4), Beswick and Fraser (2019) and Nadelson and Seifert (2017) highlight that PCK and other knowledge is required of teachers in order to teach STEM in an integrated manner. Moore et al. (2014) believe that if teachers' content knowledge in science and maths integration is problematic, then the content knowledge for STEM integration will be even more demanding. Given the different perspectives and meanings of integration, it is unsurprising that confusion is rife amongst policy makers, researchers and teachers (English 2016). Honey et al. (2014) write that in STEM research, STEM vocabulary is inconsistent, terms are not defined and there is a lack of theoretical frameworks for understanding integrated STEM education. For future research they outline a descriptive framework showing general features and subcomponents of integrated STEM education. They discuss integrated STEM goals and outcomes for students and educators as well as the nature and scope of STEM integration and features of implementation of integrated STEM education (Honey et al. 2014).

In recent years the importance of integrating engineering into the primary curriculum has grown (Hsu et al. 2011; Dare et al. 2014; Moore et al. 2014; Bagiati and Evangelou 2015; Liston 2018). The disconnect between school science and maths and real-world science and maths is recognised, and engineering is proposed as the key to provide real-world science and maths problems (Moore et al. 2014; Bagiati and Evangelou 2015; Redman 2017). Moore et al. describe engineering as 'the natural connector for integrating STEM disciplines in the classroom' (2014, p. 40).

Engineering is also praised as a gateway towards promoting 21st century skills of creativity, collaboration, problem-solving, critical thinking and real-world learning (Moore et al. 2014; Redman 2017). Redman (2017) highlights that science and maths hold an advantage, as they have well-taught units, but engineering should receive explicit focus. There seems to be a presumption that education practitioners have a clear definition of engineering education, yet engineering seems to be the area in which teachers are least confident (Redman 2017; Margot and Kettler 2019). Teachers struggle to envision engineering practically in the classroom, particularly with younger children (Cunningham 2018). Engineering may also be implicated in gender stereotypes; Cunningham (2018) has found that children hold stereotypical views of the sciences: physical science is for boys while biological science is for girls. She advises that activities should be set up to focus on the positive societal effects of engineering.

Interdisciplinary and transdisciplinary approaches to STEM integration are emerging from the literature. However, STEM integration as a distinct area of research is in its embryonic stages (Honey et al. 2014). Roehrig et al. (2012) write that while there have been substantial policy changes in STEM education, research on STEM integration has not kept pace. Many questions remain (English 2016), but possible frameworks have been put forward. The continuum by Vasquez et al. (2013) provides a framework for integration. Honey et al. (2014) propose another framework to specify a common language for teachers and researchers to investigate and discuss integrated STEM. More support is required to aid teachers as they attempt to implement integrated STEM in schools. Schools collaborating with institutions, PD, quality curricular models, materials and resources are other possible solutions to supporting integrated STEM education (Moore et al. 2014).

3.3.3 Effective features of PD in STEM

Presently in Ireland, the imminent revised curricula in maths and the proposed introduction of the draft primary curriculum offer an opportunity to provide PD experiences that introduce new teaching, learning and assessment approaches which enhance STEM. Research on effective STEM PD is in preliminary stages. This section will map current PD in STEM in Ireland. It will discuss Irish and international research on professional development, and it will outline studies that researched PD in science and STEM that reflects the good practices advocated by Desimone (2009) and Borko et al. (2010). Subsequently, one study will explore action research as an approach to PD in STEM.

In Ireland, the PDST has been instrumental in raising awareness about STEM PD and STEM related activities through social media (DES 2020). It provides a wide range of PD models for teachers, including one-off workshops, online courses and school-based PD (Leavy et al. 2020). The Education Centres nationally report a good level of demand for STEM/STEAM[5] courses (ibid.). Many of the Education Centres providing PD offer one-off workshops and summer courses in STEM education. However, STEM PD in Ireland is not mandatory, which perhaps explains the uneven adoption of STEM across the country (Leavy et al. 2020). The DES (2020) states that while the national policy has raised the profile of STEM education in all primary schools, schools are at different levels of provision and development. This is supported by findings from Leavy et al. (2020):

> … implementation of STEAM within primary schools is ad hoc, at the discretion of the staff and largely determined by the opportunities they have received/taken to engage in STEAM professional development. The extent to which the school leader is positively disposed to STEAM education may also influence a school's interest in and level of engagement with STEAM.
>
> (Leavy et al. 2020, pp. 6–7)

When examining the focus of PD, the DES (2020) advocates for a focus on content but not at the expense of skills development. Likewise, in the Irish policy on STEM education, 21st-century skills are key to its vision:

> In line with our ambition to have the best education and training service in Europe by 2026, 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)

Many literature sources are united in their findings that children have a very positive response to STEM and that it has the potential to develop positive learning dispositions and skills (Chesloff 2013; Honey et al. 2014; Simoncini and Lasen

[5] STEAM is STEM with Arts included

2018; DES 2020; Leavy et al. 2020). For the early years setting and infant classes, Aistear (2009) outlines the key affective skills (curiosity, perseverance, playfulness, resourcefulness and independence) and the importance of developing these through play and adult–child interactions. However, from second to sixth class there is no guidance on the development of skills. At second level, 21st century skills are evident in *Key Skills of the Junior Cycle* (DES 2015b). Ideally, however, skills should be explicitly stated with continuity from Aistear to second level. Currently there is no coherent approach to developing 21st century skills from early childhood through all phases of our education system. MacCraith (2016) writes that objectives for STEM education should be outlined across the education sectors to ensure smooth transitions: 'if we set about identifying the overall outcomes that we want in terms of our education system and develop those step-wise along every stage of the system we would have a much more successful outcome' (2016, p. 103).

MacCraith (2016) identifies many of the essential features of effective PD in STEM; these largely reflect the features espoused by Desimone (2009) and Borko et al. (2010) (see section 2.2). He believes that teachers' PD in STEM should be in context, be sustained, and allow opportunities for teachers to participate and reflect together. Inquiry-based approaches to science and maths should be modelled too, so that teachers are encouraged to experiment with innovative classroom practice. MacCraith advocates for the use of 'STEM champions' in primary schools: specialist teachers who would disseminate good practice and build on teachers' capacity. He acknowledges that teachers require sustained PD to successfully navigate these shifts from content-focused teaching to IBSE approaches and methodologies (MacCraith 2016).

The DES (2020) expands on this, maintaining that Cosán should reflect STEM as a learning area, thereby prioritising STEM PD across all sectors, including early years, primary and post-primary. It believes that teachers would benefit from a multi-dimensional approach in which learning may be formal or informal, individual or collaborative, school-based or external, or a combination of these forms. Because of the dearth of Irish research on STEM, an Irish study on PD in science will be discussed. The study showcases PD in science that reflects the practices advocated by Desimone (2009).

Over a two-year period, Smith (2014) carried out PD in science with children in senior classes (9–12 years) of fifteen rural schools in the west of Ireland. He identified that a significant challenge was the investment of a high-quality mode of PD in primary science. Smith used Desimone's (2009) features of effective PD, which included five main aspects: focus on content, active learning, coherence, duration, and collective participation (see section 2.2). In further research, Smith (2015) examined the impact of this programme of PD on teachers' practice and pupils' attitudes to science.

Although it was a small-scale study, some interesting findings emerged. Teachers reported the aspects of PD that had the most effect on their practice: content, active participation, collaboration and the prolonged duration of the programme. Smith also found that teachers moved from more didactic science lessons to more child-centred lessons. Teachers began to use more IBSE methodologies and more hands-on investigations. Children became more enthusiastic about science, and teachers reported enhanced confidence and motivation. Smith attributes the success of the programme to the two-year time frame and to its collaborative nature:

> It gave the participants the chance to develop their pedagogical and content knowledge and the opportunities to try out activities from in the workshops in their classroom. … Collaborative PD programmes are critical for teachers in small rural schools.
>
> (Smith 2015, pp. 231–232)

Smith believed that rural schools especially benefitted from this type of PD, as teacher isolation was broken down and trust between colleagues was boosted.

Taking an American perspective, Honey et al.'s (2014) report, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, researched approaches that would lead to positive outcomes in integrated STEM teaching and learning at K-12 level. They identify features associated with effective PD, namely teacher collaboration which supports the development of professional learning communities that extend beyond the classroom. They write that teachers working with STEM knowledgeable others outside of schools, teachers working in teams, engagement with peer feedback, and sustained support all promote deep team learning, which in turn improves teachers' efficacy and children's achievement.

Lesseig et al. (2016), in their research, focused on integrated STEM with teams of middle-school teachers. They implemented a collaborative, reflective, sustained, context-specific form of PD. They aimed to shift from teacher-centred to child-centred instruction and to engage all learners in interdisciplinary knowledge and application. Lesseig et al. (2016) found that PD changed teachers' practices and beliefs. Teachers' beliefs changed in their perceptions of children's ability to succeed at complex tasks. Children whom teachers perceived as struggling were highly motivated during STEM lessons. Teachers were increasingly likely to pursue engineering-design tasks with their class, engaging them in scientific and mathematical discussion. Teachers also reported an improved sense of self-efficacy to new pedagogical approaches, and they attributed this to the sustained collaboration.

Three types of challenges were encountered during the research: pedagogical, curricular and structural. Pedagogical challenges involved the teachers having difficulty with their facilitator role in STEM lessons; curricular challenges involved the teachers finding it problematic to integrate STEM into the existing curriculum; and structural challenges involved resourcing and timetabling conflicts. Lesseig et al. (2016) believed that the changes made to teachers' practices and beliefs in STEM were unsustainable due to these challenges, as the school required changes to their practices, policies and structures to fully integrate STEM instruction.

There are many parallels between the recommendations for PD in Ireland and internationally, and again they echo many of the features mentioned by Desimone (2009) and Borko et al. (2010). Rosicka (2016), in her review of Australia's position, advises a sustained form of PD and the introduction of science post-holders or co-coordinators. She recommends specialist STEM teachers, school-based learning communities and summer schools. Similarly, she writes that teachers should be given opportunities to reflect on their practice, and that teachers require sustained and ongoing support. The research she proposes aims to use action research as an approach to PD. Rosicka (2016) suggests the possibility of action research to inform teaching practice in STEM. However, she concedes that 'if action research does take place in primary schools, it is rarely published or shared' (2016, p. 6), perhaps hinting at the unrealised potential that action research has. As there is currently an absence of research on action research in STEM in Irish primary schools, a Canadian study is now discussed.

Goodnough et al. (2014) carried out a collaborative action research project with twenty- two teachers in STEM. When designing their PD course, they did not focus solely on enhancing STEM concepts but also aimed to emphasise teaching and assessment approaches to connect directly with children's learning. They used Shulman's work (1987), as PCK included subject-matter knowledge and specific pedagogy in teaching. Their most prominent finding was that teachers' PD must be directly linked with student learning. Secondly, the teachers found collaboration to be critical, as they could share experiences with other professionals and had an opportunity to witness good teaching practice in other schools. They planned, exchanged ideas, observed one another during teaching, and gave feedback. The hands-on aspect of action research in their PD enhanced teachers' learning. Teachers saw this form of PD as hugely beneficial because of its relevance to their own context. They perceived the challenges to be 'time, opportunities to collaborate, provision of resources, technology access, and support and guidance from administration, program specialists, and the researcher' (Goodnough et al. 2014, p. 411).

Common features of effective STEM PD are identified in the literature: a focus on children's learning, sustained support, school-based learning, active teacher learning, reflective practice and collaborative structures (Goodnough et al. 2014; Honey et al. 2014; Smith 2014, 2015; Lesseig et al. 2016; MacCraith 2016; Rosicka 2016). PD must be designed to increase teachers' competence in their knowledge but also in their confidence (Goodnough et al. 2014; Honey et al. 2014; Smith 2015; MacCraith 2016). This current study aims to provide a PD experience that encompasses many of the features described by combining LS and action research. To date, PD research in Ireland encompassing those features has not examined STEM and has instead focused on science. Also, much of the Irish research on science has focused on classrooms in upper primary school. This research aims to incorporate LS and action research to investigate STEM with children in Junior and Senior Infants.

3.3.4 Summary

In recent years, nations globally have created numerous policies to promote STEM education at primary, post-primary and tertiary level. As these policies are developed, it is important that educational research keeps pace to ensure that policy is enacted on the ground successfully. As the spotlight has focused on STEM education, there has been increasing interest in integrated STEM. This has proved challenging and elusive to implement, as there is little consensus on STEM definitions and terms. This interest in STEM education and integration has fuelled the need for effective professional development. Much of the thrust in PD is to give teachers sustained opportunities to collaborate and reflect, as this has been found to improve their pedagogic knowledge and confidence. Effective PD is required in order to help teachers overcome STEM challenges and to ensure good-quality STEM education for all ages.

3.4 STEM Education in Early Childhood

The internationally accepted definition of 'early childhood' covers the stage from birth to eight years (Organisation for Economic Co-operation and Development 2001). Policy supports the introduction of STEM in early childhood, but in practice it is a relatively new idea to educational practitioners (Park et al. 2017). Research in the area is small but growing (Tippett and Milford 2017). Fleer and Robbins (2003) argue that there has been 'Hit and Run Research', with 'Hit and Miss' results in early-childhood science education. However, research has found that play and STEM have many synergies.

3.4.1 STEM in early years education

The literature reports many advantages to young children learning about STEM. Clements and Sarama write that young children 'can think about these subjects in ways that are surprisingly broad and deep' (2016, p. 90). Studies have found that early science instruction that is integrated across different disciplines (e.g. literacy and technology) promotes young children's attentiveness towards science (Fleer and Robbins 2003; Howes 2008; Tippett and Milford 2017). Introducing STEM to children in early childhood can also be a predictor for later learning (DeBacker and Nelson 2000). Clements and Sarama (2016) expand on this, stating that engaging in STEM contributes to children's developmental goals, such as language and executive function. Mercer et al. (2004) write that STEM lessons, like science lessons, require children to use a complex set of language skills, questioning, predicting, reasoning and explaining. Van der Graaf et al. (2019) found that children with strong linguistic abilities perform better in scientific reasoning in kindergarten. Rosicka (2016) maintains that primary school is the ideal time to tackle gaps or misunderstandings in young children's STEM knowledge. In Ireland the importance of introducing STEM education in early years education seems to be recognised:

> Young children are developing curiosity, inquisitiveness, critical-thinking and problem-solving capacities. … We need a national focus on STEM education in our early years settings and schools to ensure we have an engaged society and a highly-skilled workforce in place. … Engaging with high-quality STEM experiences at a young age can have a lasting impact on learners.
>
> (DES 2017a, pp. 5–6)

Teachers' perceptions on STEM are critical, as they influence the time and consideration given to STEM education (Simoncini and Lasen 2018). In their online survey of 830 early childhood teachers on their beliefs about readiness for teaching STEM, Park et al. (2017) found that only 30% of teachers believed STEM was appropriate or significant for young children. One third of teachers did not feel equipped to teach STEM. Teachers were also questioned about the challenges in teaching STEM; these comprised seven themes:

> (a) lack of time to teach STEM (24%); (b) lack of instructional resources (16%); (c) lack of PD (14%); (d) lack of administrative support (12%); (e) lack of knowledge about STEM topics, particularly engineering (8%); (f) lack of parental participation (7%); and (g) reluctance of teachers to collaborate (6%).
>
> (Park et al. 2017, p. 284)

The challenges facing Irish teachers are reflected worldwide, as research suggests that early education practitioners are not confident teaching in this area (Czerniak and Chiarelott 1990; Murphy, Neil and Beggs 2007; Fleer 2009; Yılmaztekin and Erden 2017) and have a weak knowledge base (Fleer and Robbins 2003; Fleer 2009; Kallery 2015). Fleer (2009) noted that over the past ten years, research into teacher knowledge and confidence in early education and primary school has demonstrated little change. Chesloff (2013) draws attention to the theory–practice gap and concludes that teachers who seem confident in STEM may encounter challenges when actually teaching STEM lessons. Unfortunately, children do not seem to be receiving sufficient science experiences: 'teachers rarely offer science related activities in any context, either planned or spontaneous' (Clements and Sarama 2016, p. 78). Lawrenz et al. (2017) caution that STEM education from PreK-16 must change in content and approaches.

3.4.2 Aistear and STEM

The powerful link role of play in the learning process is sometimes overlooked (McClure et al. 2017). The literature strongly promotes the importance of play for extending children's learning (Bennett et al. 1997; Dockett and Fleer 1999; Wood 2004; NCCA 2009; Dooley et al. 2014; McClure et al. 2017; Simoncini and Lasen 2018). There are many opportunities to align STEM and play, as children are encouraged to explore the world around them (Tippett and Milford 2017). Aistear (NCCA 2009) promotes a range of different types of play – 'exploratory', 'constructive', 'pretend', 'creative', 'games with rules', 'language', and 'physical' – that could be exploited for STEM learning. McClure et al. (2017) argue that children's block play, playing at the water table, gardening and building forts show their readiness to engage with STEM.

Developing children's language and vocabulary is a significant feature of play and STEM. Vygotsky (1978) believes the teacher has a central role when modelling a broader range of vocabulary during play. Aistear (2009) advocates teacher–child conversations and interactions to include words or phrases that support children to develop a language they can use to explain their experiences. Van der Graaf et al. (2019) write that for teachers to be responsive to children's inquiry and questions, they should use specialised language, provide feedback to children's explanations and interactively discuss the inquiry process. They caution that teachers must be made aware of strategies to promote children's language, the value of teachers' interactional abilities, giving feedback to children's questions, and explanations.

Teacher quality is widely accepted to be one of the key components of quality early childhood education (McClure et al. 2017). Dockett and Fleer (1999) believe that the role of adults is fundamental in extending the type and level of children's play and science. They write that adults take on many roles during play – co-player, facilitator, mediator, assessor – while also managing time, space and resources. Current research indicates the challenges for teachers to recognise and make the most of the teachable moment, as play often becomes repetitive. Siraj- Blatchford (2009) and Ginsburg et al. (2008) contend that it is the practitioners' responsibility to encourage children to take on challenges and extend their play. Teachers must provide experiences to foster their development.

> When educators evidence a sound knowledge of maths , a pedagogical repertoire that includes play, and awareness of the connections between these, there is great potential for early childhood experiences that extend young children's mathematical understandings and dispositions.
>
> (Dockett and Perry 2010, p. 718)

The literature suggests that maths concepts are evident in much of young children's free play (Seo and Ginsburg 2004; Clements and Sarama 2016). Clements and Sarama argue that these opportunities should be channelled, as 'young children possess a broad, complex, and sophisticated informal knowledge of math' (2016, p. 76). Not all free play will lead to mathematical and scientific learning; play must be mediated by an adult, intentional and premeditated (Ginsburg et al. 2006). Teachers must maximise and harness the different types of play to expand on children's scientific and mathematical understanding.

While play is considered integral to early childhood education, there is no agreed pedagogy. Gray and Ryan (2016) highlight that the last decade has brought on an exceptional raft of play-based curricula and frameworks. In Ireland, Aistear is neither statutory nor inspected. This curriculum sought to complement and expand the PSC. However, having both Aistear and the PSC has resulted in Irish infant teachers finding themselves 'tasked with applying the competing demands of these policies to their classroom practice' (Gray and Ryan 2016, p. 189).

Aistear and the PSC have many points of convergence and divergence (O'Connor and Angus 2014; Gray and Ryan 2016; Hislop 2018). They have quite opposing views on literacy and numeracy: Aistear does not explicitly promote the teaching of literacy and numeracy skills, while the PSC highlights the development of these skills (Gray and Ryan 2016). Each curriculum has a different vision of how play should be positioned in early childhood education: 'while the Curriculum gives limited attention to learning through play, Aistear endorses the centrality of play and activity in children's early learning' (O'Connor and Angus 2014, p. 494). Gray and Ryan conclude that play 'is afforded a peripheral status' (2016, p. 202) and suggest that teachers use play before the 'real work' of the day. Therefore, there is a clash between Aistear and the PSC. Hislop (2018) argues that some teachers may have misconstrued the meaning of Aistear, as they have created 'Aistear hours'. However, Aistear espouses a playful approach throughout the day, not just restricted to one hour. Previously, Ireland has been reprimanded for an over-emphasis on formal instruction (Gray and Ryan 2016). While Aistear envisions a play-based approach being used throughout the school day, Smyth (2018) observes that formal instruction is currently a feature of most Irish infant classrooms. Fallon (2015) believes this is due to play delineating teaching invisibly and teachers are uncomfortable in this role. Hislop (2018) highlights inspectors' concerns that young children in First Class experience whole-class teaching, are seated in their chairs and are working on undifferentiated tasks for most of their day. Similar concerns are highlighted for children in Junior and Senior Infants.

PD is required by teachers, but, as Gray and Ryan highlight, mindsets towards play and learning must change. Similar to science PD (Smith 2014), Moloney (2010) finds that the implementation of Aistear was affected by the recession in Ireland, and that PD and proper implementation suffered as a result. She explains that weak PD and pedagogical practices are a common finding across Europe. She bemoans the fact that while Ireland has invested significantly in early childcare provision, the same cannot be said for investment in human resources (2010). Similarly, the NCCA has highlighted on numerous occasions the absence of national PD for Aistear (Hislop 2018; NCCA 2020). There is an unrealised potential for STEM and Aistear. Teachers require PD on how to encourage STEM skills through play for young children and to integrate STEM into well-planned, developmentally appropriate play experiences.

3.4.3 21st century skills

As discussed in section 3.3.3, developing children's 21st century skills is an important component of STEM education and PD provision. International research pinpoints early childhood as a time to develop children's 21st century skills. Chesloff argues that STEM education should start in early childhood, since 'concepts at the heart of STEM – curiosity, creativity, collaboration, critical thinking – are in demand' (2013, p. 27). Simoncini and Lasen (2018) do not mention 21st century skills but instead introduce 'habits of mind': children as observers, experimenters, inquirers and predictors. They questioned 117 early childhood practitioners on their conceptualisation of STEM education and linked this with children's capacity to develop these skills:

> responses reflected the belief that STEM education allowed children to explore the world; to think critically and creatively; to investigate, inquire, hypothesis, build theories and test them; to problem solve and work in teams; and to develop curiosity and persistence.
>
> (Simoncini and Lasen 2018, p. 366)

In delving into each 21st century skill – problem-solving, creativity, collaboration and critical thinking – there have been challenges with teachers' conceptualisations and the development of these skills in practice. Problem-solving is often associated with 21st century skills, and young children are often perceived as natural problem-solvers. Lind (1999) suggests problem-solving as an approach to involve children in inquiry-based learning, but acknowledges the challenge for teachers in setting up an environment in which problems arise. While some could assume that teachers would be most familiar with problem-solving, as it is an integral feature of maths teaching and learning, Boaler (2009) found that young children were better problem solvers before they went to school and received formal instruction. After hours of passive maths learning, children had their problem-solving abilities 'knocked out of them … they think that they need to remember hundreds of rules they have practiced and they abandon their common sense in order to follow the rules' (Boaler 2009, p. 39).

While teachers appreciate the value of children developing 21st century skills, there seems to be an expectation that teachers know how to integrate these skills into STEM instruction. Herro and Quigley (2017), focusing specifically on the 21st century skill of creativity, found that teachers struggled with their understanding of it. Teachers viewed creativity narrowly, usually in the design of final products, but they did not perceive creativity as a mode of inquiry. They indicated that they were unclear how they could integrate arts into their practice beyond media arts (Herro and Quigley 2017). As Leahy writes, 'creativity is a term that is often used in education, but is rarely defined' (2012, p. 283).

Children working collaboratively is referenced in association with other skills deemed important in Irish STEM policy: 'teachers and early years practitioners will provide collaborative environments, both in and out of school, for STEM learning, fostering curiosity, inquiry, persistence, resilience and creativity' (DES 2017a, p. 13). However, Dunphy (2009) found that in Irish infant maths classes, teachers were not confident with pair or group work. Collaborative work in STEM is a challenging aspect up to middle school level (Herro and Quigley 2017). Hummell (2016) broadens his conceptualisation of collaboration as a tool that should be used to promote children's social and cultural skills. As children complete challenging, hands-on, collaborative STEM tasks, they will recognise and appreciate in very practical ways the importance of cooperation, respect and diversity (Hummell 2016). Collaborative group work has been found to aid children's understanding and reasoning skills (Mercer et al. 2004) and to increase their interpersonal skills, resilience, self-efficacy and engagement (Master et al. 2017). It is noteworthy that collaborative projects are more appealing to girls than traditional competitive programmes (Sullivan and Bers 2016; Tanna 2016).

Critical thinking is advocated as a 21st century skill, but again, no clear guidance has been supplied on how to develop it during STEM classes. As Portelli (1994) found, the meanings of 'critical thinking', 'decision-making', 'creative thinking' and 'problem-solving' are often misinterpreted. The new primary language curriculum supports critical thinking in conjunction with 'book talk': 'Critical Thinking and Book Talk encourages children to become critical thinkers. The approach is about fostering thinkers, speakers and readers who enjoy reading, and discussion and dialogue about books' (NCCA 2016, p. 1). This explicit explanation of critical thinking, method of practical implementation and support material is required for STEM education.

Teachers seem to perceive STEM as a means of facilitating children not only to learn but also to develop a broader range of skills and dispositions. However, research finds that some teachers struggle to visualise how 21st century skills in young children could be developed. Beswick and Fraser (2019) write that teachers require a high degree of competency in 21st century skills, but that although many sources of literature state the importance of children developing 21st century skills, there is little emphasis on developing the competencies in teachers.

3.4.4 Summary

STEM knowledge is formed in early childhood. Early childhood therefore presents an important opportunity to expose children to STEM in playful ways. Many teachers have restricted knowledge and confidence, however, and this may hinder children's learning. This is also significant because teachers' perspectives of STEM may be hampered by their reluctance to engage with STEM. Teachers require robust and comprehensive PD in STEM to address gaps in knowledge, boost their confidence and efficacy and promote positive dispositions towards STEM education.

3.5 Conclusion

STEM has become a focus for governments globally as concerns centre on the synergies between research, education and the economy (Freeman et al. 2019). This chapter initially examined the context of science education in Ireland to fully assess the type of foundation laid for the introduction of STEM education. Many of the challenges reported in science teaching and learning are similar to the difficulties presenting in STEM education. However, successful integration of all four disciplines in STEM is widely reported as significantly problematic. A review of the literature suggests a scarcity of Irish research examining the implementation of STEM in early childhood classrooms. This illuminates the need to conduct studies focusing on STEM in infant classrooms with teachers in Irish primary school classrooms.

The research highlights the need for PD when attempting to implement integrated STEM teaching (Goodnough et al. 2014; Honey et al. 2014; Lesseig et al. 2016). Many features associated with effective PD are identified. PD should be linked to children's learning, professional collaboration, the school context and reflective practice. The synthesis of the literature suggests a model of effective PD which emphasises collegiality and collaboration rather than individualism and competition. PD seems more likely to be effective if there is a symbiotic relationship between the needs of individuals and the needs of institutions. PD which is long-term and context-specific is more likely to be deemed satisfactory by teachers, and these qualities should therefore be an intrinsic part of PD.

Finally, there is growing awareness of the importance of STEM learning in early years education. Important factors include teachers' competence and confidence, recognising the potential of play, the development of 21st century skills, and positive learning dispositions. Murphy et al. (2016) warn of the consequences if children are not scientifically literate: 'in society it manifests as disconnection from fundamental aspects of our lives, the world around us, the resources on which we depend and critical engagement in planning our future’ (p. 60).

Chapter 4: Methodology

4.1 Introduction

In the previous two chapters, the literature on LS and STEM, including their theoretical underpinnings, impact on teaching and learning, and their status quo in the Irish context is discussed. In this chapter I will give an outline of the methodology I utilised to conduct my enquiry. Prior to exploring the context of this research, the research questions used to guide this study will be stated. The conceptual framework will build on the literature review. The ontological and epistemological influences will be addressed as they have implications for the methodology and how the research was designed, conducted and analysed. This segues into the parallels of action research and LS. An examination of the historical origins of action research and its varied definitions are outlined. After foregrounding my discussions on action research through the founding fathers, I explore the methodology of PAR. The features of PAR will be considered with regards to the current research. This chapter further discusses details of the participants involved before exploring the ethical considerations. A comprehensive account of the research cycles are provided and following this, the data collection methods are examined. The limitations of the research are then discussed as well as the measures implemented for trustworthiness. This chapter culminates with a description of how the data was analysed.

4.1.1 Research Question

In selecting the appropriate methodologies, constant reference was made to the core research question:

Main Research Question:
What are teachers' understandings of lesson study as a professional development tool?

Embedded Research Questions:

- In what ways does teachers' practice in STEM change (if at all) as a result of engaging with LS?

- What are teachers' learning experiences of STEM education?
- How can lesson study enhance the professional agency of teachers?
- What are the cultural adjustments made by teachers when implementing lesson study?

This study aims to contribute to the development of the LS descriptive knowledge base through a retrospective, first-person account of Irish teachers' LS experience at primary level.

It is important to note that I nor my colleagues had no prior direct experience of LS. I wanted to go through the process with a group of participants who were also inexperienced and unfamiliar with this form of PD. Therefore, this first-hand account provides a unique inside look at LS from an Irish perspective and offers a rare description of this process in primary education in STEM.

4.1.2 Conceptual Framework

Maxwell (2013) states that a conceptual framework is constructed and not something that exists ready-made. Important aspects of a conceptual framework are the inclusion of the philosophical and methodological paradigms, the research questions, prior theories, research and concept maps (Maxwell 2013). The conceptual framework employed for this study was adapted from Gurhy (2017).

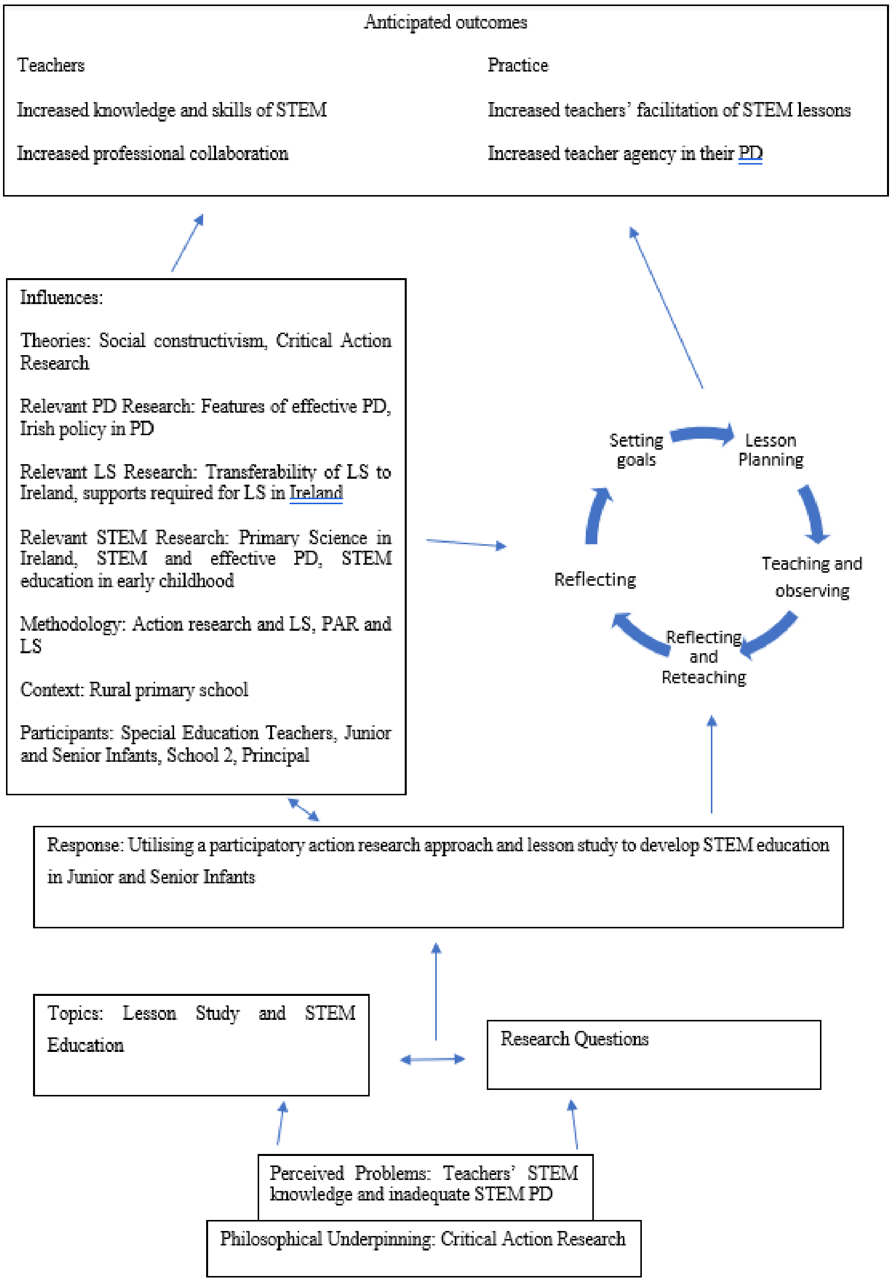

Figure 6: Conceptual Framework

4.1.3 Ontology

Action research is value laden and morally committed, it aims to understand what we are doing (McNiff and Whitehead 2006). 'We understand our ontological values as the deeply spiritual connections between ourselves and others. These are embodied values, which we make external and explicit through our practices and theories' (Whitehead and McNiff 2006, p.86). Buber's (1970) ideas about 'I-It' and 'I-Thou' relationships have been influential as his ideas have helped me to interrogate my own ontological stance in relation to others. It has provoked thought on how I engage and interact with others in my classroom. Buber (ibid) defined relationships in terms of 'I/Thou' and 'I/it'. His idea of 'I/Thou' was that it indicated a relationship of exchange and inclusion both with teachers and students. 'I/it' indicated a relationship of unequals, who are disconnected from each other. My ontological stance is that I am one among other equal 'I's', and this is why I feel compelled to do insider research. 'I/it' seems to indicate that an outsider research stance would be acceptable. 'I/Thou' is a subject-to-subject relationship whereas 'I/it' denotes more a subject-to-object relationship. The ontological position of this study is that human beings are social, active creatures who participate in social environments. Learning is social and should be meaningful to the learner. Through this research I hope to better myself and my practice while also inviting colleagues to improve their practice also. This will be achieved by participatory action research (PAR).

4.1.4 Epistemology

Epistemology is 'how we know what we know' (Crotty 1998, p. 8). The core epistemological belief of this work is that knowledge can be co-constructed (Vygotsky 1978). Social constructivists like Bruner and Vygotsky recognise the construction of knowledge through social interaction. Social constructivism emphasises that knowledge is constructed through social interactions. Therefore, taking in the social element of PAR and LS this lends itself to the epistemology of this research and the autonomy and empowerment offered to teachers by this approach. Traditional forms of knowledge are often of a technicist nature (Carr and Kemmis 1986). I have shifted my epistemology from locating knowledge solely in an objectivist perspective to a dynamic, individual, dialogical perspective. During the LS and PAR process, professional collaboration occurs as teachers of various levels of experience work together in groups to study their practice through the implementation of research lessons. My ontological and epistemological values are such that I value individuals as unique knowers, and I believe that teachers have the capacity to share and value each other's practice and also for researching and theorising their own practices. Learning should be an active process and should incorporate meaningful activities for both students and educational practitioners.

PAR and LS demand that I self- reflect on my values and practice, collaborate with others and ask questions like: 'What are we doing? How do we improve our practice?'. We will attempt to create knowledge through negotiation and collaboration with others.

4.2 LS and Action Research

An action research methodology, namely PAR, was chosen for this study. This section will discuss the parallels between action research and LS. It will outline the historical origins of action research and its varied definitions. Then it will consider the features of PAR with regard to the current research.

The overview of action research and LS reveals many synergies:

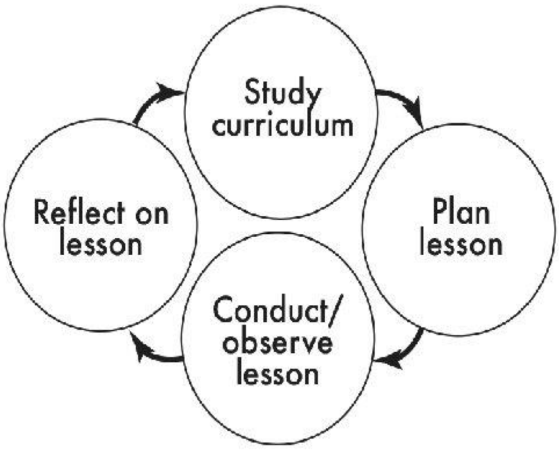

Figure 7: LS Cycle (Lewis et al. 2009a)

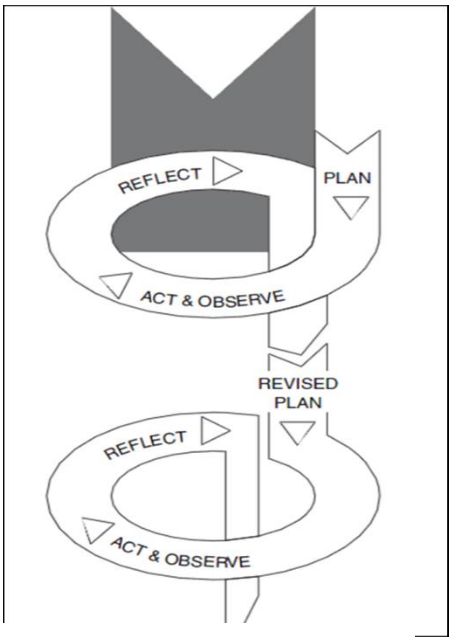

Figure 8: Action Research Cycle (Kemmis and McTaggart 1988)

- Both approaches centre on cycles of inquiry, as Figures 7 and 8 show
- Both pinpoint an area of concern
- Both seek to investigate practice and to improve it by building tacit knowledge. A group of teachers may convene to evaluate the situation at present and research the area of concern as teachers reflect
- Both occur in the practitioners' context and are adaptive to individual contexts
- Both are collaborative and require peer feedback

There seems to be no clear agreement on the relationship between action research and LS in the literature. Hanfstingl et al. (2019) argue that there is a striking lack of clarity between LS and action research throughout the literature, but they believe action research is a research attitude. Posch (2019) writes that action research is the umbrella term for a variety of approaches, including LS. Action research seems to be utilised much more than PAR in LS research. However, in their study, Pérez et al. (2010) highlight the relationship between LS and PAR. They believe that through these approaches, teachers' role as change agents is recovered, and that the most fundamental feature of LS used in conjunction with PAR is the balance between action and reflection.

Dudley (2011) links LS and action research, writing that LS began in the 1870s and therefore predates action research. He believes LS 'is a highly specified form of classroom action research focusing on the development of teacher practice knowledge' (Dudley 2011, p. 2). Murata (2011) names action research in explaining the professional programmes that incorporate many features of LS, but she notes that these approaches differ due to the live lesson. The live lesson provides a unique opportunity for teachers to engage in dialogue on teachers' PD (Murata 2011). Murata argues that 'this implicit and organic noticing does not happen in artificially replicated PD settings' (Murata 2011, p. 3).

Elliott and Tsai (2008) draw on the epistemologies of Dewey and Confucius to highlight the parallels between LS and action research, as it becomes a meeting point between Western and Eastern thought. Both Dewey and Confucius make links with reflection, knowledge and action for the common good. Elliott and Tsai (2008) write that Stenhouse's idea of the teacher as researcher has re-emerged in Confucian East Asia. They believe that Western educationalists should be in dialogue with East Asian educationalists, as they have carried out forms of educational action research designed and influenced by Confucian culture (Elliott and Tsai 2008). They strongly advocate for teachers researching their practice and taking on action research as compulsory.

Lewis et al. (2009b) recognise that the LS cycle corresponds with Noffke's (1997) three-pronged description of action research (personal, professional and political). Lewis et al. believe that LS parallels quite consistently with Noffke:

> Teachers seek to improve their effectiveness and knowledge (the personal component of the framework), by engaging in collaborative knowledge accumulation and theory building (the professional component) thereby supporting changes in the goals and culture of instruction (the political component).
>
> (Lewis et al. 2009b, p. 142)

Noffke (1997) acknowledges the growth of action research and also parallel areas such as narrative inquiry and LS. She writes that LS foregrounds the professional but also shows connections to the personal and political dimensions. She believes this is particularly important in an era when standardised tests measure progress and quality globally. Action research and LS are therefore vital to highlight the 'educator's voice'. Lewis et al. (2009b) write that LS improves teachers' knowledge of content and pedagogy and their ability to learn from each other and their practice (Fernandez 2005; Lewis et al. 2006b). These findings are common outcomes of action research also. Another finding of Lewis et al. (2009b) is based on the dissemination of LS's findings, results through networks, articles and books. They find that while Japan has a system established for disseminating results, the US's system is not as established and apparent. Similarly, Whitehead and McNiff (2006) write that the results and findings of action research and teachers' reluctance to publish and share results is a difficulty for action research. LS and action research both require a development of the teacher community, who work together to create experiences and lessons for students.

4.2.1 The origins of action research

The origins of action research are unclear, and many interpretations are offered (Reason and Bradbury 2001). It is largely accepted that action research began with the work of Collier in the 1930s and Lewin in the 1940s (Somekh and Zeichner 2009). Lewin recognised the intricacies of social situations and believed that commitment to improvement and to the importance of the group decision was integral to action research (McTaggart 1994). Lewin was the first to coin the term *action research* (Lunenberg et al. 2007). In the 1950s, Corey saw the potential of action research to be used by teachers to research their practice and reorganise their school's structure (Lunenberg et al. 2007). Both Corey and Lewin saw action research as a welcome alternative to decontextualised, conventional research (Somekh and Zeichner 2009). Corey, like Lewin, emphasised the benefits of cooperation between teachers and researchers when engaging in action research.

Freire was another influential figure, as he used action research for political purposes in the 1930s–1950s. Freire strove for a more democratic education system and endeavoured to shift education from banking education to emancipatory education. Educational action research has also been influenced by participatory research, which developed out of the liberationist ideas of Freire in countries in South America (Reason and McArdle 2004) and were then adapted by North America.

The British teacher-as-researcher movement evolved in the 1970s. Stenhouse and Elliott aimed to 'reframe the nature of teaching as in itself a form of research, and to extend the concept of the professional to highlight careful deliberation over both the ends and means of educational work' (Noffke 2009, p. 7). Stenhouse believed that teachers' work was critical for educational reform (Stenhouse 1985). He believed teachers should develop case studies in their own classrooms to contribute to educational policy and practice (Stenhouse 1978). Stenhouse's colleague Elliott developed an interpretative approach to action research. Elliott had two key areas to his educational vision:

> That teaching and learning could best be understood by classroom-based research – to which teachers contributed as equals, bringing specialist knowledge unavailable to 'outsiders'; and that knowledge and theories from key thinkers in a range of disciplines could inform and enrich teaching, research and life itself.
>
> (Somekh 2003, pp. 251–252).

Elliott's contribution of 30 years was to teachers' PD through action research. He draws on Aristotle for the concept of praxis that he defines as 'moral action' (Elliott 2007). McNiff and Whitehead have contributed to the knowledge base of action research through their publications. Whitehead developed a self-study approach to action research. Self-study grew in the 1990s and embodies 'the struggle for congruence between goals and actions' (Noffke 2009, p. 8). The public sphere of professionalism can be seen in Elliott's work in the 1970s but also with Whitehead and McNiff. Through action research, teachers are positioned as knowledge producers, and this prevents educational reform attempts to de-professionalise teachers (Elliott 2015; McNiff 2016). Goodnough (2011) believes this could result in a sense of increased self-efficacy in teachers with regard to their professional self-identity. In Australia, Stenhouse's work spread and was developed by Kemmis and McTaggart, and Kemmis and Carr. McTaggart researched cross-cultural work with

Aboriginal people and emphasised the emancipatory abilities of action research (Manfra and Bullock 2014). Carr and Kemmis (1986) encouraged more critical and emancipatory action research:

> Action Research is simply a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practices, their understanding of these practices and the situations in which the practices are carried out.
>
> (Carr and Kemmis 1986, p. 162)

Carr and Kemmis used critical theory, especially the work of Habermas, in their discussion and debate on action research (Kemmis 2006; Kemmis 2009). Kemmis has also developed ideas with a participatory focus.

Action research is closely associated with the philosophy of Dewey (Coghlan and Brydon-Miller 2014), who encouraged its use as a scientific method to solve problems (Lunenberg et al. 2007). According to Lunenberg et al. (2007), Dewey, Stenhouse, Lewin and Corey believed that research should be conducted by practitioners in the field and should be designed to answer practical questions. These pioneers introduced a range of approaches: ‘reflective practitioner’, ‘practitioner research’ and ‘action research’ (Lunenberg et al. 2007).

In the 1990s, action research was also advanced in the US through the teacher-as-researcher movement with Cochran-Smith, Lytle and Lieberman. This movement stemmed from the ideas of Stenhouse, Elliott, Whitehead and McNiff (Pine 2009). Cochran-Smith and Lytle refined the movement as they developed ‘inquiry as stance’ (Pine 2009). Cochran-Smith writes that this ‘is distinct from the more common notion of inquiry as time-bounded project or activity within a teacher education course or PD workshop’ (2003, p. 8). ‘Inquiry as stance’ benefitted practitioners as it allowed them to evaluate their work against their peers, critical friends, theory and research in a bid to improve their practice.

Also, in the US, Noffke devoted her life’s work to placing the creation of knowledge in the school and to countering the diminishment of teachers (Hursh 2014). As already mentioned (section 4.2) Noffke (1997) characterised action research as having three dimensions: personal, professional and political. She believed that the personal dimension in action research has become increasingly important, as teachers' values and beliefs are connected to teaching and learning. However, she emphasised the political dimension as paramount. She believed that while all three dimensions deal with power, 'the public sphere of professionalism and the domain of the personal are also particular manifestations of the political' (Noffke 1997, p. 306).

O'Sullivan et al. (2011) explored primary teachers' perspectives of PD north and south of the border in Ireland. The teachers concluded that the current model of PD had the least effect on their practice, and that action research and qualification programmes had the most impact. Consequently, O'Sullivan et al. (2011) question the prominence of in-service PD as the prime mode of PD, when teachers report the high impact of action research: 'questions must be asked about why such professionally respectful practices are not more prevalent in both systems' (2011, p. 52).

4.2.2 Defining action research

Researchers have defined action research in various ways over the decades. Kemmis and McTaggart (1988) define it as a form of:

> collective self-reflective inquiry undertaken by participants in social situations in order to improve the rationality and justice of their own social or educational practices, as well as their understanding of these practices and the situations in which these practices are carried out.
>
> (Kemmis and McTaggart 1988, pp. 5–6)

Inherent in their definition are the participatory and democratic processes of action research. McNiff (2013) believes in empowerment, as teachers will have the confidence and resolution to change something they are dissatisfied with. She believes that action research gives teachers the opportunity to professionalise themselves and to provide reasoning for their practice. Implicit in McNiff's definition is that the practitioner is reflecting 'on current practice and as a result focuses on a problem that needs to be solved' (Macintyre 2000, p.2). Elliott (2015), expanding on this, writes that action research has two aims: to create tacit knowledge and improve practice. Tacit knowledge acknowledges the role of feelings, emotions, beliefs and values. It recognises that knowledge is subjective. Elliott (2015) believes that traditional teaching is based on tacit craft knowledge; however, he argues that with rapid economic and social change today, a more self-reflexive mode of teaching is required.

Loughran and Hamilton (2016) point out that the action research process is relatively straightforward. Like LS, it is a cyclical process to research and PD. Educational action research investigates a research question and follows some variation of the action research spiral: plan, act, observe and reflect (Kemmis and McTaggart 1988; Elliott 1991; McNiff 1995).

Whitehead and McNiff (2006) ask that all action researchers, as a first step in the research process, should look to the values that guide how they live their educational lives and to assess whether they are applying those values in their everyday practice. Values are central, as they 'underprop the building of the research question and they also infiltrate the standards utilised to assess the research question' (Sullivan et al. 2016, p. 3). Elliott (1991) suggests conditions for identifying an area of practice that practitioners wish to improve:

> the important criteria for selecting an action research idea are whether the situation it refers to (a) impinges on one's field of action and (b) is something one would like to change and improve on. The extent to which one is able to change or improve on is it is a question which action research should address, rather than assume an answer to.
>
> (Elliott 1991, p. 74).

Macintyre (2000) believes that being able to choose an individual or group area of need and to react to situations are the chief advantages of action research. Consequently, after a research question has been formulated, a solution is imagined, implemented and evaluated; practice is then altered in light of the evaluation (McNiff 1995). Throughout, teachers collect and analyse data related to the problem of practice (Manfra 2019). As teachers research their practice, their PCK improves, they supply new theory and their knowledge base expands (Zeichner and Noffke 2001). They become empowered in the cycle of inquiry (McNiff and Whitehead 2006) as they bring about practical and social change in their school communities (Zeichner 2001). Teachers' perceptions of their identity also change as they engage with action research; inquiry becomes part of their professional identity (Cochran-Smith and Lytle 2009; McNiff 2016).

4.2.3 Paradigmatic positioning

The term paradigm may be defined as 'the philosophical intent or motivation for undertaking a study' (Cohen and Manion 1994, p. 38). Each paradigm is grounded in its own ontological and epistemological assumptions which underpin different research approaches (Scotland 2012). The researcher must locate themselves within a paradigm. Habermas (1972) argued that knowledge could be categorised as 'technical', 'practical' and 'emancipatory' based on primary cognitive interests. These interests are based in aspects of social existence; work, interaction, and power (Habermas 1972). He associated technical interests to work, practical interests to interaction, and emancipatory interests to power. These three 'knowledge-constitutive interests' will be used as a framework to outline the values, paradigms and philosophies inherent in action research. The positivist, interpretivist and critical theory paradigms will then be linked to groupings and classifications of action research stipulated through the research. I will discuss each briefly as I explored and investigated what approach would allow me to improve my practice and carry out my research.

Action research has evolved into varied forms, McNiff (2016) describes the landscape as characterised by 'tribalism' and 'territorialism'. However, Manfra (2019) states that all forms of action research converge as they wish to improve practice. Additionally, all forms of action research are similar in their departure from traditional forms of research (Kemmis 2006; Kemmis et al. 2014; McNiff 2016). Grundy (1988) advancing on the thoughts of Habermas (1972), developed the use of teachers' experiences and their observations and following the original technical action research approach, brought forward two further emerging modes, the practical and the emancipatory. She offers a different outlook to Noffke and outlines three modes of action research: technical, practical and emancipating. Grundy (1988) acknowledged that a teacher's choice in using these three modes depends on their epistemology. Akin to Grundy, Carr and Kemmis (1986) differentiated three types of action research based on Habermas's (1972) theory of knowledge-constitutive interests: technical, practical and critical action research. Loughran and Hamiliton (2016) state that despite which model a practitioner subscribes to, action research is based on the values of the participants.

4.2.3.1 Technical Action Research

Much action research is of the technical form 'most aim to increase or decrease the incidence of particular problems' (Kemmis 2001, p. 92). Within the technical mode of research teachers are consumers of innovation (Eilks 2013). Carr and Kemmis (1986) technical approach is guided by the desire for control over outcomes i.e. class assessments, the focus remains on the practitioner. There is a one- way relationship between the practitioner and the researcher, the technical approach views the teacher as the 'knower' and treats students as objects to be acted upon.

4.2.3.2 Practical Action Research

The practical approach understands the teachers and students as equal partners, the researcher works with the participants to identify a problem and decide on the interventions together. This approach may involve a facilitator but would be undertaken by a group of practitioners with equal power. The research is open 'to the views and responses of others, and the consequences that these others experience as a result of the practice' (Kemmis 2009, p. 470). Action research falling within this frame is equally concerned with process as much as the end result of the inquiry (Leitch and Day 2000). Practical action research is guided by an interest in informing or enlightening practitioners (Kemmis 2009). Much of Schön's work has a practical approach,

> Practitioners aim not only to improve their practices in functional terms, but also see how their goals and the categories in which they evaluate their work are shaped by their ways of seeing and understanding themselves in context
>
> (Kemmis 2001, p. 92)

4.2.3.3 Emancipatory/ Critical Action Research

Emancipatory action research involves power being shared evenly across a group of practitioners, not an external expert or facilitator (Grundy 1988). Whitehead (1993) and McNiffs (2013) approach to emancipatory action research is their 'living educational theory' and the practitioners' values are the starting point. From this position, two fundamental questions arise: 'How do I improve my practice?' and 'How do I live my values more fully?'. Leitch and Day concede that their approach is emancipatory, however, they criticise the emphasis on the individual rather than a collective, introspective action. Similarly, Kemmis and McTaggart critique educational action research as being too individualistic describing it as 'captured and domesticated in individualistic classroom research, which has failed to establish links with political forces for democratic educational reform' (1988, p. 51). They believe that through a more collective process there is a significant opportunity of reforming and changing education from within.

Carr and Kemmis' slant on critical action research is guided by an interest in emancipating people and groups from irrationality, injustice and harm or suffering (Kemmis 2009, p. 469). It is undertaken collectively, decisions are taken jointly 'the aim is to explore social realities in order to discover whether social or educational practices have such unsustainable consequences' (Kemmis 2009, p. 471). Kemmis (2001) believes this approach assists practitioners to critique their educational work. Critical action research links the 'political and the personal in collaborative research and action' (Kemmis 2001, p. 92).

4.2.3.4 Self -Study Action Research

Many various forms of action research have emerged for many reasons, 'often because of the nature of the problems they confront and the mismatch of dominant research methods with those problems' (Kemmis et al. 2014, p. 4). There has been tremendous growth in publication of self-study research by teacher educators (Zeichner 2001). Self -study action research is also known as first- person action research (McNiff and Whitehead 2011). It is research that attempts to achieve insights into key aspects of practice and by doing so improve practice, therefore, self- study action research is an approach to PD. Self-study action research is a process wherein theory is generated from practice. Self-study engages the individual growth around philosophical orientations and in some cases encompasses political issues. Personal beliefs and values are explored as teachers take into account their own experiences and how the children they teach have experiences unlike their own. 'The professional is also salient, in that much of the work around individual growth and learning is aimed at furthering the status of teachers and teacher educators through educational action research' (Noffke 2009, p. 9). However, Elliot (1991) maintains that there is too much emphasis on the self in action research it may divert the researcher from the focus of the study. Similarly, Somekh states

> There is a tendency for some action research to become ingrown and 'contentless', so that self-exploration and personal growth seem to become the whole focus and purpose of the research…. This may be an effective form of therapy, but it is difficult to call it research

(Somekh 1995, p. 348).

Following reflection, this research focused on a collaborative form of PD. This research does not focus on the 'self'. Neither could it be considered as a first -person account, that the 'self' is analysing the 'self' (McNiff and Whitehead 2011). While these features were of interest to me it was not the focus of the research. Therefore, I could not justify a self-study action research approach.

4.2.4 Participatory action research

Kemmis et al. (2014) believes one of the strongest claims of PAR is that participants in educational settings can do research for themselves. They state that participants using PAR have special advantages as they have access to educational life and work in local sites 'by virtue of being insiders' (ibid p. 4).

PAR can be seen as a method of research where bringing about positive social change is the principal driving force and has emancipatory goals. Ledwith (2017) writes that PAR was developed by Freire, as its methodology is based on working with people in reciprocal relationships, equalising power in the research process, and its purpose is transformative. Brydon-Miller and Maguire (2009) present the essential elements of PAR as:

> principles and frameworks to enable teacher and/or school based practitioner inquiry to become more participatory, collaborative and democratizing in a way that meaningfully engages students, families and other educators in the full range of the action research cycle, from problem identification to making project results and implications public.
>
> (Brydon-Miller and Maguire 2009, pp. 82–83)

What is distinctive is that, 'unlike much current improvement rhetoric, this approach to educational change recognises the importance of institutional as well as individual improvement' (Grundy 1994, p. 28). Those involved have the autonomy to decide the best route that will lead to an improvement of practice, and also to assess the results of strategies that have been implemented. This is a unique advantage of PAR (Kemmis and McTaggart 1988).

PAR is enacted through an explicit set of social values:

> • It is democratic, enabling the participation of all people

- It is equitable, acknowledging people's equality of worth
- It is liberating, providing freedom from oppressive, debilitating conditions
- It is life-enhancing, enabling the expression of people's full human potential

(Stringer 1999, p. 11)

PAR differs from classroom-based action research because it is collaborative and social (Hendricks 2009). The current research was democratic and involved my colleagues and me collectively engaging in data collection, analysis and planning each cycle. Teacher voice and agency were encouraged through this approach, as teachers shaped and designed each cycle. It was hoped that through teachers' involvement they would have a greater awareness of their ability to shape their own PD. The research attempted to establish teachers in theorising their practice and establishing a self-critical stance (McTaggart 1989). Because of the characteristics outlined, PAR was deemed the best fit for this research.

4.2.4.1 Features of PAR

Though there are many definitions of PAR, some common characteristics have emerged (MacDonald 2012). McTaggart (1989) outlined 16 tenets of PAR. He believes it is an approach to improving social practice by changing it, and that it is contingent on the authentic participation of its practitioners. PAR is collaborative, with practitioners establishing a self-critical community, theorising their practice. PAR requires participants to objectify their own experiences, that they put their practices and ideas about institutions to the test while also keeping records and building on these records. It is a political process, involving critical analysis, and requires participants to give a reasoned justification of their social (educational) work to others. McTaggart (1989) believes that PAR begins small, with small cycles and small groups.

Similarly, Kemmis and McTaggart (2007) outline seven of the principal characteristics of PAR; these will be discussed with relevance to the current research:

- PAR is a social process
- PAR is participatory
- PAR is emancipatory
- PAR is critical

- PAR is practical and collaborative
- PAR is reflexive (e.g., recursive, dialectical)
- PAR aims to transform both theory and practice

4.2.4.2 PAR is a social process

Kemmis and McTaggart (2007) believe that PAR probes the relationship between the individual and the social. PAR enables practitioners to work with their colleagues and collectively improve practice (Gaffney 2008). It enhances teachers' knowledge, teaching quality, leadership capacity and the building of professional learning communities (Loucks-Horsley et al. 2009). As teachers develop, test and create new knowledge, this is much more sustainable and builds capacity among teachers and schools. Working collaboratively leads not only to cultural change in the school but also to personal changes for the researcher. Action research, according to Fricke, is:

> empathy and listening while meeting the other, it is a commitment to basic values like human creativity and democratic participation, it is based on the perception of social reality as a continuing process while individuals being subjects of their history and the special contexts they are dependent on.
>
> (Fricke 2002, pp. 4–5)

Grundy (1994) points to the appropriateness of action research as a school improvement strategy. She calls on quality education to be recognised not as a matter for organisational restructuring but as a 'complex interaction between and among individual, organisational, social and political factors' (Grundy 1994, p. 35). She believes in growth focusing on the PD of the whole school and not teachers in isolation.

While Kemmis and McTaggart specify that PAR is social, challenges remain around teacher dissemination of action research. Stenhouse (1975) was very keen on teachers 'theorising' their work, communicating it to other teachers and submitting it to the scrutiny of their colleagues. He believed in a professional community of practice of teachers, perhaps researchers and curriculum specialists developing 'a mutually supportive co-operative research in which teachers and full-time research teams work together' (1975, p. 159). Elliott (2019) highlights that Stenhouse (1975) believed teachers should use explicit pedagogical theory, as this would enhance communication between teachers and provide a structure for their understanding and reflection. At present, however, this remains problematic.

McNiff and Whitehead (2011) state the importance of teachers seeing themselves as skilful practitioner–theorists and positioning themselves as having worthwhile theories to contribute to their profession and their colleagues. Like Somekh and Zeichner (2009), they maintain that while teachers acknowledge they will contribute to their practice, few will see themselves as theory creators. There is a marked reluctance among teachers to share the results of their research with their colleagues and the wider public (Zeichner 2001; Glenn et al. 2017). Somekh and Zeichner (2009) observed this when embarking on action research projects in K-12 settings: teachers were often uneasy with the term *research*. In higher education settings, they found similar discomfort with the term *action*.

Action research also faces many critiques, and the rigour of the work is often dismissed and criticised by the research community and policy makers (Cochran-Smith 2005b; Whitehead and McNiff 2006; Lunenberg et al. 2007). Lunenberg et al. (2007) question the quality of teachers' research. This negative perspective can result 'in the systematic disempowerment of teachers and in a consequent diminishing of their status as educators' (Glenn et al. 2017, p. 46). Others are dubious about whether practitioner knowledge is a trustworthy knowledge base (Hiebert et al. 2002).

Sullivan sees this process being met with resistance by policy makers, 'who perceive the task of teachers as being confined to the effective and efficient delivery of a prescribed curriculum' (Glenn et al. 2017, p. 77). Zeichner (2001) warns that many accounts of educational action research in the literature are anecdotal. There is limited evidence, he adds, that the specific characteristics of the action research experience explain the conditions responsible for the positive impact. To remedy this, Zeichner (1999 p. 279) found five conditions that appear to be related to positive outcomes for teachers and students:

1. The creation of a culture of inquiry that respects teachers' voices
2. An investment in the intellectual capital of teachers which results in teachers having control over the process
3. Intellectual challenge and stimulation in the work
4. The research takes place over a substantial length of time (at least a year) in a safe and supportive environment

5. Participation is voluntary in the research

Brydon-Miller (2012, p. 161) regards the action researcher as a responsible member of society. This is centred on the need to move away from a 'system of knowledge feudalism', and to do so by disseminating the results of action research through blogs, reports, presentations and open-source publishing in order to make 'the results of research more broadly available and useful'. Despite recent progress in making action research accessible,

> Teachers have not been active participants in the public dialogue as a research methodology in education. Ways must be found to make educational action research studies more easily available to others and involve teachers actively in the important discussions about the role of action research in educational research, policy making and teacher education.
>
> (Zeichner 2001, p. 280)

Whitehead is contributing to solving this problem: his website publishes PhDs and master's theses on self-study action research. He emphasises the importance of 'living educational theories' that are produced from practice and change through action research. From an Irish perspective, the Network for Educational Action Research in Ireland (NEARI) facilitates regular meetings, with accounts of action research being published, and also uploads support materials for potential action researchers.

4.2.4.3 PAR is participatory

Kemmis and McTaggart (2000) believe that practitioners through PAR are examining their values, knowledge and skills and the ways these are interpreted in their practice. Inclusive spaces must be created to enable participants' voluntary participation, and opportunities for free speech should be encouraged (Kemmis 2006). Whyte et al. (1991) believe that the individuals are collaborating with the researcher throughout the whole process. The participants are not passive but actively engaging and guiding the future actions of the research. Townsend (2013) acknowledges the role of power in action research groups, as certain collaborators may bring their own agendas. An action research project should not be carried out at the bidding of school leadership and should not be conducted in the guise of 'staff development' (McTaggart 1994; Kemmis and McTaggart 2000). Townsend believes that the challenge lies in making the process 'power-neutral' (2013, p. 336). He believes that the participatory ideologies of action research should form more prominent discourse than is currently apparent.

4.2.4.4 PAR is emancipatory

Emancipatory action research involves practitioners scrutinising routines, control structures and norms to identify aspects that are contradictory and irrational (Carr and Kemmis 2003). Kemmis and McTaggart (2000) believe that PAR is emancipatory because as teachers take more control of their learning, they establish a critically reflective practice and recognise themselves as extended professionals. PAR empowers and liberates teachers as they create knowledge emerging from their practice; educators are enabled to become agents of change. This leads to teachers having ownership of their own learning. PAR intent is shared power, teachers working collaboratively and thereby empowering teachers. This embodies the Habermasian (1972) emancipatory interest of knowledge, which is based on the empowerment of individuals and local, democratic decision-making processes. This research enabled an emancipatory education process, as it provoked reflection on traditional forms of PD. Through LS and PAR, teachers began to see the potential to exercise their agency and voice in relation to their PD. This research attempts to recognise the voice of the teachers, recognise the experiences of teachers, view teachers as facilitators of knowledge capable of professional judgement and redress the need for a more balanced power differential in teacher's PD.

4.2.4.5 PAR is critical

Neoliberal and neoconservative policies around the world have focused on the teacher as a mere technician rather than as a reflective practitioner Ball (2003). McNiff and Whitehead (2006) admit that while teachers are best placed to make professional judgements, they do not inform policy. There needs to be a move away from a deficit model of PD that sees the teachers as passively accepting others' knowledge. Teachers must adopt critical stances regarding the influence of governments on educational policies. Kemmis and McTaggart (2000) write that PAR is critical, as teachers are encouraged to think critically about their PD. When combining PAR and LS Perez et al. (2010) believe that the most outstanding facet of both approaches is the critical thinking of the participants from the planning stages through to the assessment and reflection. PAR supports teachers releasing themselves from constraints rooted in social structures, in their modes of work and in relationships of power (Kemmis and McTaggart 2000). Teacher autonomy should be encouraged through engagement with research, curriculum design and their preferences towards PD.

4.2.4.6 PAR is practical and collaborative

Kemmis and McTaggart (2000) believe that PAR encourages practitioners to assess the practices that link them with their colleagues in social interaction. McNiff specifies that for a team of teachers working together, validating and criticising the process has a profound effect on relationships, as teachers work together (McNiff 2002). The dual aspects of the individual and the collective are a very attractive prospect to promote collaboration and dialogue (McTaggart 1994). MacDonald (2012) suggests that this collaborative process brings together practitioners with different backgrounds and skills, which boosts the sharing of knowledge development. Grundy (1994) believes that the key terms for action research are *participatory decision-making*, *collaborative planning* and *reflexive processes*. Democratic decision-making is another appealing facet of action research, as it is 'rooted in ideas of social and intellectual freedom, that people can think for themselves, can make their own life decisions and will come together on an equal footing to negotiate their life plans' (McNiff and Whitehead 2006, p. 48).

4.2.4.7 PAR is reflexive (e.g., recursive, dialectical)

Reflection lies at the core of action research (Somekh 1995; Leitch and Day 2000; Sullivan et al. 2016). Kemmis and McTaggart (2000) believe that PAR deliberately tries to transform practice through recursive cycles of self-critical action and reflection. Dewey (1933) described critical reflection as problem-solving or investigation brought about by a moment of doubt – a process or activity that he considered central to developing practice. Leitch and Day (2000) write that it was Schön, in the mid-1980s, who distinctively promoted the image of the 'reflective practitioner' by extending Dewey's (1933) foundational ideas on reflection through observing how practitioners think in action.

Schön (1991) coined the phrases *reflection-on-action* and *reflection-in-action* as the two forms of reflective thinking. He describes critical reflection as an 'act of professional artistry' (1991, p. 12) that can involve reflection-on-action (after the event) and reflection-in-action (at the time of the event). Schön (1991) acknowledges that teachers' 'tacit knowledge' is meaningful and valuable. Tacit knowledge, according to Schön, informs teachers' judgements, understandings and actions in unprecedented circumstances. He terms this reflection-in-action. Schön uses phrases like 'thinking on your feet' and 'keeping your wits about you' to describe such an occurrence (1991, p. 54). When teachers apply their tacit understanding in their active teaching moments, they are not dependent on recognised theory or technique but are instead employing their personally formulated theories. Such personal theories are grounded in their own experiences and have been established through continuous engagement in reflective practices. These perspectives correspond with the notions that critical reflection can support professional competency and development.

Reflection-on-action is thinking about practice after it occurs. This is when teachers intentionally set time aside to reflect (Schön 1991). Reflection-on-action is in stark contrast to positivist epistemology, with its sole focus on 'rigorous professional knowledge' (Schön 1991, p. 42). Teachers write up recordings or discuss practice with a colleague, and this facilitates deeper understanding and analysis of behaviour (Sullivan et al. 2016). As such, a self-critical form of reflection can be used to gain insights and assess one's thoughts and behaviours. Critical theorists have extended Schön's categories, adding *reflection about action* as a means of ensuring that teachers reflect on the social, economic and political purposes and conditions of teaching and learning, as well as the school and classroom contexts (Zeichner 1993). However, Usher et al. (1997) are critical of the extent to which Schön investigates his own practice:

> what we do not find in Schön is a reflection by him on his own textual practice in giving some kind of account of that he does of reflection-in-action and the reflective practicum. … He does not interrogate his own method.
>
> (Usher et al. 1997, p. 149)

More vigorous interrogation of his practice may have revealed more significant insights, as he 'neglects the situatedness of practitioner experience' (ibid., p. 168). This is an aspect that researchers are more aware of, following Lave and Wenger's (1991) investigation of situated learning. Schön's contribution to understanding reflection is to be found in a teacher's ability to use a collection of images and metaphors to develop systems of framing. In this essence, it has relevance and significance for practice.

Despite the volume of literature stating the centrality of reflective practice to teaching, it is significant that little is known about the practicalities, challenges and methods of critical reflection (Finlay and Gough 2008). Reflective practice is indeed a demanding process, as the researcher adopts a dual role of both teacher and researcher. This requires them to step outside of themselves, to become 'a fly on the wall': listening to, watching, learning from and altering their own practice, while simultaneously co-constructing learning with the children as research partners (Moloney 2011).

Day (1993) writes that teachers reflect in different ways at different times in their professional lives and in different positions in their career and life cycle. He writes that it is important to be mindful of the organisational and cultural contexts in which they work if opportunities for their professional growth are to be expanded. Action research provides teachers with the space and structure for reflection. It requires reflection on practice, increasing understanding and consequently improvement to teaching.

4.2.4.8 PAR aims to transform both theory and practice

Before this research, I was unaware of the separation of theory and practice and perhaps had never given it much thought. By pursuing the research, my awareness has developed and I have begun to problematise issues to do with the dominance of forms of knowledge over the knowledge of experience. I had never questioned the expectations integral in educational discourses about what represents education or knowledge generation. I never employed critical thinking about why I was expected to sit passively, absorb theory and carry it out in my classroom. I accepted wholeheartedly that it was my duty to implement other people's theories. I accepted unquestioningly that if a strategy worked in a school or classroom, it should work everywhere. When I experimented with different teaching strategies, approaches or theories and found that some did not work, I felt it was due to my ineptitude as a teacher. Adults, like children, do not learn best in these environments.

Teachers' voices have traditionally not been heard, because of the separation of theory and practice (Reason and Bradbury 2001). Universities and colleges were perceived to be the creators of legitimate knowledge. Academics were 'seen to be eminently qualified for the task of creating knowledge and developing theory' (Sullivan et al. 2016, p. 66). McNiff and Whitehead (2006) write that practitioner research has been discouraged, mainly by portraying theory as an abstract discipline. Teachers were seen to be mere technicians, taking the knowledge developed by third-level institutions and passing it to the pre-service teachers for them to test out. In this top-down model, teachers are disempowered (Sullivan et al. 2016). Similarly, Foucault speaks of power being held by certain people and groups: 'All teaching systems, which appear to disseminate knowledge, are made of certain social class and power; and to exclude the instruments of power of another social class' (Foucault and Chomsky 2006, p. 40). Academics are in the position of power and hold the traditional role as knowledge creators.

Schön (1991, p. 43) developed the metaphor of 'high hard ground' to describe professionals who are 'hungry for technical rigor'. These professional elites, he explains, base their assumptions on established theory and technique and are fearful of 'entering a world in which they do not know what they are doing' (Schön 1991, pp. 42–43). In this way, teachers are not considered artisans of their own practice, and so their 'artistic ways of coping with phenomena do not qualify … as rigorous professional knowledge' (Schön 1991, p. 42). Schön believes it is ironic that the knowledge produced in the 'swampy lowland' is the most beneficial and practical. Professional elites tend to intentionally use their own language so it remains abstract to practitioners. Schön (1991, p. 42) describes these problems as 'crucially important' and urges practitioners to descend to these lowlands and employ 'methods of inquiry, experience, trial and error, intuition, and muddling through' to overcome such problems, instead of relying solely on methods of 'rigor' and 'technique'.

Similarly, Cochran-Smith and Lytle (1990) believe that the knowledge teachers hold is very different from the knowledge made by educational researchers. Cochran-Smith and Lytle (1993) describe university-held knowledge that is to translate to schools as being 'outside in'. They write that people who hold this view believe that improving teaching is improving the translation from theory to practice, making university-based findings more accessible to teachers. Therefore, 'school based teachers are not a primary source of knowledge generation' (Cochran-Smith and Lytle 1993, p. 24). They propose an 'inside out' approach to the knowledge of teaching. They believe that legitimising the knowledge created by teachers in their own classrooms, school and communities is a crucial change for school and university cultures. This challenges the university as the holder of knowledge, and initial teacher education as transmission, and therefore has implications for how teachers learn and for their PD.

Today, the topography is levelling out, and many academics in higher education perceive themselves as practitioners (McNiff and Whitehead 2006). Whitehead (2003) has consistently maintained that teachers should study their practice and regard it as the basis for developing their own theory of practice. He rejects the idea of the theory practice divide and wishes to recognise practitioners as creators of knowledge. Despite encouragement from the research, however, teachers seldom engage in action research (Wyatt 2011).

4.3 Sampling and Research Site

For the purposes of this study, sampling aimed to ensure an accurate representation of the intended participants. Purposive sampling was employed, as it was a sample created which suits the requirements of the research (Robson 2002). Individuals were selected because they could purposefully inform an understanding of the research question under investigation (Creswell 2013). A purposive sampling strategy centres on what the research aims to investigate and understand; therefore, a sample must be chosen that will yield the most insight into that particular phenomenon (Merriam and Tisdell 2015). Purposive sampling focuses on in-depth understanding and results in information-rich cases; thus, more information can be learned about the issues central to the research (Patton 2002). Babbie (2007) writes that purposive sampling may also be a sample that will be the most representative. The appropriate sample size is based on the aim of the research and the type of population being studied (Cohen et al. 2013). It is not intended to be statistically representative. However, by using a purposive sampling of participants, this research recognises some of the risks regarding rigour and validity. Specifically, it is acknowledged that by selecting schools and targeting teachers, there was a loss of rigour, and the findings are not representative of every school in Ireland.

LS and PAR occur in natural settings. I conducted the research in my classroom in my school (School 1). The research study required the recruitment of another school, School 2, to reteach lessons. The proposed School 2 was purposively selected as it had similar demographics to School 1 in terms of size and location. Both schools were rural and multi-class. School 1 had 69 pupils enrolled at the time of the research; School 2 had 131 enrolled. The classes selected for the study contained both Junior and Senior Infants (Table 3).

School 1 Class Total	Junior Infants	Senior Infants	Boys	Girls
16	4	12	9	7
School 2 Class Total	**Junior Infants**	**Senior Infants**	**Boys**	**Girls**
23	15	8	13	10

Table 3: Size and composition of classes in School 1 and School 2

4.4 Research Ethics

Ethical concerns, especially in educational research, have the potential to be extremely complicated and delicate. As this research was concerned with teachers and involved the presence of children, every effort was made to adhere to the principles of research ethics. In April 2018 ethical approval was received from Mary Immaculate Research Ethics Committee (MIREC). This involved submitting a detailed document with a description of my research study, research methodology, sample interview questions, participant selection, ethical issues, and implications for consent, anonymity and confidentiality, and the storage of materials. Additionally, I attended a course on Ethics in Research in the Education Department of Mary Immaculate College before undertaking this research and was therefore very aware of the issues which could arise.

There were significant ethical implications when researching in schools. Creswell's words echoed throughout the research: researchers 'need to anticipate and address any ethical dilemmas that may arise in their research' (Creswell 2009, p. 88). Baumrind (1985) writes there are three types of cost that should be considered when researching: cost to the respondents, costs to the profession and costs to society.

Costs to the respondents include a loss of trust, loss of individual control, loss of self-determination and the danger of being duped. This led me to reflect on the main ethical implications of researching with children and professionals. Informed consent, confidentiality and anonymity were deemed to be of the utmost importance. Costs to the profession include jeopardising support for research and depleting the interest of subjects. With the current research in mind, I reflected on whether there would be any risk to the profession, given that this research aimed to benefit the profession. It was ensured that the research adhered to the ethical guidelines of Mary Immaculate College and that the credibility of the institution was at no time vulnerable. A cost to society consists of society's right to know whether research has created problems (Guba and Lincoln 1987). These problems include 'trust in expert authorities … broadening the aura of mistrust that pervades daily life' (Baumrind 1985, pp. 169–170). With the current research in mind, it was hoped that trust between the participants and I would be maintained and boosted by this research.

As stated, the research focused on the effectiveness of LS for teachers' PD in STEM education. Therefore, LS required the participation and collaboration of other teachers to enable our practice to be investigated and improved. As we were investigating our practice, the research involved my class of children (Junior and Senior Infants). It was appreciated at all times that research with children must meet the highest ethical standards because of their vulnerability. I attached great importance to conducting the research within stringent ethical parameters. To ensure this, I attempted to 'respect the rights, needs, values and desires of the informants' (Creswell 2009, p. 198) at all times. *Ethical Guidelines for Educational Research 2011* (BERA) and *Guidance for Developing Ethical Research Projects Involving Children* (Cleary et al. 2012) were consulted to guide the research on ethical issues in this research project. Action research as an empowering methodology encouraged democratic participation of all participants:

> Action research is research by particular people on their own work, to help them improve what they do, including how they work with and for others. It does not treat people as objects for research but encourages people to work together as knowing subjects and agents of change and improvement.
>
> (Kemmis and McTaggart 1988, p. 22)

Ethical procedures that were adhered to in this research were informed consent, participant withdrawal, anonymity and confidentiality, and care and protection of participants.

4.4.1 Participant selection and informed consent

Participants were fully informed from the outset of what the study involved. Before the research process began, its aims and methodological design were explained to the principal and board of management of School 1. An initial meeting was then set up to explain the research to the principal of School 2, and they were invited to participate. Information letters outlining the purpose of the research were distributed to both principals and both boards of management. These letters ensured that participants' rights would be protected during and after data collection (Creswell 2009). They also contained the fundamental information for participants to make an informed decision about whether they wished to participate (Bryman 2012). Following this meeting, both schools agreed to participate. Written consent was obtained from both boards of management (Appendix A and A1) and both principals (Appendix B and B1).

I then made a presentation to all school staff in School 1 detailing LS and the research design for the upcoming academic year. Initially, two teachers (School 1) were approached and invited to be participants in the study. In line with the purposive sampling strategy, they were selected based on who could best provide an insight into this topic. They were two Special Education Teachers (SETs) already working in School 1, and we had a strong and collaborative professional relationship. Both SETs were shared with School 2 and were teaching in this school for several hours a week, so they were known to the school and a professional relationship already existed. Following the meeting, the two teachers agreed to participate in the research. Written consent was sought from them (Appendix C and C1). I also negotiated with my school colleagues that they would act as critical friends and evaluators. Table 4 provides an overview of the participating teachers.

Teacher	Class	Position	Teaching Experience	Gender	School
Teacher 1 (Researcher)	Class Teacher	Permanent	≥ 5 years	Female	1

Teacher 2 (Maria)	SET Teacher	Permanent	≥ 20 years	Female	1
Teacher 3 (Gwen)	SET Teacher	Permanent	≥ 15 years	Female	1

Table 4: Overview of teachers

I then met with the Junior and Senior Infant class teacher of School 2 to explain the research and ask if she would like to participate. She agreed, and the information sheet and consent form were distributed (Appendix H and H1). During cycle two, the purpose of the research was explained to the MKO (section 2.4.5), and they were given an information sheet and a consent form (Appendix G and G1).

As my research involved the presence of school children, I attached great importance to ensuring that the research was conducted within strict ethical limits. At an information evening that I held for parents at School 1, I distributed information sheets and consent forms explaining what I was doing and asked for their permission to allow their children to be present in the study. I explained that the focus was on teachers' PD, and that the research concentrated on teachers, not on the children in the class. I explained that my research placed a spotlight on establishing whether the teachers and I had improved our practice. The consent form entailed an 'active parental response' whereby the parent had to sign that they were conferring on me the right to carry out research with their child present (Appendix D and E). There was also an 'opt-out' option for parents.

Though the children were not recorded, both Junior and Senior Infant classes became research participants. I felt it was significant to the study that the children did not feel coerced to participate, either by me or by their parents. Given the recommendation that 'statements of purpose should be simple, straightforward and understandable' (Patton 2002, p. 407) for young participants, the purpose of the research was explained to the children in child-friendly language, and they were asked whether they wanted to participate (Appendix F). I explained that I was at school, like them, and I was writing a book. I asked them if they would like to help me and the other SETs to find out how we could make ourselves better teachers. I then distributed a sheet to the children and asked them to select the appropriate smiley face and sign their name if they wanted to participate (Appendix F). I ensured that all consent forms were returned and signed before any respondent participated.

4.4.2 Participant withdrawal

It was stressed to all participants that they were free to withdraw at any time; their participation was completely voluntary. To ensure that participants did not feel coerced to join, or that a power relationship did not exist, my supervisor was the appointed gatekeeper and their contact details (email address) were supplied to the participants (Appendix A, B, C, D, G and H) to facilitate any queries.

4.4.3 Confidentiality and anonymity

Pseudonyms were also used throughout the project to protect participants' anonymity and confidentiality. To preserve their anonymity the SETs were assigned the pseudonyms Gwen and Maria. Manning (1997) cautions that despite the best intentions, it is impossible to ensure full confidentiality and anonymity, as in this case friends, family and colleagues knew where I taught. It is probable that communities, families and teachers, through this familiarity, could guess the identity of participants, so anonymity could not be guaranteed.

> Although some may guess the identity of respondents, they can never be sure. This may seem thin justification when a respondent's job, life's work, or other life-threatening circumstances is at work, but this justification, thin or not, is part of the effort to fend off irreparable harm.
>
> (Manning 1997, p. 112)

All data collected, field notes, excerpts from reflective diaries, and interview transcripts were stored on a password-encrypted computer to protect anonymity.

4.4.4 Care and protection of participants

This research did not intend to cause distress to children, teachers, parents, MKO (section 2.4.5), principals or the wider school community. I did not try to exert any control over any participants at any stage. Contrary to causing harm, this research sought to make every effort to ensure that participants benefitted from their participation, as the primary aim was to investigate teachers and their PD. Creswell states that both the researcher and the participants should benefit from the research; he advises that 'involving individuals collaboratively in the research may provide reciprocity' (2009, p. 90). Winter (1989) points out that when writing up the research, the researcher should not write in a manner that positions them in a superior role to the participants or imply that they hold expert knowledge and the participants do not. I also ensured that Gwen and Maria were included at all times and were consulted on key decisions in the research. All teachers had full Garda clearance to teach children.

4.5 Action Plan For Improving Learning

A primary objective of this research was to place teachers at the heart of the research by engaging them in collaborative, critical analysis and reconstruction of their own practice. By using a PAR approach, I aimed to explore the implementation of LS as a model of PD. This approach gave the participants the opportunity to become actively contributors to the research work, with a view to improving their own practice in STEM education.

PAR, like action research involves reflective cycles of planning, action, reflection and evaluation (Kemmis and Wilkinson 2008; Morales 2016). Thus in the planning stages I took as my starting point the action plan outlined by McNiff and Whitehead (2010). This action plan supported discussions around improving the quality of practice, understanding practice and the social context in which the practice was located. This action plan now acts as a retrospective checklist of whether the research process has been systematic and has achieved methodological rigour, for the purposes of testing the validity of my claims to knowledge. This section is organised according to that checklist:

Had I taken stock of what was going on in my practice and identified a concern?
Did I identify my concerns?
Did I try to think of a possible way forward?
Did I monitor the action by gathering data to show what was happening?
Did I evaluate progress by establishing procedures for making judgements about what was happening?

Had I taken stock of what was going on in my practice and identified a concern?

When deciding upon a focus for my research, my primary concern was locating a vehicle for PD that succeeded in bringing teachers out of isolation to work collaboratively in an effort to improve classroom practice in a rural school. As the study was using a PAR approach I also endeavoured to familiarise teachers with action research as an approach to PD. I broached this with the principal and she believed learning about action research would benefit the school staff. She maintained action research would complement School Self Evaluation as both approaches encouraged teachers to research their practice and seek ways to improve it. I booked two speakers from NEARI for a Croke Park (section 2.3.5) hour in September 2018 to discuss action research with the teachers. This talk covered researching our practice, reflection, the role of critical friends and the relevance of action research to School Self-Evaluation. I also sought to investigate, 'Does LS facilitate meaningful collaboration in an effort to make improvements in classroom instruction?' Another focus for my research was developing integrated approaches to STEM; consequently, STEM became the focus of LS. As part of LS and action research, I wanted to empower teachers in their own PD and give them a voice.

In May 2018, the principal and I held a meeting to discuss the upcoming research, and we decided that the whole school could pursue STEM as part of School Self-Evaluation. Following this, in June, I presented the basis of the study to the whole staff, and the principal put to them the prospect of pursuing STEM as part of our School Self- Evaluation. All staff members agreed. However, as September progressed, we found that we lacked direction in our aims for STEM and enlisted the help of a PDST facilitator, who provided guidance and direction on STEM and School Self- Evaluation. Following this visit we had several staff meetings to examine the school's strengths, areas for improvement and priorities for action (Appendix I).

We examined and reflected on our context and recognised that children were quite passive in their learning. We were giving children scientific knowledge without them being active in their own thinking and learning. We were delivering information, our lessons were overly prescribed, and children were not exercising their natural curiosity and conducting child-led investigations. While we promoted collaborative, investigative work, we were not working from children's ideas. We wanted to give the children opportunities to think and generate knowledge for themselves. Our concern as school staff was that while we valued active learning, collaborative learning and the children being independent thinkers, we were not teaching like this;

I was therefore experiencing myself as a living contradiction (Whitehead 1989). This led us to aim at developing the children's critical and creative thinking abilities.

Did I identify my concerns?

As a staff we articulated our values of teacher voice, teacher and child collaboration, critical thinking and inquiry-based learning. We saw that in certain areas, particularly in cultivating children's critical and creative thinking, inquiry-based learning, and teacher collaboration, we were not living in accordance with these values. I examined my educational history to identify where these values came from. Brydon-Miller (2012) suggests that before entering a research setting, we have to self-reflect and critically analyse ourselves as researchers and find our core values. I saw how my critical thinking abilities had been inhibited in my education. Easterby-Smith et al. pointed out that one of the common criticisms made by external examiners 'is that students undertaking postgraduate level work use literature in a very accepting way, often with very little comment and without critiquing it or explaining its limitations or context' (2008, p. 30). I encountered the same problem with critical thinking and creative thinking. When I reflect on my education, children being active in their education was not very visible. For my Leaving Certificate, the teachers distributed essays and booklets of pre-written answers that we memorised. This is reminiscent of Freire's banking concept. Students are asked to memorise and repeat ideas, phrases and formulas, perhaps without understanding their meaning. It is a passive process. Freire sees pupils as 'critical co-investigators in dialogue with the teacher' (2006, p. 62). It raises the question: Am I encouraging the children I teach today to be critical thinkers?

Yet despite my technicist inclinations, I am drawn to the writings of action researchers, particularly Irish teachers Roche, Glenn, McDonagh and Sullivan and their books on educational action research. I also read renowned international action researchers Carr and Kemmis (1986), McNiff (1988) and Whitehead (1989, 1993). The ideas of the teachers as reflective practitioner (Schön 1983, 1987, 1991) and as researcher (Stenhouse 1975, 1985) resonate deeply with my beliefs and values. The ideas of empowering teachers and promoting teacher voice appealed to me, and I wanted to explore this through promoting teacher agency in their PD. I was aware of the disconnect between theory and practice, as 'action research is a powerful tool for change at local level' (Cohen et al. 2000, p. 297), and I sought through my research to promote the teacher as researcher and taking charge of professionalism.

As a school, we recognised that gender also played a part in STEM, and as part of School Self- Evaluation we investigated whether this was the case in our school. We asked the children to draw a scientist. Most drew a male figure, many of whom had lab coats, test tubes, glasses and grey hair, making explosions or saving the world. Many children in Junior and Senior Infants were not sure what a scientist was, while some had recognised them from television or film. Interestingly, as we surveyed the children in our school, we observed that the older children were more likely to draw a male scientist. This correlates to an American longitudinal study that states: 'children are more likely to draw women than in the past – but they become skewed toward sketching men as they get older' (Yong 2018).

Did I try to think of a possible way forward?

On a personal level I reflected on my practice and asked, 'How do I do it better?' At a staff level we collectively asked, 'How do we make school practice better?' Initially, we decided to look for ways of introducing critical thinking through STEM. We decided to research inquiry-based learning. This progressed through whole-school meetings with a STEM knowledgeable other and also through a Science Foundation Ireland (SFI) course that introduced inquiry-based learning approaches to STEM (section 4.6.1). As a whole school we decided to conduct one STEM investigation per term; this structure also fit the cycle of LS. We integrated LS into the school and class timetable and allocated time during the week to meet. We decided to take a playful approach to learning to experiment and to encourage the children to take risks. Through discussion during staff meeting three final School Self- Evaluation targets were agreed upon:

- Give specific attention to the participation of girls in STEM
- Encourage teachers to move from dialogical and traditional teaching methodologies to the inquiry-based approach
- Encourage students to exercise their problem-solving skills and critical thinking skills in STEM
- Collaborate and share good STEM practice with each other

There was considerable overlap between the School Self- Evaluation targets and the LS goals. The second, third and fourth target were relevant to the current study as they focused on encouraging inquiry-based learning, skill development and teacher collaboration. The long-term LS goals were:

- Encourage teachers to move from traditional teaching methodologies to provide children with inquiry-based STEM activities
- Encourage children to develop their 21st century skills in STEM i.e. problem solving, communication, collaboration and critical thinking
- Collaborate and share good STEM practice with each other through LS

Did I monitor the action by gathering data to show what was happening?

LS was the vehicle that afforded the opportunity to meet with Gwen and Maria to discuss the learning that evolved week by week. I audio-recorded conversations and kept transcripts of discussions with Gwen and Maria. We also monitored our progress at a whole-school level through our staff meetings. I did not record meetings but instead took detailed notes on meetings that centred on School Self-Evaluation and STEM, meetings with the NEARI associates, the PDST facilitator, the science/STEM facilitator and SFI facilitators. Throughout the pilot and LS cycles, I also kept field notes and a reflective diary.

Did I evaluate progress by establishing procedures for making judgements about what was happening?

After the pilot cycle and each cycle of LS and PAR, different changes were made. Each cycle built on the previous cycle, being modified according to insights we had gained into practice. Improvements were made in teacher practice, the organisation of LS structures and resources. We began to develop our practice by asking more critical questions and pushing for higher order thinking in collaborative meetings. I saw too that I was changing my pedagogical style in the classroom generally and outside of STEM classes to promote more critical thinking. I believe that in detailing my response to each of the questions outlined by McNiff and Whitehead (2010), I am showing how my enquiry was systematic and methodologically rigorous (Winter 1989). What was carried out at each stage of the research cycles will now be detailed.

4.6 Research Cycle

The following section outlines the LS planning phase and the four cycles of LS. This includes pertinent school meetings, PD sessions and relevant activities that occurred during each LS cycle. It also includes brief details of each of the STEM lessons. More in-depth detail on the lessons and background decision-making will be discussed in Chapter 5. The LS planning phase was conducted from May to June 2018. This involved meetings with the principals, teachers and staff in both schools, outlining the research and distributing the information sheets and consent forms (section 4.4.1).

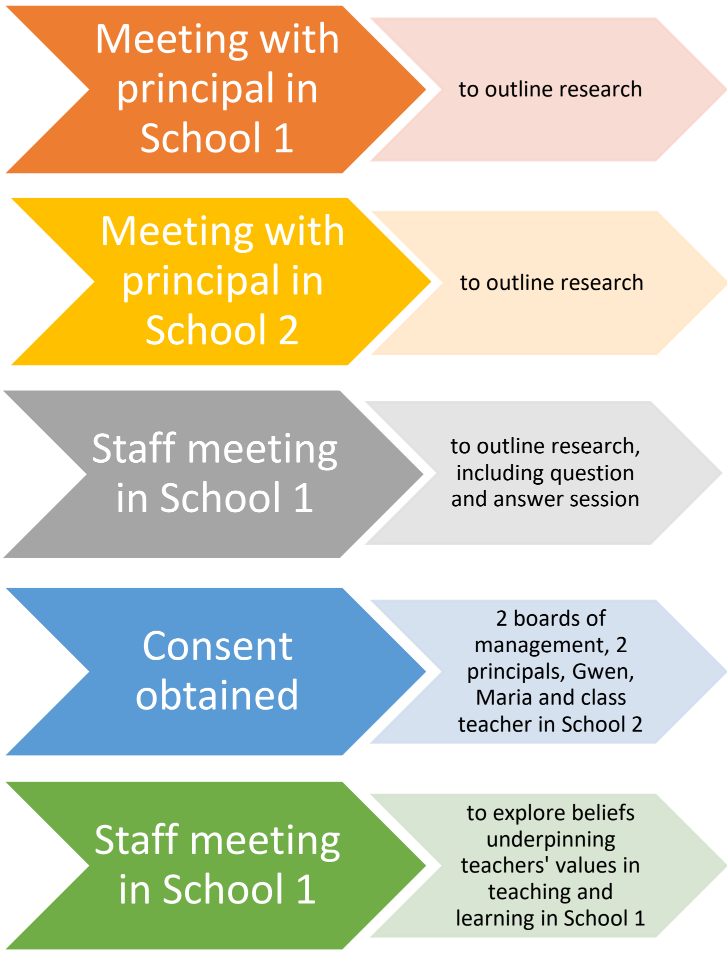

Figure 9:Lesson Study Planning Phase (May -June 2018)

The cycles of LS began in September 2018 and continued over an eight-month period until April 2019. In total this research consisted of a pilot study and a further three cycles of LS (Figure 10).

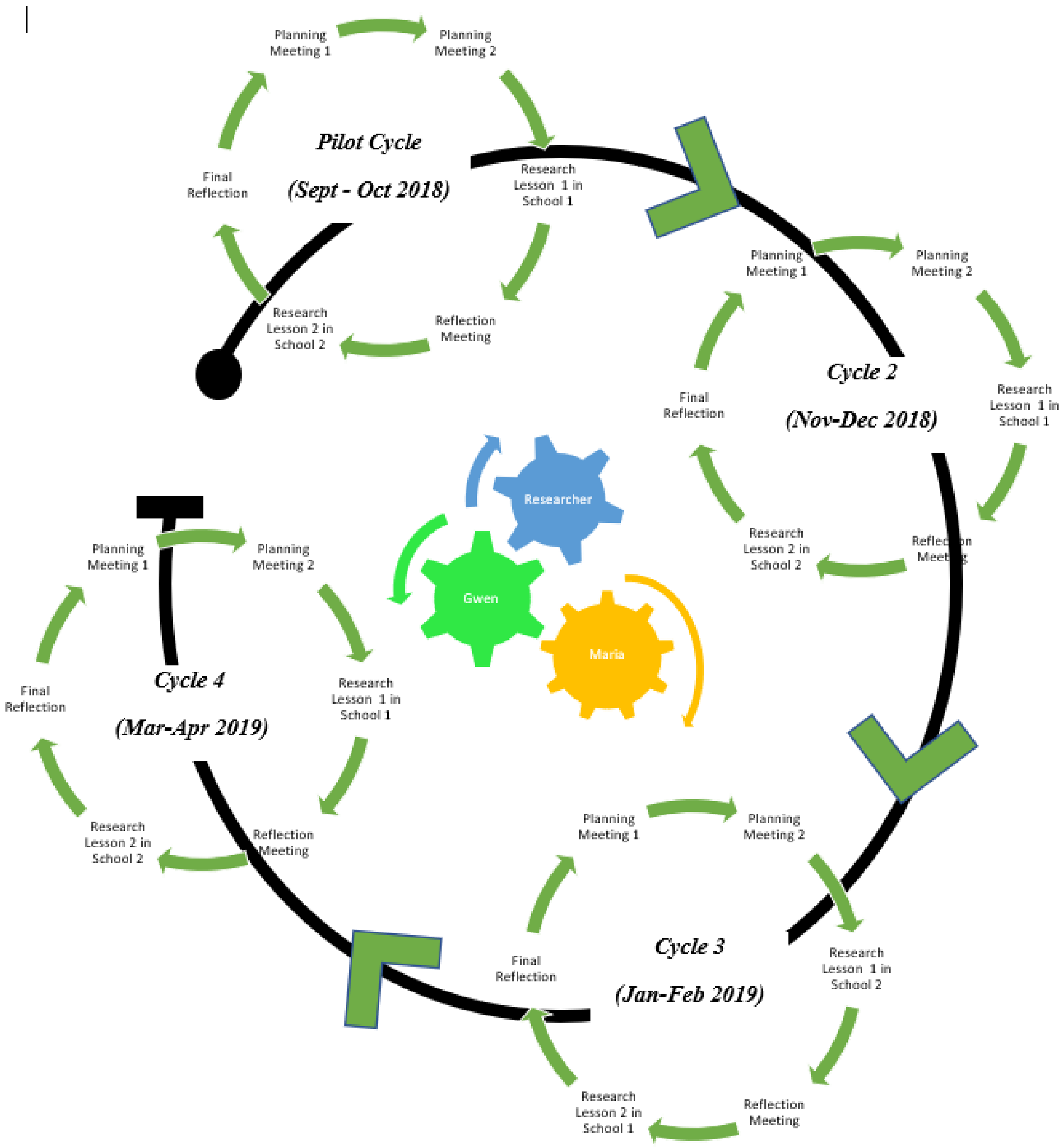

Figure 10: Research Cycles

Each cycle usually lasted six weeks. Two planning meetings were followed by the teaching of the first research lesson; a reflection meeting was then held to reflect on the learning and to plan any changes for the subsequent lesson. The second research lesson was then taught, followed by a final reflection. Figure 11 outlines the number and type of meetings conducted during a typical cycle of LS.

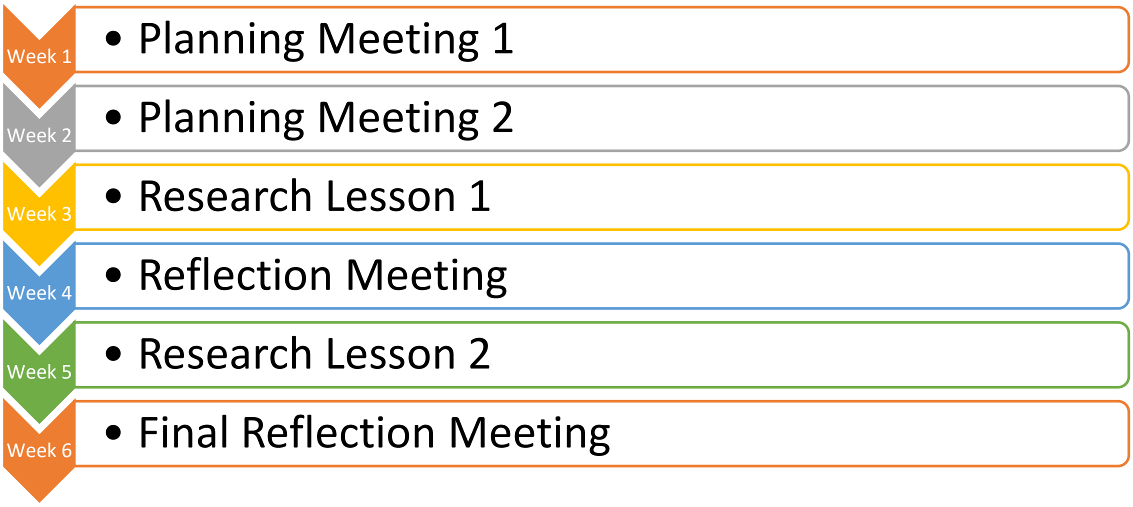

Figure 11: Weekly breakdown of meetings in the LS cycles

Collaborative meetings, specifically the planning meetings and reflection meetings, are explored further in section 4.7.4. Table 5 provides an overview of the LS cycles, teachers who taught the lessons, the school involved and the lesson topic.

LS Cycle	Lesson	Teacher	School	Topic
Pilot Cycle	Research Lesson 1	Researcher	School 1	Floating and Sinking
	Research Lesson 2	Maria	School 2	Floating and Sinking
Cycle 2	Research Lesson 1	Gwen	School 1	Humpty Dumpty
	Research Lesson 2	Researcher	School 2	Humpty Dumpty
Cycle 3	Research Lesson 1	Researcher	School 2	Gingerbread Man
	Research Lesson 2	Maria	School 1	Gingerbread Man
Cycle 4	Research Lesson 1	Researcher	School 1	Goldilocks
	Research Lesson 2	Gwen	School 2	Goldilocks

Table 5: Overview of STEM lessons

4.6.1 Pilot cycle

The pilot cycle was quite intensive (Figure 12). In an effort to enhance the collective capacity of the staff as we grappled with questions surrounding STEM, I organised external PD with several providers. PD in science and STEM featured throughout the cycles of LS. It came from four sources: SFI, a PDST facilitator, a science/STEM coach and NEARI facilitators. The SFI PD comprised of three sessions throughout the school year. Through these sessions teachers explored inquiry-based learning and observed science lessons taught using the DPSM/ESERO Framework for Inquiry lesson template. This was intended for all teaching staff. We also availed of support from a PDST facilitator, attended by the principal and I. The facilitator advised that science practice in the school be evaluated by all staff (Appendix I). All teachers also attended a science/STEM PD session provided by a facilitator affiliated with a local education centre. The principal and I had previously attended science PD classes with this faciliatator, and he had called to the school's senior classes, teaching science lessons. Lastly, I invited two NEARI facilitators to talk to the staff during a Croke Park (section 2.3.5) hour. It was hoped that these forms of external PD would help teachers increase their knowledge and confidence in STEM education and action research (section 4.5).

In September, the principal and I held a meeting for the parents of Junior and Senior Infant children in School 1 (section 4.4.1). I explained to parents the LS process and the importance of developing STEM education with young children. School Self-Evaluation required each school to choose an area for improvement, and STEM was the topic that the school had chosen for the academic year. The interview schedule was piloted with two critical friends, and semi-structured interviews were then conducted with Gwen and Maria. Figure 12 outlines all pilot cycle activities.

Figure 12: Activities during the pilot cycle

The lessons during the pilot cycle focused on the energy and forces strand in the science curriculum, particularly floating and sinking (Appendix L and L1).

4.6.2 Cycle 2

As a reflection of the pilot cycle, it was decided to include an MKO (section 2.4.5) for the subsequent cycles of LS. The MKO was a knowledgeable other in the area of LS and STEM education. Also, as the whole school was pursuing the topic of STEM as part of School Self- Evaluation, it was decided at a staff meeting that the whole school would focus on the same science strand for the winter term. It was decided that all classes would complete one STEM investigation that was relevant to the materials strand of the science curriculum, as this had been a focus during one of the PD sessions provided by SFI. The STEM lessons would be taught using the DPSM/ESERO Framework for Inquiry Lesson Plan. As part of cycle 2, the principal and I also presented at a TeachMeet at a local education centre on the development of STEM in the school. A PDST facilitator visited to evaluate progress on STEM and provide assistance (Figure 13).

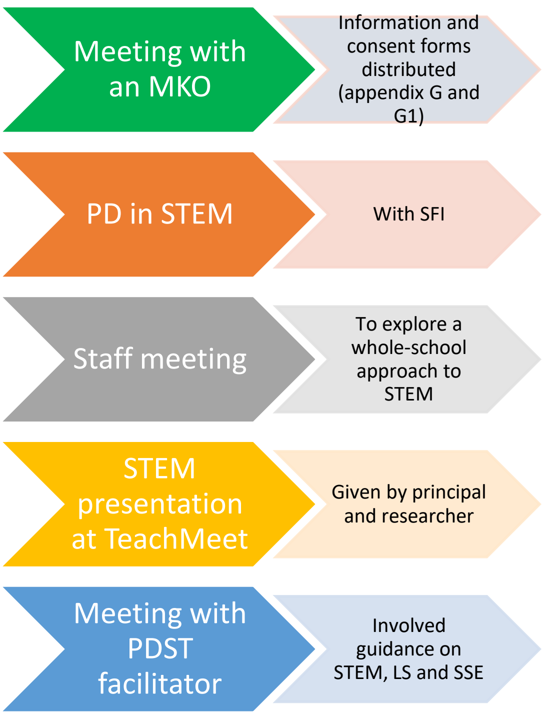

Figure 13: Activities during cycle 2

Because of the focus on the materials strand, the LS group focused on materials for the lessons in Cycle 2. Humpty Dumpty provided the stimulus, and children investigated which material would protect Humpty when he fell from the wall (Appendix M and M1).

4.6.3 Cycle 3

Cycle 3 consisted of two SFI sessions. Due to their focus on the strand of forces, it was decided that the whole school would conduct a STEM investigation in this area during January to February 2019 (Figure 14).

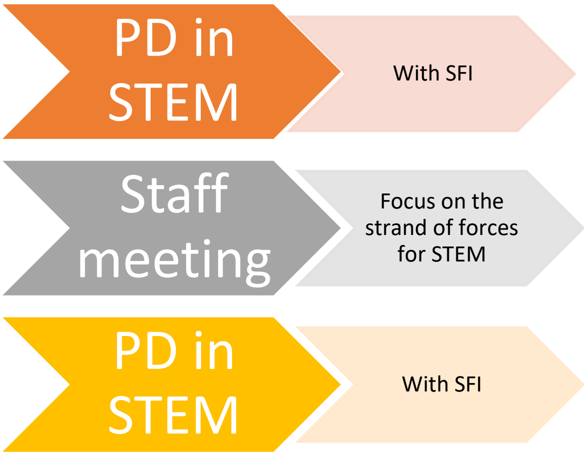

Figure 14: Activities during cycle 3

The LS group decided to create a lesson around forces and design and make; therefore, engineering had an increased role. The story of the Gingerbread Man provided the stimulus, and the children made boats to help him cross the river. Research lesson 1 was conducted in School 2, and the children made boats from tinfoil squares (Appendix N). For research lesson 2, it was decided that the children in School 1 could be challenged additionally by making boats from recycled materials (Appendix N1).

4.6.4 Cycle 4

In the final cycle of LS, the interview schedule was piloted with two critical friends. Gwen and Maria were interviewed on their experience of participating in the research (Appendix J), and the principal was interviewed to ascertain her perspective on the research (Appendix K). A staff meeting discussed teachers' experiences of the STEM lessons.

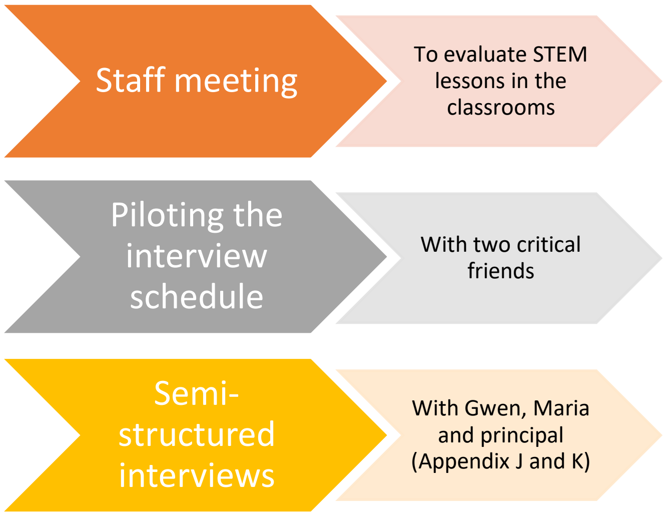

Figure 15: Activities during cycle 4

In the final cycle, the LS group again focused on an engineering task. The stimulus was the fairy tale Goldilocks and the Three Bears. The children had to design a chair for Goldilocks and make it from Lego, using Barbie as the prototype. Research lesson 1 was taught in School 1, and the MKO was present for a site visit (Appendix O). As the prototype of Barbie proved overly challenging for School 1, it was decided to use smaller models (Sylvanian families) for research lesson 2 (Appendix O1).

The research cycle encompassed the four cycles of LS that comprised this study. Details of the LS planning phase and the number of meetings per cycle were outlined. The contents of planning and reflection meetings were summarised. Each cycle was then discussed, with details of PD, meetings, and activities that were happening concurrently. As the timeline and overview of the LS cycles have been presented, the data collection methods are now discussed.

4.7 Data Collection Methods

Data Method	Activity	Participants	Pilot Cycle	Cycle 2	Cycle 3	Cycle 4
Interviews	Semi-structured Interviews	Gwen Maria Principal	/ /			/ / /
Document Review	Collaborative Lesson Plans	Gwen Maria Researcher	/ / /	/ / /	/ / /	/ / /
	Observation Sheets	Gwen Maria Researcher	/ / /	/ / /	/ / /	/ / /
	Reflective Journal	Researcher	/	/	/	/
	Field Notes	Researcher	/	/	/	/
Discussion Methods	Collaborative Meetings	Gwen Maria Researcher	/ / /	/ / /	/ / /	/ / /

Table 6: Overview of data collection methods

As discussed in section 4.1.3 and 4.1.4 the ontological and epistemological beliefs of this research are that humans are social creatures. People are active agents in the construction of their social world (Comstock 1982) and knowledge is co- constructed with others in social situations (Vygotsky 1978). This study selected the PAR approach as it enabled me to interact with my colleagues, elicit participant voice whilst being immersed in the lived experience of the research. The methods used attempted to highlight the social dimension of learning, emphasise the co-construction of knowledge and the importance of meaning-making. The methods chosen invited participants to partake in dialogue instead of the experimental manipulation of people (Comstock 1982). Lastly, it was important that the methods utilised treated the participants as agentic and active in their learning.

4.7.1 Semi-structured interviews

Interviews are one of the most popular and compelling ways to attempt to understand human beings and the human perspective (Fontana and Frey 1994). Qualitative interviews were selected for this research as they are much more focused on gaining the perspectives of participants and gaining rich answers (Bryman 2012). Qualitative interviews were used to capture teacher voice and to try and understand the meaning behind what the participants were saying. Interviews were also chosen as they encourage the researcher to reflect on how the interview 'will improve the human situation (as well as scientific knowledge)' (Creswell 2009, p. 90). However, it is important to be mindful that interviewers are usually in a position of power as regards creating questions and conducting the research in accordance with their research interests (Kvale 2006). Less-structured interviews therefore offered the participants the opportunity to have more control over the course of the interview as they chose how much they wanted to reveal. However, I was cognisant of the role of power dynamics and the construction of meaning when conducting the interviews with each participant.

Two semi-structured interviews were conducted with Gwen and Maria at the beginning and end of the research (Table 6; Appendix J). The initial interviews captured Gwen's and Maria's perspectives on PD and STEM education. The purpose of the final interviews was to explore their experiences after they had implemented four cycles of LS. One semi-structured interview was conducted with the principal at the end of the study (Table 6; Appendix K). Its purpose was to convey the principal's experience of LS as a vehicle for PD in a rural school.

The semi-structured interview methodology was favoured for this research, as it allows for increased depth by giving the interviewer the opportunity to probe and expand the responses (Hitchcock and Hughes 1995). Semi-structured interviewing allowed for increased autonomy to investigate issues that may crop up, and it provided the best of both worlds, merging the structure of a list of themes to be covered together with the freedom to follow up issues as necessary (Thomas 2009). The interview schedule provided a good structure for the interviews but also allowed the participants to lead the conversation and divert it to issues they felt were pertinent. Similarly, the semi-structured interview format enabled responses to be probed, but always neutrally (Babbie 2007). Probes 'are a device to get interviewees to expand on a response when you intuit that they have more to give' (Robson 2002, p. 276). Using this format, questions were flexible, and questions that had not been included could be asked, as certain issues may have been mentioned in the course of the interview, so there arose a chance to probe and ask follow-up questions (Bryman 2012). As I was collaborating with my colleagues, it was also hoped that matters which they regarded as relevant to the research question, but which I had not considered, would come to the fore using this technique.

Each semi-structured interview (Appendix J and K) consisted of a list of predetermined open-ended questions, with additional questions emerging through dialogue with the participant (Creswell 1998). For Gwen's and Maria's interviews, introductory questions included teachers' experiences and perspectives of PD (Appendix J). Questions were also based on some of the elements of PD and its effectiveness for subject knowledge or pedagogic knowledge. Questions also probed teachers' experience of science and their perspective on the relatively recent emphasis on STEM. All interviews took place on school premises, in the participant's classrooms. Interviews were audio-recorded so that I could concentrate fully on the interview content instead of being distracted and taking notes (Bryman 2012). This also allowed for detailed analysis and greater accuracy, as the responses are depicted in the interviewees' own language (Bryman 2012).

The interview schedule was piloted with two critical friends – two teachers in different schools – to help the official interviews run more smoothly (Creswell 2013). Piloting the questions also ensured better clarity and flow in the wording (Bryman 2012). The interview questions were then adjusted accordingly. To aid the interview process and to help the participants feel at ease as I transitioned from colleague to interviewer, I conducted research on successful interviews. Kvale (1996, p. 148) lists the ten criteria of a successful interviewer:

- Knowledge
- Structure of the interview
- Simple clear questions
- Gentle
- Sensitive, empathic listening
- Flexibility
- Steering
- Critical
- Remembering
- Interpreting

Bryman (2012) added two more: balance and being ethically sensitive. Menter et al. (2011) write that the volume and quality of the information gleaned through an interview increase when there is a rapport between interviewer and respondents. Every effort was made to ensure the participants felt comfortable and that the interview was interactive. Each interview lasted 20–40 minutes. Immediately after, I listened to the recording and made notes. Each interview was then transcribed.

4.7.2 Lesson observation

An intrinsic element of LS is lesson observation. Corcoran explains the importance of lesson observation as it 'helps build a more complex, possibly more challenging and certainly more useful picture of the learning ecosystem' (2009, p.39). Lesson observation guidelines are offered by Lewis and Hurd (2011), who explain that lessons should have opportunities for teachers to observe children's thinking. They advise against worksheets and instead recommend the inclusion of opportunities for children to discuss their thinking, reason with their peers and work on active tasks that reveal their thinking. The template was guided by observation schedules available in LS research (Lewis and Hurd 2011). The lesson observation criteria were discussed with Gwen and Maria during the pilot cycle. We decided to include checklist items that focused on children's 21^{st} century skills, collaboration, communication and critical thinking. We also included checklist items pertaining to children's engagement and assessment. With the criteria items finalised, I then compiled a template for observation (Appendix P).

The observing teachers were supplied with observation sheets during live lessons in Schools 1 and 2 during cycles two- four. The teachers observing the lessons recorded their observations and shared them in the reflection meetings; see Appendix Q for a sample of a completed observation sheet. In addition to lesson observation sheets, I also took pictures of the children during the STEM lessons which resulted in a comprehensive picture log. These methods were utilised to accurately capture the learning taking place in the classroom. Critics of participant observation as a data gathering technique stress the subjective and potentially unreliable nature of human perception. However, Lincoln and Guba (1985) believe that such research accounts are more credible if they result in repeated observations over an extended period of time, therefore this study took a longitudinal approach to data collection.

4.7.3 Reflective journal and field notes

Reflection was encouraged throughout the data collection stage. I consistently completed a reflective diary, which included reflections and field notes. My reflections were completed throughout the data collection, as it was imperative to aid a critical, analytical perspective. These notes were made within hours after meetings or after significant occurrences and included my thoughts, feelings, questions and concerns. The reflective diary entries captured the experiences, problems and perspectives throughout the research (Flick 2009). They also promoted reflexivity and helped me scrutinise personal beliefs and values (Ahern 1999). Gwen and Maria were also encouraged to keep a reflective diary. However, they tended to use these only when reminded and for minor observations during the planning of STEM lessons. The data gathered in these journals was therefore not as rich as the data gathered from the interviews and collaborative meetings.

I was mindful of how my years teaching in the school would affect my ability to reflect on my experiences. Coghlan and Brannick (2014) point out that an organisation has two lives: their formal life in their mission statement, goals and resources; and their private life, its cultures, traditions and power. They argue that while this knowledge is beneficial, it is also a disadvantage, because being part of a culture makes neutral evaluation and assessment challenging. They recommend a supervisor to aid this understanding, and also journaling, as this supports 'meta learning of content process and premise in the arena of preunderstanding as it can expose what you know and do not know due to your closeness to the issues and the organisation' (2014, p. 136).

4.7.4 Collaborative meetings

Collaborative meetings consisted of planning meetings and reflection meetings. Collaborative meetings occurred regularly during LS cycles (Figure 11) and were attended by the Gwen, Maria and me. As with the interviews the challenge of this method was minimising any power differentials between the participants and me. Furthermore, interviews and the collaborative meetings present the 'reactivity risk', a participant may give answers to please the researcher and in doing so this restricts the voice of the participant (Hitchcock and Hughes 1989). Therefore, through these meetings I aimed to empower the participants and elicit genuine teacher voice. Initially, I hoped our familiarity with each other as colleagues would allow different perspectives and thoughts on practice to be shared honestly and openly. Therefore, the meetings proceeded more like discussions with questions being asked and the teachers were free to respond as well as lead the discussion. These meetings were integral components of the LS process and they promoted dialogue and critical questioning in a relaxed setting.

Teachers met in the opening two weeks of each LS cycle to design the lesson plans. Planning meetings occurred after school hours. After negotiation with the principal from cycle two onwards, one planning meeting took place during Croke Park (section 2.3.5) hours, and the other meetings took place in the teachers' own time. The planning meetings occurred on the school premises in my classroom. During planning meetings, teachers collaborated to design the lesson plan while attempting to anticipate children's prior understanding. During the planning meetings the curriculum was consulted for maths and science objectives; online resources and textbooks were also examined. All participants contributed to the lesson design, and teachers regularly critiqued each other to ensure that the topics, language and activities were age appropriate. During planning, teachers built on one another's ideas, and this collective planning of lessons proved lengthy. During this time, teachers collaborated to complete the STEM task that was described in the lesson plan. This was an important task and helped teachers see the activity from the children's perspective; it also proved beneficial for troubleshooting any potential pitfalls in the live lessons. Additionally, it helped teachers predict any possible misconceptions that children may have or questions they may ask. For the pilot cycle, the MKO (section 2.4.5) was not involved and the lesson plan was devised simply through Microsoft Word. After PD with SFI, teachers were introduced to the DPSM/ESERO Framework for Inquiry Lesson Plan (Appendix M1). From cycle two to cycle four, the research lessons were created using this template. This template provided a useful design for the STEM lessons while also encouraging inquiry-based learning. Once the lesson was designed, it was emailed to the MKO for input. Upon its return, the teachers discussed the changes and amended the lesson. During the live lessons, some teachers observing made notes on the lesson plans and observation sheets to share afterwards in the reflection meetings.

Lewis and Hurd (2011) recommend that reflection meetings take place as close as possible after live lessons. This was attempted insofar as possible. If it was not possible to hold the reflection meeting directly after the live lesson, it was conducted after school hours. All teachers collaborated in the reflection meetings, and discussion centred on Lewis and Hurd's (2011) questions on reflection. Meetings began with input from the teacher teaching the lesson. The observing teachers then shared their insights and reflections. During the reflection meetings, the lesson plans were also used as a focus for reflection and teachers often referred to notes taken on their observation sheets. Discussion also centred on the pitching of the lesson, children's engagement, questions that children asked, their ability to communicate their understanding, the pitching of the STEM activity, 21st century skill development and how the children collaborated. Through this discussion it was decided whether to make changes to the lesson plan for the subsequent lesson. Generally, planning and reflection meetings had the same parts (Figure 16).

Planning Meetings

- Introduction: the learning intentions for the meeting ahead
- Decide on the curriculum area of focus
- Discuss children's prior understanding/ possible misconceptions/ questions they may have
- Opportunities for children's skill and thinking development
- Research the topic and the conjecture of the lesson
- Discuss the questions teachers will ask
- Discuss materials to be used/ ICT/ videos/ the sourcing of the fairy tale/ assessment for learning
- Design lesson
- Complete the STEM activity outlined in lesson
- Discuss feedback from the MKO
- Interrogate final draft of lesson plan
- Review key decisions made

Reflection Meetings

- Introduction: initial reactions to the lesson
- Input from all teachers (teacher teaching the lesson first)
- Consult observation sheets
- Discuss questions the children asked
- Discuss children's skills and thought processes observed
- Discuss new learning and how this will contribute to the revised lesson plan
- Discuss new learning in STEM education
- Discuss new insights into children's learning
- Review key decisions made
- (Reflection meetings guided by questions from Lewis and Hurd 2011)

Figure 16: Planning and reflection meeting elements

During all collaborative meetings, I assumed the role of planner, note taker and facilitator. All collaborative meetings were site-based (School 1) and audio-recorded. Transcripts from these meetings encompassed part of the data set. The live lessons were not audio-recorded, but observations were recorded through the observation sheets and notes written on the lesson plans. Coupled with collaborative meetings, many informal chats occurred throughout the process based on a forthcoming lesson and insights that occurred after a meeting.

The methods employed by this study ensured that social interaction was central and that eliciting the voice of the participants was emphasised. Prolonged engagement in the field also allowed for repeated cycles of data to be collected.

4.8 Triangulation

Power issues may exist between the researcher and the participants and I identified the potential risk of jeopardising the authenticity of the data through the 'Hawthorn effect' (Robson 2002). Therefore, it was hoped that by using methodological triangulation that my bias and the participant's bias would be reduced (Cohen et al. 2013). Multiple methods were chosen to increase reliability and validity as 'exclusive reliance on one method may bias or distort the researcher's picture of the particular slice of reality she is investigating' (Cohen and Manion 1994, p. 233). Denzin (1970) identifies 'between methods' triangulation as being an effective way of checking on validity. Therefore, this research involved using a number of methods to examine the same dimension of the research problem. The focus remained on LS and STEM education while the data collection methods varied between interviews with teachers and the principal, lesson observation, reflective journal, field notes and collaborative meetings. By merging a number of methods over four cycles this enabled me to gain a greater understanding of experiences of the participants as they engaged with LS and STEM education. Additionally, it was envisioned that the limitations of one method should average out across methods leaving a true estimate of a single result (Brinberg and Kidder 1982). While every opportunity was made to ensure the soundness of this research, there were also potential limitations.

4.9 Potential Limitations of this Research

A number of limitations were identified in this research design. These include children's voice, generalisation, my diverse roles within the research and researcher bias. How these were addressed will be outlined below.

4.9.1 Children's voice

Possibly the most striking limitation is that the children's voice, perspectives or attitudes were not captured adequately in this research. Considering the shifts in teacher practice, the capturing of children's voice would have enhanced the findings.

Children’s voice aids dialogue and reflection and is a valuable tool for evaluating the efficacy of teaching practices (Timperely et al. 2008). This data would have allowed insights to be provided between STEM practice and children’s perspectives. The research acknowledges that while it was investigating PD, some aspects were outside the remit of the study, because of the timeline.

4.9.2 Generalisation

Firstly, generalisability was not intended, as this was a small research sample. The results and discussions therefore represent a snapshot of the phenomenon. As to size and duration, the study lasted eight months in the infant classroom. This is a relatively short timeframe in the life of the school. A more sustained study over a number of years would yield interesting findings. Similarly, the study was limited to two infant classrooms and three teacher participants. Ideally, it could have expanded to include the whole school and encompassed all teachers. This research may not represent the larger population of Irish PD or primary teachers teaching STEM, and it does not help us to understand all the ways that all teachers may participate in LS for STEM. However, the knowledge generated from participants is a local knowledge of practice; it is knowledge that can be ‘borrowed, interpreted, and reinvented in other local contexts’, as Cochran-Smith and Lytle write (2009, p. 132), and it can be publicly shared with others such as university-based educators, researchers, primary teachers and principals.

4.9.3 Diverse roles of the researcher

As the research occurred in my school, my role was multifaceted. Figure 17 shows a simplified outline of the roles I occupied throughout the research project. I was the class teacher, deputy principal, colleague, researcher and participant.

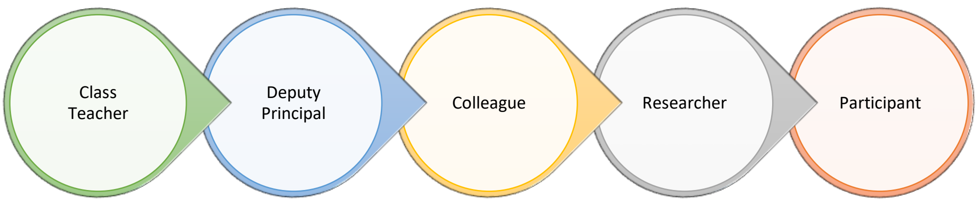

Figure 17: Researcher positioning

As a deputy principal I had a responsibility towards the children, my colleagues and the principal. As a researcher I had to recognise my dominant position and the possibility of power differentials between the participants and I. As a colleague I had a special obligation towards the participating teachers and as a class teacher I had to ensure I delivered the curriculum to a high standard. My various roles throughout the research meant that a reflexive focus and an awareness of my position at any given time were required throughout the research period. However, my multifaceted role also helped establish empathy with the participants as they felt I might have a greater understanding of their challenges

> *Well you're a teacher and a researcher, you know what it's like. You're at the coalface so you're not going to say 'it's the teachers fault they're not doing x'. You can see it from both angles*
>
> (Gwen, Pilot Cycle, Research Lesson 2, Reflection Meeting)

Inevitably there were times when my roles as researcher, colleague, LS observer and class teacher clashed

> *I am anxious about tomorrow, the MKO is coming to the school to observe the lesson. Maria is after contacting me to say she won't make it in to observe due to illness. I have to contact the principal with a gentle reminder to see if my class can have cover while I attend the reflection meeting. I also contacted Gwen with a reminder to bring in the extra Lego. And I also have a meeting with a parent after school.*
>
> (Researcher, Cycle 4, Reflective Diary, 19 Mar. 2019)

Malone (2003) highlights the ethical and institutional power issues of researching in your own 'backyard'. This was pertinent for me as I was researching in my work setting. Through continuous reflection I identified issues that could arise in terms of power relations and the representation of participant voice. It was aimed that through the combination of the data collection methods employed, active listening, member checking, verbatim transcribing and continuous reflection (section 4.10) that power differentials would be minimised and participant voice would be elicited truthfully and accurately.

4.9.4 Researcher bias

Given my role as the researcher in LS and PAR, researcher bias was also established in the context of the study. Due to the collaborative nature of both approaches, I initially assumed a more interactive role. During collaborative meetings, I hoped that all teachers saw it as part of my research and were comfortable contributing to it. While I guided the LS process, I did not adopt the position of an expert. However, I did organise meetings and gather all data. I also posed questions to the group to stimulate discussion about STEM topics, the development of the lesson, designing the lesson and reflecting on the learning. I strove to keep bias out of the study insofar as possible; therefore, I was not personally involved in LS prior to the start of the research. I felt that having no previous involvement would add to the rigour of the research, as I would have no preconceived bias. Also, I would not be perceived as an 'expert' by my colleagues at school, thereby achieving a more democratic process. I also hoped to limit bias by working with a group of teachers who had no previous experience of LS either.

Role duality between my identity as teacher and researcher was a pertinent issue. I am a teacher and I was working with a group of teachers: this required reflection on the perceptions of and biases towards teachers. My vision for this process was to bring practical improvements to the way that I and others teach. Schoenfeld (2014) believes that research and practice can work in harmony:

> Two themes that have been central to my work. … 1. Research and practice can and should live in productive synergy, with each enhancing the other. 2. Research focused on teaching and learning in one particular discipline can, if carefully framed, yield insights that have implications across a broad spectrum of disciplines.
> (Schoenfeld 2014, p. 404)

However, Labaree's (2010) advice is to relinquish the practitioner perspective. He believes that professional priorities must change when moving from a teacher to a researcher, as there is a shift from a normative to an analytical perspective. Cochran-Smith and Donnell (2006) do not share this belief as they highlight the benefits of the practitioner in research:

> Boundaries between teaching and inquiry must blur so that practitioners have opportunities to instruct their own questions, interrogate their own assumptions and biographies, gather data of many sorts, develop courses of action that are valid in local contents and communities and continuously revaluate whether a particular solution or interpretation is working and find another if it is not.
> (Cochran-Smith and Donnell 2006, p. 510)

However, the position of an entirely objective observer cannot be claimed in this study. Biases may unwittingly creep into any research project. My values, experiences and perspectives cannot be overlooked in the belief that they will not affect the research, so they must be explicitly noted (Manning 1997). Special attention was paid to the analysis of data at the interview and collaborative meetings because, as Bell warns, ‘there may be dangers in placing too much reliance on preconceived ideas’ (Bell 1999, p. 173). Tracking bias in this study was achieved by employing reflexive bracketing. Ahern’s ten tips for reflexive bracketing were used; these include writing down my personal issues, describing potential areas of role conflict, identifying feelings that indicate a lack of neutrality and reflecting on my analysis (Ahern 1999). I used a reflective diary throughout the study to track bias (Creswell 2009).

Reflexivity is ‘a conscious experiencing of the self as both inquirer and respondent, as teacher and learner’ (Lincoln and Guba 2000, p. 183). As I was researching my own school setting and I was also the primary instrument of data collection a commitment to reflexivity was integral to validating my immersed role. Throughout the research process, time was spent in regarding assumptions, worldview biases and theoretical orientation. To ensure reflexivity as a researcher, I had to negotiate the ‘swamp’ of endless self-disclosure and self-analysis (Finlay 2002, p. 212). Time devoted to reflexivity allowed my subjectivity to be ‘re-viewed as a resource that can be tapped in order to contextualize and enrich… research process and its products’ (Gough and Madill, 2012, p. 374). Detailed field notes together with constant reflection at each part of the LS process allowed me to reveal and interrogate personal biases. Acknowledging these subjective views allowed me to face each stage with a renewed freshness and willingness to gather the data. With this in mind, it was hoped that the study was strengthened and not limited by my in-depth understanding of the Irish primary school system.

4.10 Provisions for Trustworthiness

The term ‘validity’ in action research is quite contentious and complex (Burns 2015). Reason (2006) prefers to avoid the term, as he maintains that it has strong links to positivist research and that there is only one validity. He prefers to use the term ‘quality’. Zeichner and Noffke (2001) use the term ‘trustworthiness’ instead of ‘validity’. Therefore, because of the qualitative nature of this study, various protocols were followed to ensure trustworthiness. These included reliability and validity procedures, incorporating a pilot study, member checking, authenticity, and quality.

4.10.1 Reliability and Validity

Gibb’s (2007, cited in Flick 2009) reliability procedures to ensure that data was consistent and reliable were followed. These included checking transcripts for mistakes, and, in the process of coding, checking that the definition of codes did not shift. As stated, audio recordings were made during collaborative LS meetings and at the semi-structured interviews. These were transcribed to aid analysis and to enhance reliability. Flick (2009) states that the quality of recording and documenting the data collected becomes a fundamental foundation for assessing their reliability and that of subsequent interpretations. Furthermore, Anderson and Herr (1999) five validity criteria for action research projects were also adhered to. Outcome validity included the creation of the LS group and improving children’s learning in STEM education. Process validity was achieved by selecting appropriate methods and the use of triangulation. Democratic validity was reached by working collaboratively with participants and children and the inclusion of multiple voices. Catalytic validity was the ability of the participants to deepen their understanding and transform reality. Lastly, dialogic validity was obtained by disseminating the research and seeking the feedback of peers.

4.10.2 Pilot study

Robson (2002) advises that the first round of data collection should be a pilot. The pilot study was conducted in September and October 2018. It was envisaged that this would identify practical problems, solve technical matters and translate the plan into a reality (Robson 2002). The pilot study also provided an opportunity to revisit the design if required (Robson 2002). The aim was not to guarantee success in the main study, but to increase its likelihood and to reveal problems to be solved before the initial cycles. The pilot study was intended to test the feasibility of the study, by assessing the data collection methods, the PD sessions for the staff, the weekly collaborative meetings and the viability of implementing a full LS cycle in six–eight weeks. In the words of De Vaus, ‘do not take the risk. Pilot test first’ (1993, p. 54).

Regarding the methodology, Creswell writes that 'a core idea of action/participatory research is that the inquirer will not further marginalise or disempower the study participants' (2009, p. 88). LS required teachers to collaborate in greater depth and frequency. Thus, the pilot study also served to establish trust and respect amongst the participants as they became familiar with this new way of working (Robson 2002; Creswell 2009). It also increased the reliability of the research (Cohen et al. 2000). Findings from my pilot study were presented at the World Association of Lesson Study (WALS) Conference 2018 in Beijing. The subsequent cycle was then adapted with input from participating teachers and the MKO (section 2.4.5).

4.10.3 Member checking

In qualitative research, Lincoln and Guba (1985) refer to member checking as an important technique for ensuring the research has credibility. Once data analysis was completed, the data was shown to the participants to ensure the meaning was represented accurately. Merriam describes member checking as 'taking data and tentative interpretations back to the people from whom they were derived and asking them if the results are plausible' (1998, p. 204). Member checking ensured that the outcomes and results of the research arose from the collaborative process and the participants (Manning 1997). At the end of the study a presentation of the main findings was made to the school staff. Furthermore, on three occasions the principal and I presented this research to other cohorts of teachers at a local education centre.

4.10.4 Authenticity

Guba and Lincoln (1985) describe five dimensions for strengthening authenticity: fairness, ontological authenticity, educative authenticity, catalytic authenticity and tactical authenticity. Bryman (2012) believes these criteria merge very fittingly with action research. I will outline how this research met the authenticity measures.

'Fairness may be defined as a balanced view that presents all constructions and the values that undergird them,' write Lincoln and Guba (1986, p. 79). Fairness is ensured when all participants are empowered to use their voice and participate fully in the research. Shannon and Hambacher (2014) believe that authenticity is achieved when the researcher can demonstrate numerous perspectives and an understanding that fairly epitomises these perspectives. As advocated by Manning (1997), some of the ways that fairness was enhanced in this study include informed consent, member checking, reflexivity and prolonged engagement in the research.

Ontological authenticity assesses whether participants' awareness increased as a result of taking part in the study. Manning (1997) writes that dialogical conversations, openness of purpose and establishing a relationship with the participants based on care and trust are methods to boost ontological authenticity. Because reflection was built into each cycle of LS and PAR, this gave participants an opportunity to reflect on their practice and learning, thereby increasing their awareness.

Educative authenticity refers to how much the participants learned as a result of taking part in the study: 'this suggests that a study is not merely a study of convenience but one with significance and intentionality' (Shannon and Hambacher 2014, p. 2). Through the iterative cycles of LS, teachers learned about STEM education and children's learning and achieved deeper insights into their practice.

Catalytic authenticity can be assessed by how participants in the research acted based on new understandings (Guba and Lincoln 1989). It can also be assessed based on whether inquiry provoked the participants to act (Shannon and Hambacher 2014). The research aimed to capture this through regular collaborative meetings, as participants stated what they would change about their practice and how they would change as a result of taking part in this research. Therefore, each cycle of LS and PAR contributed to insights and action, which affected the subsequent cycle.

Finally, tactical authenticity refers to whether there was redistribution of power among stakeholders. In this research, the construction of knowledge through social interaction between the participants, and by empowering the participants to make changes and reflect on their practice, was the underlying assumption of LS and PAR.

4.10.5 Quality

Reason and Bradbury stress that action research must strive towards feasible outcomes and build new ways of understanding, 'since action research without understanding is blind, just as theory without action is meaningless' (2001, p. 2). Reason (2006) lists five choice points on which the quality of action research may be judged: being explicitly aimed at and grounded in the world of practice, being explicitly and actively participative, drawing on a wide range of knowing and linking appropriately to form theory, being worthy of the term 'significant', and emerging towards a new and enduring infrastructure.

The research cannot rate all of the quality points equally highly, so an action researcher needs to be aware of the choice points (Coghlan and Brannick 2014). Reason (2006) writes that sometimes an immediate practical outcome is most important; or perhaps exploring values is rated higher; or ensuring all voices are heard. In this research, the points that were significant were that the research was grounded in the world of practice and that improvement to teachers' practice was a central focus. Similarly, as the study adopted a PAR approach, this was research by people and with people; the participants were encouraged to be co-investigators and co-researchers in the study. However, Reason (2006) writes that the quality of action research must be based on explaining the choices made during the research and must offer them to the scrutiny of others:

> Quality rests not so much on getting it right but on stimulating open discussion. I think it is a question of seeing these choices, seeing through the choices, and being clear in a first-person sense, being collaborative in a second-person sense, and raising the wider debate in a third-person sense.
>
> (Reason 2006, p. 199)

To outline how this research met the 'quality' measure, I, as researcher, made choices in the first-person sense; I then made choices with the participants in the research, also consulting with school colleagues at staff meetings and discussing choices with the MKO (section 2.4.5). In a wider debate, I have presented my work-in-progress to colleagues at a local education centre, to fellow practitioners (Flanagan 2019c; 2020) and to others involved in academic work at various educational conferences (Flanagan 2018a; 2018b; 2019a; 2019b) as I invited them to engage critically with the descriptions and explanations I was offering for my practice.

4.11 Data Analysis

Data analysis occurred throughout the data collection process (Miles and Huberman 1994) and involved multiple stages of analysis. The initial stages took place continuously during data collection by transcribing meetings and interviews, and writing reflective diary entries and field notes. For this study, inductive thematic analysis (Braun and Clarke 2006) was deemed most appropriate for a number of reasons. Firstly, it is considered a method rather than a methodology (King 2004; Braun and Clarke 2006). This makes it very flexible (King 2004; Braun and Clarke 2006), as it is not tied to a particular epistemological or theoretical perspective. Thematic analysis also complements many types of research questions, including exploring people's experiences and understandings (Clarke and Braun 2013). The inductive element of thematic analysis allows the theory to emerge from the data, and themes are realised from the researcher's interaction with the participants. Since the aim of this research was to capture teacher voice and experiences, inductive thematic analyses enabled teachers' voices to emerge from the data, rather than pre-determined ideas or themes being forced. While Braun and Clarke's six phases of thematic analysis appear in chronological order, it is a recursive and reflective process that develops over time and involves a constant shifting back and forward between the steps (Nowell et al. 2017).

Phase	Description of the Process
1. Familiarising yourself with the data	I collected, transcribed and immersed myself in all of the data.
2. Generating initial codes	I used Microsoft Word to identify codes and themes.
3. Searching for themes	I organised the codes into potential themes.
4. Reviewing themes	This involved two levels of reviewing and refining the themes. Level one involved reviewing at the level of the coded data extracts. Level two involved this, but in relation to the entire data set.
5. Defining and naming themes	I defined and further refined the themes and analysed the data within them.
6. Producing the report	The aim of the thematic analysis report was to tell the story of the data in a way which convinced the reader of the merit and validity of the analysis.

Table 7: Thematic analysis (Braun and Clarke 2006)

4.11.1 Data analysis process

To help explain the data analysis process, a number of appendices are referenced throughout this section. Appendix R gives a sample of the raw codes compiled at the beginning of data analysis. This is followed by Appendix S, which illustrates a worked example of thematic analysis from an initial interview with Maria. Appendix T outlines the grouping of initial codes and quotes under candidate themes, and Appendix U reveals a mind-map linking initial codes to a candidate theme. Lastly, Appendix V shows the development of a sample of codes and subthemes for the five main themes.

The general steps of data analysis in this research included the following:

Stage 1: Familiarisation with the data

Lincoln and Guba (1985) advise that researchers at this stage document their theoretical and reflective thoughts through immersion in the data. Interview and collaborative meeting data was transcribed from audio recordings, whilst reflective notes, lesson observation notes and field notes were expanded and typed. The entire data set was read through once without coding, to become familiar with the ideas (Braun and Clarke 2006). On the second read through, some ideas for codes, notes and early impressions were jotted down, to be returned to in the next stage of analysis (Lincoln and Guba 1985).

Stage 2: Generating initial codes

I began by identifying interesting elements and patterns and then coded each segment of data. Open coding was used although I had already developed initial ideas about codes from the 'familiarisation with the data' stage. Coding was completed in Microsoft Word. Codes were made using coloured font; a sample list of initial codes is available in Appendix R. Additionally, a worked example of coding an extract from an initial interview is provided in Appendix S. The codes continued to be developed and defined throughout the entire analysis process (Braun and Clarke 2006).

Stage 3: Searching for themes

Once the initial coding stage was concluded I began to look for patterns in the data and potential themes that represented something significant in relation to the research questions (Braun and Clarke 2006). I tried to figure out how to group the codes under candidate themes. I gathered all of the codes and data extracts relevant to each candidate theme using the cut and paste function on Microsoft Word. A sample of this is provided in Appendix T. Mind-maps were also made to make links between potential codes and themes, this is available in Appendix U. Some codes fitted neatly together into candidate themes. For example, there were several codes that related to perceptions of collaboration, reflection and opportunities for learning. These were collated into an initial theme of the ‘benefits of LS’. While most codes were associated with one theme some codes were associated with more than one theme, for example ‘children’s 21st century skills’ seemed to be pertinent to three themes; ‘teacher knowledge’, ‘teacher practice’ and the ‘focus on children’s learning’. This would be reviewed in the stage 4 of the analysis.

Stage 4: Reviewing themes

During this step the candidate themes were reviewed to ensure they accurately reflected the meanings represented in the data set as a whole (Braun and Clarke 2006). Braun and Clarke (2006) advise a second comprehensive reading of the data set, to revise the codes and the candidate themes with the research question in mind. Therefore, I read through all the data and questioned whether it was relevant to the theme and whether the data really did support it. I then reflected on how the themes worked in the context of the entire data set. For example, in some cases themes did not work and it was required to collapse them together (the theme of ‘resistance to LS’ and the theme of ‘cultural context’ were collapsed into the theme of ‘factors that affected teacher engagement in LS’). In other cases it was necessary to divide a theme into two or more themes (the theme of ‘benefits of LS’ divided into the themes of ‘LS and the development of teacher learning’, ‘LS and the impact on classroom practice’, and ‘LS and a greater focus on children’s learning’). Subsequently, there were too many themes identified in stage 3 and themes were merged to form the following five main themes:

1. LS enabled greater collaboration amongst participating teachers
2. LS and the impact on teacher practice
3. LS and the development of teacher learning
4. LS and the increased focus on children’s learning
5. Factors that affected teachers’ engagement in LS

Appendix V includes diagrams showing the relationship between the themes, subthemes and a sample of the codes.

Stage 5: Defining and naming themes

I analysed the five main themes to define the specifics of each one. Each theme identified a story which had to fit into the overall story of analysis. This aided clarity for analysis and producing the report (Braun et al. 2014). As King (2004) notes, one of the hardest decisions may be to know when to stop defining and redefining themes. By devoting time to the progression, it was hoped to increase the findings' trustworthiness and reliability (Lincoln and Guba 1985; Nowell et al. 2017).

LS enabled greater collaboration amongst participating teachers

This theme was the largest. It reflected references made to teachers enjoying the increased opportunities for collaboration, feelings of teacher isolation, the united vision of the staff, relationships of trust and belonging, and the opportunities that collaboration held for learning.

LS and the impact on teacher practice

This theme captured statements about teachers changing their practice to a more inquiry-based approach and the challenges and merits involved. It also included statements about teachers having increased confidence to take risks in their teaching.

LS and the development of teacher learning

This theme reflected the area of teacher learning in this research, how teachers learned subject matter knowledge in STEM, and the vast area of PCK.

LS and the increased focus on children's learning

This theme includes teachers' changing expectations as they observed children during LS, and teachers' observations of children's positive experiences of STEM education.

Factors that affected teachers' engagement in LS

This theme reflects the challenges of LS, including teacher buy-in, STEM as a new subject area, teacher reluctance to being observed, time management, and sustaining LS.

4.12 Conclusion

This chapter highlighted significant parallels between LS and action research. It discussed the seven characteristics of PAR with regard to the current research. Both PAR and LS break away from traditional forms of PD, seeing teachers instead as change agents. Both PAR and LS mean that teachers ask questions about their practice and seek to improve it. Both approaches exemplify the teacher as a collaborator and researcher, critically reflecting on and improving their practice. LS and PAR seek to empower teachers in their practice, and both approaches also remind teachers that teaching need not be individualistic (Elliott and Tsai 2008).

A fully qualitative approach to this study was deemed the most appropriate because of its ability to capture the perspectives and experiences of the participants. Every attempt was made to employ ethical measures that protected the participants. The study comprised of a pilot cycle and a further three cycles; details of each cycle have been outlined. The use of qualitative data was examined, including teacher interviews, observation sheets, reflective journal, field notes and collaborative meetings. To boost the rigour and trustworthiness of this research, numerous measures were put in place. The data collected was analysed through inductive thematic analysis, consisting of reviewing, refining, defining and re-defining codes and themes. The following chapter will discuss the findings of the study.

Chapter 5: Findings

5.1 Introduction

This chapter outlines the dominant findings in this study that emerged following analysis of the data. It provides a comprehensive account of teachers' perspectives and experiences as they participated in four cycles of LS. Five key findings are discussed. First, the chapter explores the social processes enabled and necessitated by LS. Second, it looks at how shared experiences through collective planning and reflection helped teachers develop insights into their practice and subsequently change their practice. Third, it discusses the meaningful learning associated with collaboration and teaching a new subject. Fourth, it details the effects of a stronger focus on children's learning experience. Lastly, it explores the factors that hindered teachers' engagement with LS.

5.2 LS enabled greater collaboration amongst participating teachers

This section details how the increased opportunities for collaboration during LS helped create a stronger community of teachers, reduced feelings of isolation, and increased opportunities for learning. Prior to this, the teachers had never engaged in collaborative planning, teaching or reflection, and all teachers noted overwhelmingly that the main benefit from their participation in LS was professional collaboration. LS built a collaborative group of teachers united in their goal to improve children's learning in STEM. The teachers regarded the peer support and collaboration that are integral to LS as fundamental to their learning.

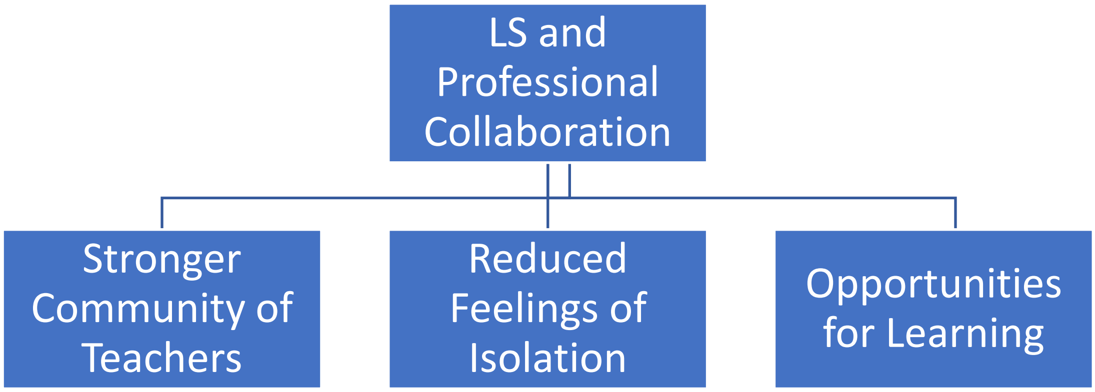

Figure 18: LS and professional collaboration theme and subtheme

5.2.1 Stronger community of teachers

Prior to the research, a personal and professional relationship existed between the participants, as we had worked together for three years. However, the extent of collaboration between the teachers was exchanging resources or teaching tips. We had no prior experience of collaborative planning or team teaching. As we were initially getting accustomed to the LS process, I became aware of the importance of bolstering the trusting, collegial relationship if the teachers were to share their successes and difficulties experienced during LS:

> *It's really about building that safe, open relationship that we could contribute our ideas in meetings to teach in front of each other without fear of criticism.*
>
> (Researcher, Cycle 2, Reflective Diary, 27 Oct. 2018)

Through the cycles of LS the nature of collaboration evolved with the teachers. Using O'Sullivan's (2010) continuum of collaboration (Figure 4) the evolving nature of collaboration is evident over the LS cycles. Initially, teachers began the process by planning lessons together

> *The first planning meeting was a little stilted. We were unsure of ourselves as we had never planned a lesson collaboratively before… Planning a STEM lesson is new to all of us and raises more questions than answers.*
>
> (Researcher, Cycle 1, Reflective Diary, 9 Sept. 2018)

During the planning meetings teachers shared resources they had found which were helpful towards the designing of the lessons. These resources were usually science books or STEM activities found on the internet. Teachers also shared teaching across the cycles of LS (Table 5). Teachers were initially reluctant at the prospect of shared observations. They moved from a position of being reluctant to being observed to seeing it as an opportunity to learn from their colleagues about teaching and learning (section 5.10.3). Teachers also shared feedback on the research lessons during the reflection meetings.

Researcher:	I don't know, what did you think about them [the children] using the cubes as passengers on the boat? A lot of them [the children] weren't counting they were just loading cubes on to see how many they could get on
Gwen:	I saw that too and [teacher name] did remind them to count, they did for a little while but they forgot again because they were getting so excited over their tinfoil boat

Maria:	Yes the accuracy in counting wasn't there. We will have to think of a different way to keep a record of the counting for the next lesson

(Cycle 3, Research Lesson 1, Reflection Meeting)

Lastly, teachers shared improvement together as they extended their knowledge and refined their practice. They began to support each other in discussing problems of practice in relation to SMK (section 5.6.1) and challenges in adopting the inquiry–based approach (section 5.4.1).

As collaboration evolved relationships between the teachers strengthened as a result of their involvement in LS. One of the participating SETs, Gwen, mentioned the existing relationships of trust between the participants, and linked collaboration with her peers to improving her teaching:

> *I loved the collaborative planning; the collaborative teamwork is brilliant with another teacher to sit down with and be comfortable enough that you're to teach with and accept critique, but you're doing it for them as well – it's for the purposes of learning and bettering your own teaching. The better you are in front of the class, the more rewarding it is, the more you learn they are learning, and that's what you want.*
>
> (Gwen, Final Interview)

There were indications of growth in individual capacity and collective capacity: teachers were more enthusiastic to collaborate with other colleagues and showed greater confidence in their own capacity as a staff. Maria, the other participating SET, reported that collaboration with colleagues aided her understanding and trialling of STEM education. It also seems that the 'safety' she experienced through her involvement in the LS group enhanced her enjoyment of the process:

> *There's that safety when you're with people, you're kind of scaffolded and guided along, so it was fun, fantastic from that point of view.*
>
> (Maria, Final Interview)

The principal felt that the collaboration between the teachers during LS would have a sustained effect on staff relations. LS introduced a new way of working and created a better rapport and trust amongst the staff. She believed this new mode of professional collaboration would benefit the development of team teaching in the future. The principal noted the positive effects of planning and teaching collaboratively on teacher relationships, as it became common for teachers to participate in other teachers' classes:

> *I think it [lesson study] benefits in-class support. It's definitely a benefit in terms of we've gone from total withdrawal [of the children from the classroom], whereas now we're an awful lot more comfortable with people coming into our rooms. So that's a huge benefit that has gone hand in hand, and it seems to be naturally going on. So, I mean, in the morning if you said, 'Look, you teach that and I'll do that', that would happen an awful lot easier.*
>
> (Principal, Final Interview)

Gwen reflected on the benefits of LS as a form of PD over other forms she had experienced. While none of the participants had experienced collaborative PD, their involvement in LS introduced them to the potential of other forms of PD. Gwen recognised the positive effects of greater collaboration with her peers:

> *I think it's a hands-on, face-to-face interaction … getting the ideas from people. I think the teaching community needs to come together for professional development. Otherwise, I don't know, it's not as effective.*
>
> (Gwen, Final Interview)

While the LS group consisted of three teachers, the effects of collaboration permeated the whole school. As a result of LS and the focus on STEM, the staff decided that School Self- Evaluation would also target the area of STEM (section 4.5). This ensured that all teachers would prioritise STEM education as an area of improvement for child and teacher learning. Usually, the principal set the vision for School Self- Evaluation and shaped the direction in the school. But through LS, teachers had already formulated their long-term aims for STEM education. Drawing up the long-term goals for School Self- Evaluation ensured there was a calibration of individual, team and school goals. It also enabled teachers to reflect on long-term goals for children's learning rather than on the immediate future. Teachers contributed to the creation of the bottom-up, united vision of STEM education, and this created a sense of membership. Therefore, LS participants experienced increased commitment to STEM teaching and learning throughout the school. Maria noted the positive effect of a united vision on her ownership of the project and the shared sense of responsibility of delivering STEM in the school:

> *It was a whole-school approach, so that meant everybody was on board and everybody was trying to set up targets and achieve them. So it was kind of a whole-school effort. ... So that was good from that point of view, and it was a positive thing working together.*
>
> (Maria, Final Interview)

From a leadership perspective, the principal recognised LS's potential to contribute to the collective vision of the staff:

> *LS certainly drove it [school vision of STEM] on for us here at school.*
>
> (Principal, Final Interview)

Relationships developed during LS, resulting in a stronger community of teachers. LS aided teachers to engage in dialogue on the aims of STEM learning, and this enabled shared ownership of the school vision. This was the first time that all staff had been involved in the creation of learning aims. This vision was inclusive of all teachers' views, which ensured that all teachers had shared responsibility and clarity of purpose. The merging of LS and School Self- Evaluation made School Self-Evaluation much more inclusive.

5.2.2 Reduced feelings of isolation

The predominant culture in the school prior to this research was an isolationist style of teaching. While teachers did not seem to be aware of this prior to the study, the collaboration inherent in LS highlighted the individual ways we had grown accustomed to working. The introduction of LS helped teachers see the potential of a more collaborative culture, and participants found that LS led to reduced feelings of isolation. Gwen, who had previously taught in an urban school with a larger number of staff, felt that time for collaboration should be timetabled in small schools:

> *I think it's [lesson study is] hugely beneficial, and I think one of the huge things in it is the collaboration between teachers ... we tend to plan in isolation ... So I think the collaborative planning was absolutely brilliant … because the teaching community, especially in a small school, we don't see each other very often when we are in our own classrooms, and that makes it isolated. It's very hard to build that time for collaboration … you need that time, and that time should be timetabled for discussion and reflection with your colleagues.*
>
> (Gwen, Final Interview)

Similarly, Maria mentioned that her participation in LS led to reduced feelings of isolation. She appreciated the opportunity that LS presented to teachers to enhance their own teaching methods:

> *I think … how isolated teaching can be, we just go with what we think is the best lesson, and very often another teacher will give you valuable ideas that can enrich the lesson. It's been a very enjoyable experience from the point of*

view that there are three of us planning … working together, because it's shared responsibility. ... It was great working as a team ... because of the isolation.

(Maria, Final Interview)

Evidently, feelings of isolation were palpable amongst the teachers, but as the research progressed, LS contributed to the teachers identifying themselves as part of a team. On a personal level, I noted:

It really reduces the feeling of isolation to be able to collaborate with another teacher about the experiment, or even outside of the research to share observations with them on the child that you are struggling with and get their perspective in how to approach this. Instead of trying to solve things on your own, you feel like it's a team effort.

(Researcher, Cycle 2, Reflective Diary, 12 Nov. 2018)

LS also introduced the teachers to talking about their practice with their colleagues. What began as reflection meetings with the LS participants led to practice being discussed at staff meetings with a wider audience. The principal noted that LS began to break down teachers' individual style of teaching:

That type of collaborative planning has come out of it, and I think it's a plus. ... There's definitely more collaboration, more talking about what's going on in your classroom and coming out from between the four walls and having a chat.

(Principal, Final Interview)

The culture in the school prior to this research had been one of individuals working in isolation. The introduction of LS aided teachers to experience the potential benefits of a more collaborative culture. Meaningful collaboration through shared planning, teaching and reflection contributed to creating a culture where dialogue about practice was introduced. There was increased acceptance to sharing professional vulnerabilities, and this contributed to feelings of interdependence. Teachers began to see a school culture that encourages collaboration as beneficial.

5.2.3 Opportunities for learning

STEM education was an approach that teachers were unfamiliar with at the beginning of the process. Despite participating in previous forms of PD, teachers were unsure in implementing STEM education. Creating STEM research lessons through LS gave teachers a wider variety of professional decision-making skills in their planning, integration, teaching and assessment of STEM. LS gave teachers the opportunities to tackle problems in their understanding of STEM and to solve problems of practice and implementation collectively. Through teacher collaboration and the creation of a safe community, teachers felt they could trial ideas and learn from their own and their colleagues' successes or failures.

Gwen noted the potential for learning from reflection and frank discussion. She recognised that her knowledge was enhanced by situating the STEM lessons in practice, as this served to contextualise the learning. She also appreciated teachers' reluctance to 'lose face' when lessons did not go as planned:

> *Definitely the fact that we learn so much from each other, and if people are open and honest and say, 'It was a disaster', and look at what went wrong and don't be afraid to say it, because we all have those lessons, and it can be a way of learning.*
>
> (Gwen, Final Interview)

LS provided a context where teachers planned, taught and reflected collaboratively. LS supported the embracing of a problem-solving attitude to the implementation of STEM. The principal recognised that teachers were now more inclined to share practice:

> *It's lovely to hear what's gone on in other classrooms, like it's even with you and the Lego and making the chairs and then you find they [the children] couldn't join the blocks ... that's fascinating, because we are talking and that's the collaboration and generating more knowledge. ... You know at the start of the year and our apprehension: 'What is STEM? How do you teach it?... Is STEM through maths or science?' All of that debate and conversation was brilliant.*
>
> (Principal, Final Interview)

Teachers felt that LS provided the time and freedom for teacher reflection. The opportunity for reflection, coupled with colleagues observing the lesson and the various perspectives from teachers, provided opportunities for learning:

> *But it is having other people to reflect with on the other person's perspective that can really enrich it, and then of course you have somebody who was viewing the lessons, you were up there teaching and then that's seeing it from a different angle.*
>
> (Maria, Final Interview)

> *It [lesson study] was very beneficial … the teaching it and the planning of it*

and the evaluation of it and discussions afterwards.

(Gwen, Final Interview)

Maria appreciated the importance of reflection to analyse her teaching and learning:

> *Quite frequently we don't often review our lessons and say, 'Well, where did that go wrong?', because in the class situation you're moving on to the next subject and you're not reviewing, and when it comes to an assessment in maths or whatever, and you see, 'Oh gosh, they don't know that aspect of this.' ... So that was a very positive aspect of it [lesson study].*
>
> (Maria, Final Interview)

Maria specifically recognised the value of the questions that a live lesson provoked and the opportunity to probe these questions in reflection meetings afterwards:

> *It's getting you to look at your own teaching, it's a way of getting you to think. There's so many questions that have to be answered at the end of a session, and that time for reflection allows that.*
>
> (Maria, Final Interview)

The principal linked the LS process with improved teaching: she believed that the quality of the participants' teaching approaches and practice improved. LS offered many benefits to teachers when faced with a new approach like STEM:

> *Yes, it would have huge benefits for our own teaching, your planning with someone ... it would raise the quality. ... There are huge benefits, I would think, huge benefits to collegiality, the planning the lesson, the confidence building and to the teaching of the subject STEM, especially a new topic like STEM.*
>
> (Principal, Final Interview)

LS provided the vehicle for teachers to work together and solve problems of practice. The existing relationship between the participants was the basis for the success of LS, as there was a requirement for honesty if practices were unsuccessful, and a relationship of trust was necessary when issues of dissonance arose. The foundation of trusting, honest relationships opened up the colleagues to the benefits of collaboration. Teachers appreciated the unique opportunity that LS offered to reflect with their colleagues on their practice. This opened the teachers up to insights they would otherwise not have been aware of.

5.3 Summary

It appears that the teachers viewed the prospect of increased collaboration positively, and that LS gave them an opportunity to experience this. This research found that increased collaboration enabled the growth of a stronger community of teachers, reduced feelings of isolation and facilitated opportunities for learning. Relationships were strengthened by the teachers' participation, as they experienced the affirmation of their colleagues and this created a stronger community of teachers. As a result of their involvement in LS and STEM, teachers were enabled to contribute to the development of the school vision for STEM education. Consequently, this gave the teachers increased feelings of ownership and membership. LS necessitated collaborative planning, teaching and reflecting on STEM lessons, and the increased opportunities for collaboration reduced teachers' feelings of isolation. Teachers recognised that creating an atmosphere of openness enabled them to share challenges of practice and provide solutions. Teachers especially appreciated the space that LS offered for collective reflection, as this was something they could not achieve regularly. It helped teachers to recognise the potential that their colleagues could offer to enriching teaching practice.

5.4 LS and the Impact on Classroom Practice

All teachers believed that LS had positively impacted their practice. Multiple cycles of LS gave the teachers opportunities to reflect on current practice, and this resulted in teachers becoming more critical of their teaching approaches and methodologies. With the support offered from their colleagues, teachers showed increased confidence to move away from teacher-led approaches. LS encouraged teachers to introduce new pedagogical practices, specifically inquiry-based education, but this process proved lengthy. As the research progressed, teachers shifted from a position of demonstrators of information to facilitating children's understanding, as LS had enabled them to bridge the gap between theory and practice.

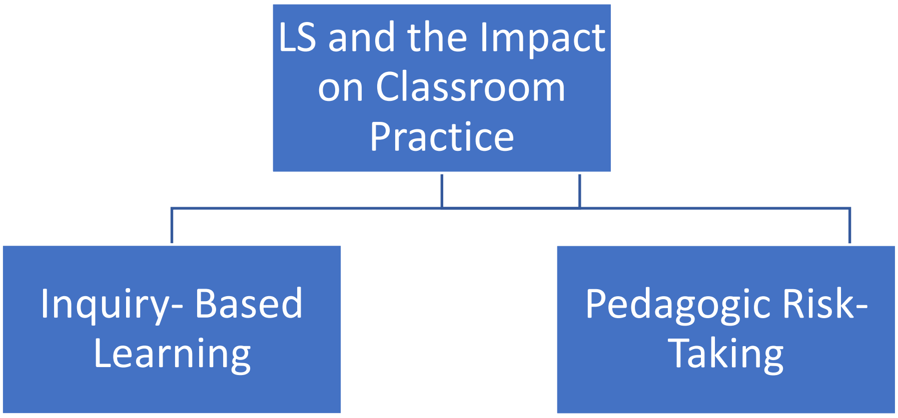

Figure 19: LS and the impact on classroom practice theme and subthemes

5.4.1 Inquiry-based learning

This subtheme outlines the introduction of inquiry-based learning to the teachers, how it was adopted through the STEM lessons, the challenges encountered, and, eventually, how the approach permeated throughout the school as all teachers observed its benefits to the children's learning. Initially, teachers were unfamiliar with inquiry-based teaching approaches:

> *The teachers are not aware of inquiry-based approach, and they are not confident in how to approach a STEM lesson.*
>
> (Researcher, Pilot Cycle, Reflective Diary, 22 Sept. 2018)

Through dialogue in planning meetings and staff meetings, teachers likened inquiry-based learning to discovery learning. The initial focus for teachers was how inquiry-based learning would effect changes in their practice. They did not mention other important features, including children making connections with scientific knowledge, children discussing their findings and communicating their ideas.

Through the SFI course teachers were exposed to the inquiry- based approach.

> *You felt this approach was very much going to engage the children and that it would get the children wondering and asking questions*
>
> (Maria, Pilot Cycle, Research Lesson 1, Reflection Meeting)

Therefore, through the LS cycles teachers trailed this approach. LS offered a supportive framework and a safe environment to experiment with practice and advance their STEM teaching. The teachers' focus developed as the research cycles progressed and they began to observe the effect of the inquiry-based approach on the children's learning. During cycle two Maria noted

> *I have written here that [Child's name] took the recording sheet and guided her group through it, she showed great leadership skills [laughs]. The inquiry approach enables children to take charge of their learning.*

(Maria, Cycle 2, Research Lesson 2, Observation sheet)

The children's 21st century skill development was also recognised as another effect of the inquiry- based approach on children's learning.

> *When the tinfoil boats sank the children were posing questions about why and how they sank, their problem solving abilities were really coming out.*

(Gwen, Cycle 3, Research Lesson 1, Observation sheet)

Teachers began to reflect on their role in STEM lessons, and they became aware of the importance of teachers as the facilitators of the learning process during inquiry-based learning. While they were mindful in theory that they were not the sole transmitters of knowledge, this was not realised in practice initially. During cycle two, I observed that teachers were reluctant to offer the time and space for children to struggle with problems:

> *There's too much spoon feeding.… [Teacher name] just asked a question and then gave them the answer; the children would have arrived at the answer themselves but they weren't given the time.*

(Researcher, Cycle 2, Research Lesson 1, Observation sheet)

Evidently, our idea of the teacher as facilitator was still evolving. Through discussion we realised that by intervening too early, we were impeding meaningful learning. During Gwen's first teach of a STEM lesson, she indicated her discomfort with the busy nature of STEM lessons, and she was unsure of her role in the inquiry-based approach:

> *I don't think I pulled it off. The idea behind it was perfect, I think I must have talked a load of waffle. I don't think I got enough language out of them [the children] – could I have got more? It was chaotic … STEM is so busy, and they're so young.*

(Gwen, Cycle 2, Research Lesson 1, Reflection Meeting)

Gwen seemed uncomfortable with the active and hands-on nature of the STEM lesson. She appeared uneasy with her perceived loss of control and lacked confidence in her approach:

I lost control of them [the children], they were going ahead of me with the activity; I couldn't keep up with them.

(Gwen, Cycle 2, Research Lesson 1, Reflection Meeting)

This contrasted sharply with what was noted in the observation sheets:

There's an enthusiastic, productive buzz in the room … the children are engaged and interested.

(Researcher, Cycle 2, Research Lesson 1, Observation Sheet)

The children are working well in their groups and conducting their investigation independently.

(Maria, Cycle 2, Research Lesson 1, Observation Sheet)

Gwen's comments indicated uneasiness with the inquiry-based learning approach and with giving the children freedom to work independently:

STEM requires a fundamental swing away from teacher-led instruction to a teacher as a facilitator. With inquiry-based learning, the teacher has the role of enabling discussion amongst the children to try and encourage them to think more deeply about a problem or a question and to aid them in finding out the answers to their own questions. The teacher's role is to enable the children to discover the learning for themselves, and this can be a difficult change for teachers to make.

(Researcher, Pilot Cycle, Reflective Diary, 20 Oct. 2018)

As the teachers engaged in LS and had the opportunity to observe children's learning, they became aware of the richness of inquiry-based learning. Gwen's perspective begins to shift as she realised the importance of children experiencing a productive struggle:

Gwen:	You are not solving the problem for the child – they are the problem solvers.
Researcher:	Yeah, I think as teachers we try and step in and solve problems too quickly for children.

(Cycle 2, Research Lesson 2, Reflection Meeting)

While teachers were aware of the 'teacher as facilitator' in theory, it took more time to realise this in practice. Inquiry-based learning was therefore adopted into practice in small steps. We began by attempting to activate children's interest and thirst for knowledge. Teachers began to see the value of an appropriate trigger in stimulating children's thinking and learning:

Maria:	But also, with inquiry-based learning, we start off with a question or a statement or a problem, and that's the productive struggle there, because the

	children are thinking from the get-go.
Researcher:	Yeah, for inquiry-based learning we are limiting teacher talk and increasing pupil activity.

(Cycle 3, Research Lesson 1, Planning Meeting)

Teachers aimed to use an appropriate trigger to hook the children's interest and motivation. In all lessons, literacy was incorporated through a story or nursery rhyme, to provide the stimulus or learning trigger for the STEM lessons. The teachers also recognised that selecting a stimulating trigger increased children's engagement and motivation:

Maria:	Why don't we leave a Gingerbread Man in a container of water for the lesson, so the children can observe what happens?
Researcher:	Brilliant, that will really hook their curiosity, and they can predict beforehand and use their observation skills throughout the lesson.

(Cycle 3, Research Lesson 1, Planning Meeting)

The teachers also recognised the importance of context for children in early years education by selecting stimuli and learning triggers that the children could identify with. Teachers then created an activity around these literacy triggers. This approach ensured the children were faced with a problem situated in a context they were familiar with (Appendix M and M1):

> *Because it draws on children's prior knowledge, so Humpty Dumpty is a good stimulus; they will want to solve that problem to help Humpty. I think they will be very motivated by that experiment.*
>
> (Maria, Cycle 2, Research Lesson 1, Planning Meeting)

It was evident that teachers regarded learning triggers and context in learning activities as important, and they featured as norms in their pedagogical practice as the research progressed. Teachers also began to incorporate an element of choice into lessons, thereby affording the children more agency. In cycle three, Research Lesson 1 (Appendix N), the children were required to make their boat from tinfoil, but for Research Lesson 2 (Appendix N1), the teachers decided it would be more beneficial for the children to choose which materials they wanted to use, so the potential for the children to be creative was greater:

Maria:	They can explore the materials.
Researcher:	It's trial and error.

Maria:	And they are learning instead of being told; they have to decide for themselves.
Researcher:	Yes, whereas the first lesson was very structured: 'Here is your tinfoil – make your boat.'
Gwen:	There's a lot more exploring in this lesson.

(Cycle 3, Research Lesson 2, Planning Meeting)

By utilising the inquiry-based approach teachers included learning triggers, identifiable contexts and choice in the lesson plans. All teachers believed that the inquiry-based approach facilitated children's learning particularly their thinking skills and agency. This increased the teachers' willingness to adopt this approach. Gwen, who initially struggled with this strategy, concluded that it was beneficial and worthwhile. She noted that inquiry-based learning promoted children's agency and invited the children to think more deeply:

> *Inquiry-based is a no-brainer really; an abstract way of teaching just isn't going to work with kids of 2019. They need to be active; they need to be engaged. So that's how you get those little brains working. Everything is a remote control, everything is a flick of a switch. And you know, work is messy, and it's getting stuck in, and I think they experience that in a different way because they're doing more thinking. ... It focuses you so much. The skills or the methodology is transferable to everything else ... there's so much to be gained from it.*
>
> (Gwen, Final Interview)

Equally, Maria felt that the inquiry-based approach promoted children's learning and also motivated them:

> *I loved the idea of throwing out a question to them and seeing, Well, what can I do? And waiting for the children to give a response and asking them what materials they might use, so it was really getting the children to think. Yeah, yeah, it was fantastic – they're straight away engaged, and then you know they're learning without them even knowing. They love to explore, they loved the experiment, they enjoyed the hands-on, the predictions and checking to see, you know, were they right in their predictions. So it was very engaging for them.*
>
> (Maria, Final Interview)

All teachers were now mindful of including opportunities for the children to predict, problem-solve, collaborate and test their hypotheses with other children in STEM lessons. Maria contrasted more didactic styles of teaching with inquiry-based learning and saw value in the children being active in their learning. She also noted that inquiry-based learning promoted positive habits of learning and made children's learning more meaningful:

> *So yeah, it was very active rather than sitting down and listening. They were up and moving around, so it kind of forces them to think, and it's getting them to have inquiring minds, and that's the critical thinking we wanted to adopt.*
>
> (Maria, Final Interview)

Teachers recognised that adopting the inquiry-based approach to learning could be transferrable to other subjects:

> *It was very insightful, so as I say, it's something that we can use across the board in our Maths and, you know, even English.*
>
> (Maria, Final Interview)

LS gave teachers the opportunity to reflect on their practice and trial new approaches; this time was also used to reflect on the teacher role in STEM lessons. In this research, teachers trialled inquiry-based learning and observed its effects on children's learning. As a result of discussions during LS and staff meetings, this approach to STEM learning circulated throughout the school. The principal observed that without LS this development would have been unlikely:

> *We were very aware of what we were doing with inquiry-based learning. ... Yes, it focused me on my STEM lessons ... and that all came from lesson study and your focus on STEM in the lesson study. ... Remember when we said I had to stand back and let them [the children] at it, because I suppose traditionally, we've always been the reverse ... we're teaching too much rather than the discovery learning. ... So that was the thing I learned from it in terms of lesson study – I think it made us focus on our way of teaching.*
>
> (Principal, Final Interview)

Like Gwen, the principal acknowledged the difficulty of moving from a didactic to a facilitative role. She said that discussing the challenges of inquiry-based teaching during Croke Park (section 2.3.5) meetings created a safe space and supported teachers in adopting the inquiry-based approach:

> *Yeah, it was that inquiry-based format for all the lessons, and it was definitely a way of getting the teachers and me to change how you approach a STEM lesson and to get that trigger going.*
>
> (Principal, Final Interview)

As the research concluded, teachers had implemented a change in their practice, and

LS had enabled this to happen. Initially, teachers were unfamiliar with inquiry-based learning, and some were uncomfortable with their role as facilitator. However, as teachers reflected on their role as teacher, they saw the value in shifting from a more didactic role to a facilitative role.

At the completion of the research, all teachers had successfully taught STEM lessons using the inquiry-based approach and had found it beneficial to children's learning. As the cycles progressed teachers reported they were feeling more confident in their role as facilitator. Inquiry- based learning was embraced throughout the school as an approach to STEM lessons. Engagement in LS had supported teachers to experiment with pedagogy, helping them develop their skills, knowledge and beliefs and ultimately change their practice.

5.4.2 Pedagogic risk-taking

While all teachers had a history of PD, some had come to distrust PD courses, as they could not envision them working in their context:

> *Well, you need an instructor with relevant classroom experience; they can tell you pie-in-the-sky stuff that's not realistic with a class of 32 with two Lego kits. ... A tutor that knows what they're talking about is very important.*
> (Gwen, Initial Interview)

LS aided teachers in creating lessons appropriate to their context and responsive to the children's needs. Participating teachers planned STEM lessons, and this was a new and unfamiliar area for all participants. The recurrent LS cycles allowed teachers to take pedagogic risks which enabled their understanding of STEM teaching to evolve over the course of the research. The first lesson on floating and sinking (Appendix L) in the pilot cycle appeared to be very traditional, and it was a lesson that all teachers would have been very familiar with before the research began. Over the course of the research, however, the STEM lessons evolved into unfamiliar territory that included activities and lessons not previously attempted by the teachers. Due to the supportive framework of LS, teachers felt confident to design lessons containing unfamiliar content. They were now experimenting with the inquiry-based approach; they used more hands-on activities, with additional opportunities for children to collaborate and to engage in scientific and mathematical discussion. LS gave teachers the opportunity to make multiple professional decisions on lesson content, to consult the curriculum and to explore teaching approaches to utilise. The principal praised this leap of faith that the teachers had taken as they experimented with their practice:

> *I mean, this year was very much trial and error, and we were trying this and trying that ... I suppose pushing yourself outside your comfort zone. ... It's good to be challenged, especially as it was a new topic, and that confidence would be there.*
>
> (Principal, Final Interview)

Similarly, I had noted:

> *Lesson study has been a huge learning curve for the teachers; they are trying collaborative planning and collaborative reflection. They are trying a new approach in inquiry-based learning which has led the children to exercise their problem-solving skills and be more active in their learning. They were very unaccustomed to being observed in their teaching only in evaluative circumstances, and they have never taught a class in School 2. They have taken risks in STEM and they have been very enthusiastic about it.*
>
> (Researcher, Post Cycle 4, Reflective Diary, 21 June 2019)

As well as teachers taking increased pedagogic risks, their agency was promoted, as each teacher made changes to their teaching and working environment when teaching STEM classes. Maria noted her personal growth and the benefits this had for children's learning:

> *It makes you go to PD training, and it sounds like a subject I haven't ventured near, and then you realise, OK, well actually we have been doing this all along. But now trying it out, and you're making it very child-friendly, and the children love it. At the end of the day it's all about the children learning.*
>
> (Maria, Final Interview)

Despite research suggesting a heavy reliance on textbooks and worksheets, none of the STEM lessons were acquired from a textbook or other readymade resources. At this time, admittedly, STEM was a recent development, and there was a scarcity of textbooks on the market. But there were a number of educational companies supplying resources in the form of STEM work cards and STEM kits. As the research progressed, teachers displayed increasing confidence as they created the tasks collaboratively without the use of textbooks. They developed the agency and the confidence to consult different resources and various websites to design unique lessons.

5.5 Summary

This research exposed teachers to LS, STEM and inquiry-based learning for the first time. LS impacted classroom practice by encouraging teachers to adopt a new approach, namely inquiry- based learning and to take pedagogic risks. This study identifies LS as a powerful approach that supported the teachers to reflect on their practice, experiment with pedagogy and observe children's learning. Teachers acquired insights into PCK as they reflected on the limitations of their former role as teacher, where they focused lessons on transmitting content instead of designing meaningful learning activities. LS enabled a positive environment for constructive, peer-to-peer discussion which was firmly grounded in classroom practice. All the teachers in this research said their involvement in LS improved their teaching. Teachers recognised the rich learning that can occur by using the inquiry-based approach, and they were motivated to take pedagogic risks to provide authentic learning experiences for the children. This indicated that LS encouraged a more in-depth analysis of pedagogy through professional dialogue. Through this collaborative process, the teachers cultivated feelings of efficacy with new pedagogical approaches.

5.6 LS and the Development of Teacher Learning

As LS progressed and teachers reflected, they reported on the impact that LS had on their learning. Important components of teacher knowledge (Shulman 1987) were strengthened through their participation in LS. LS contributed to teachers' STEM subject matter knowledge (SMK), in particular their specialised content knowledge (SCK) and STEM pedagogical content knowledge (PCK), including both knowledge of content and teaching (KCT) and knowledge of content and students (KCS).

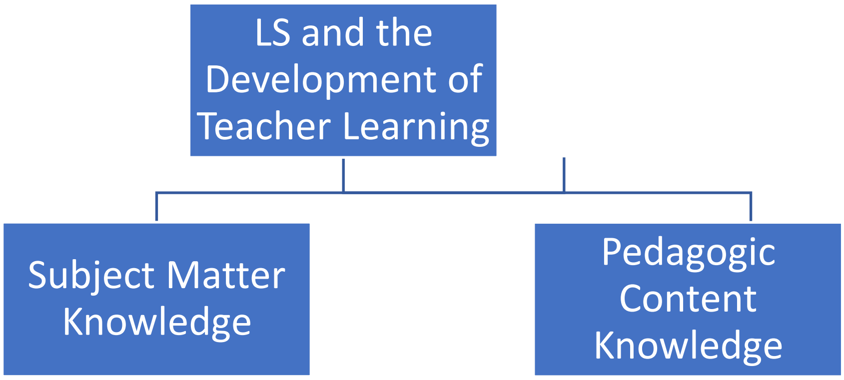

Figure 20: LS and the development of teacher knowledge theme and subthemes

5.6.1 Subject matter knowledge

At the outset of the research, teachers did not have in-depth practical knowledge and experience of STEM content, and no prior experience of teaching engineering or technology. However, as they were initially grounding the STEM lessons in science, it quickly became apparent that teachers' SMK of science proved to be a problematic area. During the pilot lesson, their knowledge of density in the floating and sinking lesson revealed misconceptions. Initially, there seemed to be misunderstanding that the latent energy of an object was linked to density:

Gwen:	Well, if water gets into paper that will sink, it has latent energy.
Researcher:	What is latent energy?
Gwen:	Latent energy is ... oh, don't quote me on it.
Researcher:	God, I had never heard of that.

(Pilot Cycle, Research Lesson 2, Planning Meeting)

The initial LS meetings discussed children's prior knowledge and difficulties or misconceptions that they may have before the lesson. Hence, when teachers were predicting questions that the pupils would ask, their SMK was tested; as one teacher asked, 'How do you explain density to four- to six-year-olds?' (Pilot Cycle, Research Lesson 1, Planning Meeting). Teachers struggled with their own understanding of density:

Researcher:	I had a discussion yesterday with the children. ... One child had said that heavy things sink, but two children disputed that and said that they had seen their swimming cap sink and their goggles sink. But why did those things sink? How can I explain it?

Maria:	Now there you go, they're [the children are] thinking ... well, plastic sinks ... so that's why the goggles would sink. ... Now it also depends on the volume of water ... the goggles sank because of the water they contain.
Researcher	Does plastic always sink? ... No, because a ruler would float, or light plastic would float.
Maria:	Okay, right … And if they ask me why does a ship float, that's because it holds air ... so we could show them a life jacket, and because it has air, it floats.

(Pilot Cycle, Research Lesson 1, Planning Meeting)

The issue of density provoked worry about gaps in teachers' understanding. During a Croke Park (section 2.3.5) meeting, density was discussed with other colleagues, and the definition was resolved. LS had provided a forum to discuss misconceptions and collaborate with colleagues to provide answers:

> *I enjoyed the opportunity to thrash out what density was and being able to ask other colleagues what they thought. I have been teaching the same age group for five years and this issue never arose, because I had always just thought about floating and sinking, having never thought that deeply about children's questions or what their thinking might be.*
>
> (Researcher, Pilot Cycle, Reflective Diary, 3 Oct. 2019)

Science SMK was an area that teachers felt vulnerable in. They expressed fear of being asked a question they would not be able to explain:

> *I think yeah, like you said there about the scientific jargon and maybe look up a lesson pitched at a higher level, so you do have a higher level of information, not just information you need for this particular lesson. Because you don't know, you have a very bright spark there in Junior Infants who could really bombard you with a sticky one [question], and you want to be able to have some answer. They're too small to be telling them to 'go off and look that up yourself'. So you would have to have some scientifically based response and it would have to be accurate, you know. I suppose to read on a bit and be more ahead of it.*
>
> (Gwen, Pilot Cycle, Research Lesson 1, Reflection Meeting)

Gwen's comment suggests feelings of fear and insecurity in her science knowledge. She seemed to lack confidence in her ability to accurately answer children's questions. This is concerning, as children rely on teachers for accurate content knowledge. Gwen attempted to explain the discrepancies evident in teachers' background knowledge of science:

> *You see, the education of primary teachers is vital – they don't have the science and maths. The people who had brilliant science and maths*

knowledge went on different career paths. If you are not predisposed to science and maths, you are not going to avail of professional development in STEM voluntarily; you have to be made do it.

(Gwen, Pilot Cycle, Research Lesson 2, Reflection Meeting)

Here Gwen speaks for teachers and suggests they do not have adequate science and maths knowledge. It is interesting to note the comment ‘you have to be made do it’ and the notion of teachers’ own interests driving which PD they attend, or perhaps avoiding PD in certain subjects that do not interest them.

Again, in cycle four, teachers’ SMK was tested on mass and weight, and definitions were sought using the internet.

Researcher:	When we went to the Discovery Primary Maths and Science PD … they asked mass and weight, what’s the difference?
Gwen:	Mass is to do with displacement of its weight, I think.
Researcher:	Because at the course, they said we are using weight in the wrong context, it’s mass we should be using. Have you heard that before?
Gwen:	I heard something but I still use the word ‘weight’; it’s in all the books [textbooks].
Researcher:	‘Weight’ is used in the pupil book, but ‘mass’ is used in the teacher book.
Maria:	Does it matter that much at the moment? Not at this age, I would say.

(Cycle Four, Research Lesson 2, Planning Meeting)

This vignette suggests not only a misconception about the terms ‘weight’ and ‘mass’ but also a reliance on the maths textbook. The use of the term ‘weight’ in the textbook seemed to be the determining factor, and since ‘weight’ was in the textbook, the teachers seemed reluctant to change this.

STEM education requires teachers to have broad content knowledge. LS ensured that teachers engaged in planning, teaching, observing, reflecting and discussion, a process that illuminated weaknesses in teachers’ knowledge. This research revealed that teachers’ SMK was problematic, and this is linked to lack of confidence and self-efficacy in their competency to answer children’s questions. Teachers’ maths, engineering or technological knowledge did not seem as problematic. As this research dealt with young children, one can only presume that teachers’ SMK could have proved more problematic with older children. Additionally, this LS research examined only four research lessons. Teachers’ content knowledge could be tested further if a wider array of science concepts had been taught. In areas of weakness, teachers consulted each other, the wider staff or the internet for answers. This is not sufficient. Teachers require comprehensive conceptual understanding of science, mathematical, technological and engineering content knowledge if they are to develop an appropriate teaching approach to STEM. Teachers require robust content knowledge to pose and answer questions and address children's misconceptions.

The ongoing cyclical nature of respective LS stages provided the format for teachers to discuss and develop their content knowledge in some areas. Traditionally, problems of practice would have been solved independently or perhaps masked to 'save face' amongst peers, but LS supported challenges being tackled through collegial collaboration. It created conditons where teachers could disclose areas of weakness in their knowledge and enabled the co-construction of knowledge between the participants. While LS aided teachers exposing their vulnerabilities or gaps in knowledge, teachers require direct guidance to build their STEM content knowledge. Quality SMK, SCK combined with PCK is imperative for comprehensive STEM education.

5.6.1.1 Limited understanding of an interdisciplinary approach

During the pilot cycle, teachers were unsure how STEM could be integrated into the existing curriculum. Ireland does not have an obligatory, complete STEM policy or curriculum at primary level. The PSC contains science and maths curricula only; therefore, curriculum objectives for technology and engineering were created by the teachers. Confusion surrounded the terms 'technology' and 'engineering' initially, as teachers tried to envision how they could be realised in the classroom. Technology was initially perceived as coding, robotics and programming; we associated it with digital equipment.

Teachers struggled to perceive how young children could develop engineering and technological skills through STEM:

> *Integrating the technology here is the thing that you made … the engineering… the engineering is actually putting the thing, the materials, into the bag and making a protective cover for that egg – that's the engineering, the technology … Didn't the [Science] facilitator say technology is anything that does work for you? Is the metre stick technology?*
> (Gwen, Cycle 2, Research Lesson 1, Planning Meeting)

During cycle two we decided to adopt Sharapan's definition of technology for our lessons: 'adults tend to think of technology as digital equipment like cameras and computers or sophisticated machines in factories. But crayons and pencils are tools. So are rulers, magnifying glasses, scissors…' (Sharapan 2012, p. 37).

> *So we have tinfoil as our tool aka our technology for the lesson, they [the children] will create the boats with that*
>
> (Researcher, Cycle 3, Research Lesson 1, Planning Meeting)

Teachers also felt that timetabling issues made the interdisciplinary nature of STEM lessons challenging:

Maria:	I suppose what I noticed is, it's very challenging to incorporate all four areas into one lesson.
Researcher:	Within a half an hour or forty minutes you really need to have a unit of work for three to four weeks maybe.
Maria:	Because you have the language element, you need to get their prior knowledge, then you're discussing the materials, you're making your predictions and then where is the time to explore? You're rushing through that, and you don't have the time to recap in half an hour

(Cycle 2, Research Lesson 2, Reflection Meeting)

The duration of one STEM lesson and integrating all four components into a research lesson were recognised as initial obstacles. Lessons in the pilot cycle (Appendix L and L1) and cycle two (Appendix M and M1) encapsulated teachers' apprehension of STEM as they focused on science and maths, with superficial links to technology and engineering:

> *I don't think that first lesson was a STEM lesson, we had no engineering in that experiment…*
>
> (Researcher, Pilot Cycle, Research Lesson 2, Reflection Meeting)

While the research states that an interdisciplinary approach to STEM should be adopted to ensure that children can make links across the disciples, this proved challenging for the teachers to adopt in reality.

After consulting the STEM literature and research, it was decided to base a lesson on engineering and on making connections with the other STEM disciplines. Therefore, research lesson 3 (Appendix N and N1) and lesson 4 (Appendix O and O1) signalled a departure from previous lessons and instead veered in the engineering direction.

Teachers found that engineering naturally integrated scientific, technological and mathematical aspects:

Researcher:	When the lesson has something we are building, the STEM components seem to come more naturally together.
Gwen:	Most of the STEM lessons on Twinkl [educational website] are building something.
Researcher:	With Humpty or the floating and sinking lessons, we weren't building anything.
Maria:	And the children making the boat – that's bringing the four components together.

(Cycle 3, Research Lesson 1, Planning Meeting)

Research lessons in cycles three and four had a strong engineering element, involving constructing a boat and a chair, respectively. As the research progressed, I reflected:

> *The engineering element of STEM became increasingly important as the research had progressed. The last two cycles involved the children utilising the Engineering Design Process to design and construct various objects, and this has united science, maths and technology together.*
>
> (Researcher, Cycle 4, Reflective Diary, 8 April 2019)

> *I think a turning point has been placing engineering as a basis for the lessons… using the Engineering Design Process gives a good structure to the lessons as well… it's a new way of looking at it and making it accessible to them [the children]*
>
> (Maria, Cycle 4, Research Lesson 1, Planning Meeting)

During the integrated STEM activity in cycles 3 and 4, the children engaged in a simplified version of the Engineer Design Process: they had a problem to solve, drew a blueprint, planned their construction, constructed their creation in a collaborative group and improved their design based on the prototype:

> *This is a lesson that engaged higher thinking skills ... but having the doll – the prototype – there really made them test, and they were testing and they were adjusting and redesigning, so they were doing all of the things we wanted them to do.*
>
> (MKO, Cycle 4, Research Lesson 1, Reflection Meeting)

As teachers began designing the first STEM lesson, they were shrouded by a cloud of confusion. Teachers were uncertain about multiple issues; the definitions of technology and engineering, how they could be realised with 4–7-year-olds, durations of lessons, integrating all four disciplines into one lesson, and engineering's role in STEM. LS enabled the teachers to solve many problems of practice. Teachers realised they had a narrow view of technology and engineering. Initially teachers viewed technology as iPads, digital cameras and laptops, however by adopting Sharapan's (2012) definition of technology (section 3.3.1), teachers viewed different tools that children used in their STEM invesitgations as technology, i.e. tinfoil or the recycled materials as the tools in cycle three, or Lego as the tool in cycle four . Similarly, at the beginning of the research teachers struggled to envisage how engineering could be implemented with the younger classes. Through the LS cycles, teachers broadened their idea of engineering to include children creating, constructing and tinkering. They adopted a simplied version of the Engineering Design Process (section 5.6.1) for cycle three and four. Teachers observed children using their engineering skills to create boats and build chairs. Consequently, teachers found ways to implement technology and engineering practically in the infant classroom.

In the pilot and cycle two teachers believed STEM was science based, however teachers found that with science as the basis for a STEM lesson it was difficult to integrate the other disciplines. Through trial and error teachers and the following cycles of LS teachers discovered engineering as a potential foundation of the integrated STEM lesson, naturally connecting concepts from science, technology and maths. A simplified version of the Engineering Design Process was then used for cycle three and four. Integration of the four disciplines enabled the teachers to improve their design of STEM lessons, and it was hoped this would contribute to a more robust understanding for children. In this way, LS helped teachers develop SCK, and this journey is evident through the progression in the lesson plans. It was in their collaboration and trialling of STEM lessons that teachers navigated towards a more robust understanding of STEM education.

5.6.2 Pedagogical content knowledge (PCK)

Participating in consecutive cycles of LS developed teachers' PCK, as they identified practices and content that would be effective in developing young children's knowledge in STEM. Teachers developed KCT and KCS as they examined strategies and teaching approaches that would support the best learning experience for the children. Teachers' PCK and KCS developed as they found ways to engage with children with SEN. Teachers struggled to conceptualise and implement some 21st-century skills, but they strove to create STEM experiences in which children developed both skills and knowledge.

5.6.2.1 21st-century skills

From the outset of the research, teachers appreciated the need to develop children's 21st century skills. While they did not mention 21st century skills specifically in their initial interviews, they mentioned skills which would enable children to develop resilience, problem-solving, collaboration, critical thinking and communicating their thinking using appropriate scientific and mathematical terms. Teachers recognised that these skills were inherent in STEM education and should be developed at primary age; however, gaps in PCK were evident as they struggled to make all skills relevant and accessible to the children.

Problem-solving

Previous standardised assessment in maths (i.e. SIGMA-T), coupled with teacher observation, determined that teachers were concerned about children's problem-solving ability. Teachers recognised problem-solving and resilience as relevant life skills for children to develop through STEM. At the outset of the research, both teachers mentioned in their initial interviews that children tended to dismiss activities when challenges arose:

> *They tend to leave it [an activity or task] if they get frustrated.*
>
> (Maria, Initial Interview)
>
> *Society's busier now, so we need to give them a chance and give them the time. And as teachers we should take on that task that we are going to give them that time to think it out, to persevere with it, not just cast it aside.*
>
> (Gwen, Initial Interview)

We planned to cultivate an environment that promoted problem-solving and resilience, and we reflected initially on our practice. At the end of the pilot cycle, teachers demonstrated KCT, as it was decided that STEM lessons would begin with a problem such as 'How could we help Goldilocks say sorry to Baby Bear?' (Appendix O and O1), or 'How can we help the Gingerbread Man cross the river?'

(Appendix N and N1). Teachers endeavoured for children to experience problems that had multiple solutions and to persevere with tasks when they faced obstacles. We also discussed the need to emphasise 'thinking' language as a pedagogical strategy to support problem-solving and reflection: 'I want you to put on your thinking caps'; 'Let's take a few seconds and just think about this on your own, then we will share with a buddy'; 'That's really good thinking'. Teachers also became mindful of giving children enough time to grapple with a problem.

Researcher:	We don't let them struggle enough, we tend to jump in.
Gwen:	Yeah, that's what I was thinking – we don't give them enough time to formulate their own ideas, let them think about it…

(Pilot Cycle, Research Lesson 1, Reflection Meeting)

It was decided to incorporate wait time into the lessons; this is evident through the lesson plans (Appendix M1, N, N1, O and O1). It was intended that including a period to reflect on their ideas would give children the freedom to construct new learning and develop their conceptual understanding, and time to formulate questions:

Researcher:	And we probably should pause to allow children to voice what they learned in the lesson … maybe pause and get a bit more out of them.
Gwen:	As teachers we tend to jump in and do too much and tell them too much. We should let the children struggle with problems. Because if you get into that habit of pausing to allow them to think, it will become a habit and will have to infiltrate all the other curricular areas.
Researcher:	And maybe if we model what happens if we make something that fails or falls apart, and how we cope with that. We can pretend to get stuck, and that will help them see we [adults] make mistakes too.

(Pilot Cycle, Research Lesson 2, Reflection Meeting)

This conversation refers to teachers' beliefs that it was important for children to take risks and for failure to be seen as part of the learning process. Teachers observed the effect of this on children's responses:

> *The wait time seems to be making all children contemplate an answer, and it seems to be resulting in more children raising their hands.*
> (Maria, Cycle 3, Research Lesson 1, Observation Sheet)

Additionally, teachers felt that having children in collaborative groups would boost their resilience, as they would support each other in the problem-solving process:

I think group work would help their resilience and their ability to stick with something.

(Researcher, Pilot Cycle, Research Lesson 2, Reflection Meeting)

As the research progressed, teachers observed that children's problem-solving ability and resilience had both developed:

There was a lot of problem-solving opportunities in this lesson: they had to design their construct, revise and adjust to take into account the size of Goldilocks … that made it more challenging, as it wasn't just making any chair they wanted to make.

(Researcher, Cycle 4, Research Lesson 1, Reflection Meeting)

As the research progressed, teachers were mindful of creating STEM lessons with opportunities for children to problem-solve, reason, collaborate and reflect. Maria reflected that while STEM education was a new approach for both the teachers and the children, she noted how naturally disposed children were to it:

So they were using their skills, which we wanted them to do without having to teach them, you know, it just came naturally to them. So that was a really positive aspect of it … They love to problem-solve, they love to explore, they loved to experiment, they enjoyed the hands-on, the predictions and checking to see, you know, were they right in their predictions. … I think that was the main thing, that the children were learning from it and they were enjoying it. Yes, if the children are enjoying it and they're learning, that's a really good move there.

(Maria, Final Interview)

STEM lessons supported children to learn that some activities require struggle and that resilience is required in the face of constraints. Incorporating wait time into the lessons allowed children the space to reflect and make links between ideas. We realised that a productive struggle would be pertinent for the subsequent STEM lessons; therefore, opportunities for this were integrated into the future lessons. Children's higher-order thinking skills were encouraged, as there were opportunities for problem-solving, reasoning, reflection and critical thinking. By focusing on ways to incorporate attention to problem-solving, teachers developed and implemented a range of new pedagogies to support that.

While the school system can be critiqued for too much rote learning and chalk and talk, STEM education employs lots of higher-order thinking skills, as children are problem-solvers, reasoning, communicating, drawing conclusions from cause and effect.

(Researcher, Cycle 4, Reflective Diary, 15 April 2019)

Communication

Teachers regarded the development of children's communication skills as central to STEM lessons. They recognised that promoting children's dialogue supported the development of their verbal reasoning skills. From the first planning meeting in the pilot cycle, teachers were concerned with the children's ability to explain their STEM understandings. They were aware of children's various levels of language development and the possible difficulties with acquiring scientific and mathematical vocabulary or terms. Teachers sought to capitalise on the learning experience that would be created during the STEM activity and to ensure that children's oral language development was a focus throughout the process:

Gwen:	One of the things I think is important – some of them might have the knowledge but not the language to go with that, so that language is often missing. They might not be able to tell you how something happens…
Maria:	You have to make sure they have the language for it; they won't be able to talk about the experiment or express themselves if they don't have the vocabulary.
Researcher:	Yeah, I know some children would have it quite naturally, some not, so what if I did a story and poem in the weeks leading up to it that would have some of the language? Yeah … I could set up an Aistear corner with water in it, and they could get used to things floating and sinking ... that could be their free play, their exploration?

(Pilot Cycle, Research Lesson 1, Planning Meeting)

During the first lesson, teachers were surprised by their observations. Generally, we had underestimated children's ability. Gwen was surprised by the differences in children's prior knowledge:

> *I think the very clued-in child versus the child that is only barely with you, there's a distance between what some of the kids know and what other kids know at that age.*
>
> (Gwen, Pilot Cycle, Research Lesson 2, Reflection Meeting)

Growth in PCK and KCT was evident as teachers trialled thematic planning during the pilot cycle to investigate whether it would tangibly affect children's vocabulary development. Teachers felt that thematic planning would ensure that children would have multiple instances of exposure to the targeted language. Thematic planning revolved around the STEM research lesson to be taught. As teachers reflected after the pilot cycle, it was noted in the observation sheets and the post-lesson discussion that the children's language in School 2 was not as developed as in School 1. Teachers felt that children in School 1 had been exposed to the relevant scientific and mathematical language on numerous occasions in various contexts through thematic planning, so their vocabulary and ease of expression were at a more sophisticated level. This was taken as an early indication of the success of thematic planning, and it was adopted for the course of the research. Opportunities for language progression were discussed during the lesson planning in each cycle (see Tables 8–11).

Music	Song: Row, Row, Row Your Boat
Literacy	Story: The Gingerbread Man
Aistear	Water Play
Numeracy	Early Mathematical Activities: classify objects on the basis of one attribute, such as colour, shape, texture or size

Table 8: Thematic planning for pilot cycle: Subject integration for floating and sinking lesson

Literacy	Poem: Humpty Dumpty Story: Little Lumpty
Aistear	Creative Area with various types of materials The Post Office
Visual Arts	Children created a Humpty Dumpty picture with various materials

Table 9: Thematic planning for Cycle 2: Subject integration for Humpty Dumpty and materials lesson

Gaeilge	Scéal: An Buachaill Sinsear
Visual arts	3D Boats and waves
Geography / Science / Green School Flag Initiative	Reusing materials to make new objects
Story	Michael Recycle
Aistear	Water area Creative area: making new objects from recycled materials

Table 10: Thematic planning for Cycle 3: Subject integration for construction of boats for the Gingerbread Man lesson

Literacy	Story: Goldilocks and the Three Bears
Gaeilge	Cinnín Óir agus na Trí Bhear

Aistear	Lego and Block Play
Numeracy	Setting the Table: one-to-one correspondence
Social, Personal, Health Education	Goldilocks' perspective of events
Geography	Houses and Homes

Table 11: Thematic planning for Cycle 4: Subject integration for making a chair for Baby Bear lesson

Teachers demonstrated PCK, as they recognised that thematic planning was a powerful tool in igniting and sustaining children's interest in a topic and enabling them to connect knowledge across subjects. The principal noted the success of this approach, and she advised that it should be used across the school; she encouraged all staff to adopt thematic planning for their STEM topic.

Principal:	If we all had a mind-map up in the classroom about how we are integrating it and even for the kids, put the theme of materials in the middle and how we are integrating it into different subject areas stories, poetry, etc.
Maria:	That would be great for struggling kids to see the links between different subjects.

(Pilot Cycle, Croke Park Meeting, Oct. 2019)

Despite thematic planning being embraced by the whole school, participants felt that the integration of STEM in other subjects was ideally placed at infant level.

Gwen:	It's so easy to even integrate it into what we're all doing ... even more so the junior end. That should be integrated, because we're doing an awful lot of early number work … You know, I mean playing and Aistear, it totally does.
Maria:	Yes they don't learn in neat little boxes; they learn in an integrated manner.

(Cycle 3, Research Lesson 2, Reflection Meeting)

By cycle four, the participants felt that children's communication skills had improved. Most children could reason and justify their thinking; they were familiar with being questioned and asked to explain their thinking.

> *With the language coming from it [the lesson], your blueprint and the language around the chair, the seat, the legs, the back and the materials you might use. ... They got to use their language in the construction. They had said to me, 'A couch doesn't have legs' – that's how they described it to me, which I thought was brilliant, that they could justify their thinking ... so then we talked about how we might change it.*
>
> (MKO, Cycle 4, Research Lesson 1, Reflection Meeting)

> *The children are able to evaluate their boats and say, 'That didn't work', and why it didn't work.*
>
> (Maria, Cycle 3, Research Lesson 2, Observation Sheet)

One of the earliest concerns for teachers was that children would be equipped with the appropriate vocabulary to express themselves. Teachers recognised thematic planning as a means to develop children's communication skills. Through thematic planning, they were able to provide rich linguistic contexts that emphasised the vocabulary and language which supported children to communicate their thoughts. The thematic approach gave children repeated opportunities to use the relevant language, and this supported children to learn and utilise new words.

Critical thinking

Before the research commenced, teachers discussed the long-term aims of STEM and LS. In response to that discussion, teachers discussed the skills we hoped to nurture in the children. One teacher recognised that STEM was ideally placed to support the development of children's critical thinking skills:

> *It [STEM] develops in the children the essential critical-thinking skills to get them to think outside the box, to get some to think of other ways, to slow down in their approach, to how they figure out the problem and maybe hoping that that would transfer to a life skill.*
>
> (Gwen, Initial Interview)

In a subsequent staff discussion, teachers expressed that children should be equipped not only with content knowledge but also with the ability to think critically. They believed that critical thinking would be beneficial for the children to develop as a life skill. After consultation with the PSC, teachers found the term 'critical thinking', but it was not specified how to put it into practice in the classroom.

Researcher:	What do you think of critical thinking? That could be one of our goals for student learning, but how do you measure it? How do you teach it?
Gwen:	I don't know that you can teach it…
Maria:	Is it a problem and digging a little deeper and saying, Why did you say that? So you're getting them to use their resources instead of giving the answers to them.

(Pilot Cycle, Croke Park Meeting, 10 Sept. 2018)

Teachers' PCK was challenged, as they struggled to conceptualise critical thinking and how to develop it practically in the classroom. The feasibility of promoting critical thinking with Junior and Senior Infants was also questioned:

Researcher:	With children as young as four to six, how can we develop that in the children? Is it possible?'
Maria:	I think it is the way you question the children.

(Pilot Cycle, Research Lesson 1, Planning Meeting)

Teachers sought to extend children's critical thinking through a range of questioning. Bloom's Taxonomy was consulted to ensure we were employing lower to higher order questioning, and these were included in the lesson plans. Gwen felt that higher order questioning with higher-achieving children was an area that had previously been neglected:

> *That's fine, but you need to bring them [children with higher ability] on, they need to reach their potential, and they won't reach their potential in spite of you – that is where our questioning comes out, and about putting that critical thinking and problem-solving back on them, getting their brains working.*
> (Gwen, Pilot Cycle, Research Lesson 2, Reflection Meeting)

The progression on questioning occurred as the cycles advanced. There were no questions included in the research lessons during the pilot cycle (Appendix L and L1). Cycle two details various questions as the trigger for the lesson. These questions probe children's prior knowledge of materials and their projections of what material 'would work best to protect Humpty?' (Appendix M1). During the investigation stage in cycle three the children are asked if they can 'alter the shape so that the boat will take more passengers before it sinks' (Appendix N and N1). This question invited the children to redesign, experiment and evaluate differently shaped boats. Again, in cycle four it was hoped that the questioning in the trigger section would develop the children's empathy for Goldilocks and explore how she could apologise to the three bears (Appendix O and O1). For the remaining cycles teachers placed an emphasis on children's communication and critical thinking skills through the development of questions

Researcher:	Right to get them [the children] thinking what questions could we ask?
Maria:	Well lower order questions would be [looking at Bloom's Taxonomy poster] 'How did you make your boat' or 'Why did you do this?', higher order questions could be…. 'Your boat has a flat base why did you make it flat?' or 'What would happen if it had a pointy base?'

(Cycle 3, Research Lesson 1, Planning Meeting)

In cycle four there was further emphasis on including a range of questioning in the lesson

Gwen:	Ok through the questions we could get the little minds working to lead us to the investigation
Researcher:	We could ask them [the children] 'How can we help Goldilocks say she is sorry, is there anything she could do?', develop their empathy maybe?

(Cycle 4, Research Lesson 1, Planning Meeting)

When asking questions and inviting children's predictions and hypotheses, teachers frequently probed the children's answers by asking 'Why?' or 'How do you know that answer is correct?' It was hoped that this would enable children to externalise their thinking and develop their critical thinking skills.

> *The children are exhibiting problem-solving skills, reasoning; they're testing their design for a boat and redesigning if the boat is not working.*
>
> (Researcher, Cycle 3, Research Lesson 2, Observation Sheet)

Teachers appreciated critical thinking as a valuable life skill to be developed in children. They believed it could be developed through STEM education. Unlike developing children's problem-solving and communication skills, teachers' PCK was challenged, as critical thinking proved difficult to realise in practical terms. A focus on questioning was our interpretation of how to develop critical thinking.

Creativity

Teachers appreciated the skills of problem-solving, communication, critical thinking and collaboration. However, children's ability to be creative was not a focus for the teachers initially. In the early stages, the STEM lessons planned did not explicitly promote children's creativity:

> *In the pilot and cycle two, I wasn't happy with the STEM lessons, when I reflected … they were not allowing the children to exercise their creativity; they were closed activities. The lessons in cycle three and cycle four were more open-ended and had much more opportunities for the children to be creative. … I don't really know how to integrate creativity into my teaching; I don't think in my education there was much space for creativity.*
>
> (Researcher, Cycle 4, Reflective Diary, 15 April 2019)

Teachers did not place an obvious focus on developing children's creativity; rather it occurred as a by-product of the STEM lessons. Gradually teachers became aware of this during the research lessons. In cycles three and four, teachers introduced more open-ended activities, thereby allowing considerable potential for the children to be more creative.

> *The children had so much potential to be creative and think outside the box in the boats they had built. I don't think my current teaching employs creative teaching approaches; my imagination isn't as good as the children.*
> (Researcher, Cycle 3, Research Lesson 2, Observation Sheet)

Teachers observed that STEM activities provided opportunities for children to showcase their creativity and to express themselves.

> *There are some children in the class who really see outside the box.*
> (Maria, Cycle 3, Research Lesson 1, Reflection Meeting)

> *Really the children were fantastic in their creativity and the way they could think in such abstract ways.*
> (Maria, Cycle 3, Research Lesson 2, Reflection Meeting)

This was also witnessed by the MKO in the final cycle:

MKO:	They made some fantastic, imaginative pieces.
Gwen:	And then [child's name] with his chair and radio.
Researcher:	And a cup-holder – he always sees outside the box.

(Cycle 4, Researcher Lesson 1, Reflection Meeting)

While teachers recognised children's creative ability, it was generally realised as a by-product. Creativity was never given the same priority as children's problem-solving, communication, critical thinking or collaboration abilities. Furthermore, teachers were unsure how to model and develop creativity through STEM lessons – again highlighting gaps in teachers' PCK and the scope for more development of children's creativity through the research.

Collaboration

All lesson plans throughout the project incorporated pair or group work (Appendix L–O1). Teachers recognised the potential of collaborative work in developing children's interpersonal skills and, in turn, life skills.

> *And I think with pair and group work, getting the children to share their thoughts with somebody and explain their thinking … so it's important to use group work for the children.*
> (Researcher, Pilot Cycle, Research Lesson 2, Reflection Meeting)

Initially, in the pilot cycle, teachers noticed that the children found collaborative work challenging due to the children's limited communication and social skills at this age:

> *In the pilot cycle, children's level of collaborative group work was low in both schools. The children found it challenging to work together and rarely listened to each other's opinions; they went off on solo runs.*
>
> (Researcher, Pilot Cycle, Reflective Diary, 3 Nov. 2018)

As a result, teachers developed their PCK and KCS, deciding to spend time building the children's communication and collaboration skills. Maria and I spent two lessons modelling good listening and speaking skills with the children, and we used these lessons as a reference point for future group work. 'Ground rules' for talk (Mercer et al. 2004) were introduced, and it was hoped that this would aid all children engaging in group work:

Maria:	So, if the group of four are predicting, and two of them say it will crack and two of them say it won't crack, how do they record that outcome?
Researcher:	So ideally, I think they should problem-solve that for themselves.

(Cycle 2, Research Lesson 1, Planning Meeting)

Some children with SEN found group work particularly challenging. Some were bypassed by their group, or they became disinterested and did not participate. One child seemed to find the unstructured nature of the STEM lesson challenging, where children moved freely around the classroom, coupled with the noise level. The child would grow increasingly frustrated and disengage from the activity:

> *[Child A] was very restless and irritated in the lesson, despite being paired with a more considerate senior infant and the teacher encouraging him to help his partner; he did not understand what was being asked of him. Group work was an issue, as were the instructions for his activity. He continually blew bubbles in the water for the duration of the experiment. After splashing his buddy, wetting his jumper and sinking his friend's boat, he was clearly frustrated.*
>
> (Researcher, Cycle 3, Research Lesson 2, Observation sheet)

Afterwards, the teachers deliberated on what had caused this behaviour, thus developing KCS:

Maria:	Maybe building the boat was too abstract for him; he didn't understand.
Researcher:	He doesn't seem to like the noise in the classroom and the way children are

	moving around to get materials, either.

(Cycle 3, Research Lesson 2, Reflection Meeting)

A gradual approach to group work was introduced for child A, beginning with concise instructions and completing the activity on their own. Introducing another peer for short tasks and activities, coupled with explicit teaching on social skills, supported the beginnings of collaborative group work. Overall, teachers felt that STEM activities were beneficial for the children with SEN, as they had the opportunity to develop their social and language skills. During cycle four, the MKO reported on the collaboration observed during the research lesson:

MKO:	[Child's name] was very engaged with everything … she was very engaged in her social group, she was happy.
Researcher:	That's great to hear. These STEM activities are probably good opportunities for social skills and turn-taking.
MKO:	Yes, there's the opportunity for them to work together.

(Cycle 4, Research Lesson 1, Reflection Meeting)

The MKO commented on the collaborative skills of all children:

> *They're so young, you know, they're fantastic at group work … how well able they are in terms of groups and how united they are. I know some of them go off on solo runs that are very normal, so the fact that they're not just bickering is so fantastic.*
>
> (MKO, Cycle 4, Research Lesson 1, Reflection Meeting)

As the year progressed and all children became accustomed to group work, it was decided to adopt a group work approach to other subject areas. Teachers found that collaborative group work had been very beneficial for the children, promoting their dialogue and enhancing their understanding.

> *The thinking that goes on during it, and even the collaboration between kids when they're working together. There's definitely no fear of it; they're just so excited to be doing it.*
>
> (Gwen, Final Interview)

While teachers always appreciated and encouraged group work, LS's focus on children's learning enabled teachers to analyse the quality of collaborative group work. Teachers felt that children required an abundance of practice in group work in order to develop the interpersonal skills required for collaborative STEM lessons to be effective. Special attention was required for some children with SEN, and their participation was much more gradual. However, through consistent exposure to group work, all children's interpersonal skills improved, as did their capacity to work collaboratively.

In the interviews, at the beginning of this research, teachers emphasised the development of 21st century skills through STEM lessons. They focused on developing children's problem solving, communication, critical thinking and collaboration skills. The iterative nature of LS helped teachers to create opportunities for children to develop these skills. After the pilot cycle, teachers developed the skills of problem solving by incorporating problems into the STEM lessons and also including wait time and thinking time. To develop children's communication skills, teachers worked through the four LS cycles to build a theme around the STEM lesson, therefore children encountered the target language and vocabulary on numerous occasions. Various LS meetings and research lessons were required for teachers to discover how children's critical thinking skills could be developed through the STEM lessons. For cycle three and four Bloom's Taxonomy was used to expand the range of questioning teachers used with children, thereby developing their critical thinking skills. Collaboration was incorporated into the four cycles and good listening and speaking skills were modelled for the children. The four LS cycles offered teachers the opportunity to expand their understanding of how children's skills could be developed through STEM.

5.6.2.2 Learner-centred methodologies

During the course of this research, participants expanded their PCK and KCT as they used numerous methodologies that they recognised as supporting children's understanding, namely active learning, triggers for learning and choice. There was a directed focus on children's thinking and possible misunderstandings they could have. Teachers also used LS meetings to rehearse or role-play exchanges they predicted might happen in the lesson. This supported teachers to access their tacit knowledge of the children and how their role might impact their learning, thus developing their KCS:

Researcher:	Okay, what kind of prompt questions?
Maria:	'What do you think would happen if I took off one leg?', and you could put

	on Goldilocks on [the chair] or ask them, 'What happens when Goldilocks sits on the chair?' She's going to fall over, she will collapse, or the chair will collapse and she will fall over, she could hurt her head. So, you know, you're eliciting information like that, and if she has a back on her chair, she has something to support her. Yes, and 'What do we call a chair that does not have a back?' A stool.
Gwen:	Or 'Could you make a chair with three legs? Could you make a couch?'

(Cycle 4, Research Lesson 1, Planning Meeting)

While teachers were mindful that lessons should have introductions that motivate their learners, LS focused teachers on types of triggers and the value of an appropriate trigger to engage children in their learning:

Maria:	But also, with inquiry-based learning, we start off with a question or a problem, and that's the productive struggle there, because the children are thinking from the get-go.
Researcher:	Yeah, for inquiry-based learning we are limiting teacher talk and increasing pupils' thinking and activity.

(Cycle 3, Research Lesson 1, Planning Meeting)

As already mentioned in section 5.4.1, literacy was incorporated in all lessons, where a story or nursery rhyme provided the stimulus or learning trigger for the STEM lessons. The teachers exhibited KCT, as they recognised the importance of context for children in early years education, selecting stimuli and learning triggers that children could identify with. These stimuli served to activate children's prior knowledge, hook their curiosity, and give them a context for the subsequent activity. The literacy stimuli for all four cycles included 'The Gingerbread Man' (Appendix N and N1), 'Humpty Dumpty' (Appendix M and M1), and 'Goldilocks and the Three Bears' (Appendix O and O1).

Teachers then created an activity around these literacy triggers, and children were faced with a problem to solve. Participants attributed children's engagement to the integration of the literacy triggers into the STEM lessons. These triggers hooked children's curiosity to solve the problem presented in the STEM lessons, and teachers felt that children made strong connections to the fairy tales:

> *You could hear a pin drop when Humpty was dropped and he cracked, and Bridget pretended to be crying – they were eating out of her hand.*
>
> (Gwen, Cycle 2, Research Lesson 2, Observation Sheet)

I loved how they responded to the story and that: 'She didn't even knock, she didn't even get permission' – it was fabulous, they were so engaged.
(MKO, Cycle 4, Research Lesson 1, Reflection Meeting)

As teachers regarded context and learning triggers in learning activities as important, they featured as norms in their pedagogical practice as the research progressed:

Maria:	Why don't we leave a gingerbread man in a container of water for the lesson, so the children can observe what happens?
Researcher:	Brilliant, that will really hook their curiosity, and they can predict beforehand.

(Cycle 3, Research Lesson 1, Planning Meeting)

Teachers also began to include an element of choice into lessons. In cycle three, research lesson 2, the teachers decided it would be more beneficial for the children to choose which materials they would use to construct the boat. Therefore, the potential for the children to be creative was greater and their agency was encouraged:

Maria:	They can explore the materials.
Researcher:	It's trial and error.
Maria:	And they are learning instead of being told; they have to decide for themselves.
Researcher:	Yes, whereas the first lesson was very structured: 'Here is your tinfoil; make your boat.'
Gwen:	There's a lot more exploring in this lesson.

(Cycle 3, Research Lesson 2, Planning Meeting)

While teachers were aware in theory that children should be placed at the centre of their learning, LS placed an emphasis on learner-centred methodologies in practice. Teachers recognised the potential of questions, triggers, problems and choice to facilitate success and challenge for all children.

5.6.2.3 Aistear and STEM

Teachers highlighted play as a fundamental learning context for young children, and it was used as such for the duration of the research. Teachers developed KCT and KCS, as it was noted in the pilot cycle how integrating STEM into Aistear could provide the opportunity to introduce children to the vocabulary and language associated with the concept (section 5.6.2.1). For the duration of the research, when planning for play, the teacher considered the STEM vocabulary to be modelled for the children.

Aistear provided an opportunity for children to test and extend their knowledge and also to practise and use scientific language. Different types of play were harnessed to explore STEM learning: the creative area, block play, junk art, water play and sand play. STEM language was taught in discrete lessons that the children had the opportunity to use in the play areas. All teachers noted the synergy between play and STEM:

> *Children loved it, it was very much geared at their level and they were learning through exploring learning through play.*
>
> (Maria, Final Interview)

In the pilot cycle, the children had exposure to water play during Aistear. This allowed them to explore forces in water, observing items that sink and float, and capacity while experimenting with a piece of hose and a water wheel. Additionally, for cycle two, in the creative area some children made pictures of Humpty Dumpty, and in the junk-art area they made containers to protect Humpty when he fell from the wall. Some children used the creative area to make blueprints to plan what they could make in the engineering or construction area. All of these activities helped children to plan their play and detect any potential pitfalls when they began constructing or engineering. The use of play enabled children to communicate creatively and also incorporated art and design into STEM:

> *Through Aistear and the junk-art area with recyclable materials, the children were motivated through playful experimentation to take risks, problem-solve and investigate. Aistear is the ideal opportunity to develop in children the dispositions to take risks in a no-pressure scenario, and this is a great foundation for STEM.*
>
> (Researcher, Cycle 3, Reflective Diary, 2 Feb. 2019)

Initially, it was decided to integrate Aistear and STEM to expose children to appropriate STEM vocabulary. However, as I observed children at play, many positive dispositions were being developed, and this aligned very naturally with STEM's 21st century skills. Children were allotted time at the beginning of Aistear to plan their play. Planning their play was an opportunity for troubleshooting and for detecting any potential pitfalls. Through play, I encouraged children to make predictions, explain their thinking and contribute to conversations using scientific and mathematical language through play. Children worked in groups during play, which aided their collaboration and communication skills. Aistear also gave children an opportunity to problem-solve, test and extend their knowledge in an informal, risk-free environment. Often, buildings were flattened, creations fell apart and disputes arose; this built on children's acceptance that mistakes happen, and it built their resilience to try again. It was found that STEM and Aistear approaches are complementary:

> *Through Aistear, the children were motivated through playful experimentation to take risks, problem-solve and investigate. Aistear is the ideal opportunity to develop in children the dispositions to take risks in a no-pressure scenario, and this is a great foundation for STEM. It's not play versus STEM: it's approaching STEM as playful STEM; it's about incorporating STEM into play.*
>
> (Researcher, Cycle 4, Reflective Diary, 5 June 2019)

Positive dispositions exhibited by the children and the targeted STEM language were noted and highlighted to the whole class during the reflection phase of Aistear. The teacher could also participate as an important role model to assess their knowledge and understanding and also to probe and elicit the children's prior knowledge. Through the LS cycles teachers discovered that play provided a very motivating context for children to explore STEM concepts and develop positive attitudes. Children could tinker, design and create, while the teacher could shape the learning by interacting and questioning. Aistear provided natural opportunities for playful experiences that enabled children to test and experiment with their thinking, and it proved highly effective in supporting children's language development.

5.7 Summary

Despite the arrival of national policy, plans and strategies, teachers were unsure of STEM education and how to implement it practically in the classroom. This research found that teachers drew upon a broad range of knowledge when designing and implementing the STEM research lessons. While LS contributed to teachers' SMK, they require additional targeted support in increasing their content knowledge, thus developing their competence and confidence in STEM education. Teachers understanding of STEM teaching developed over the LS cycles. Additionally, teachers' understanding of the interdisciplinary nature of STEM education evolved. Additionally, the findings illustrate that teachers developed PCK, KCS and KCT during the LS process. The focus on developing 21st century skills required teachers to draw on and implement new pedagogies to support the children's skills development. LS offered the teachers the opportunity to plan collaboratively and observe astutely, thus boosting the engagement of all children, especially some children with SEN.

5.8 LS and the Increased Focus on Children's Learning

LS placed a strong focus on children's experience and offered a greater understanding of the children's learning in STEM education. Teachers were surprised that their observations challenged formerly held beliefs about learners who surpassed or contested their anticipations. Catering for a wide range of abilities that presented in the classroom became a point of focus for the teachers. Teachers found that STEM education promoted engagement and participation.

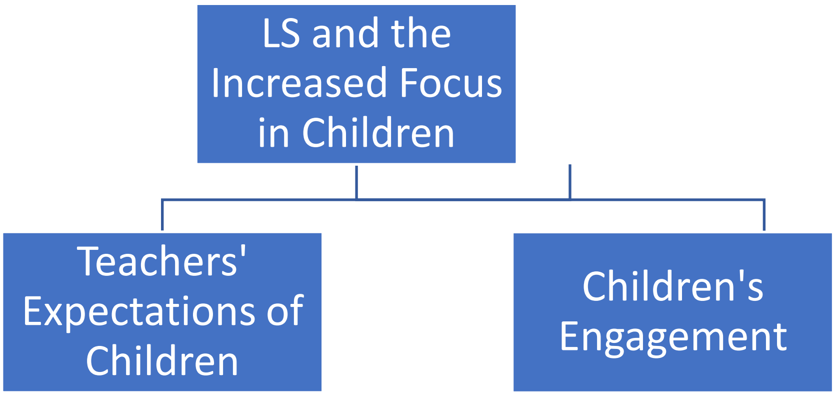

Figure 21: LS and the increased focus on the children's learning theme and subthemes

5.8.1 Teachers' expectations of children

Despite all the participants' years of experience, we were surprised by our observations of the children. Some children's level of reasoning in STEM activities either exceeded or contested our previously held expectations. Gwen found that she had underestimated children's prior knowledge:

> *I think one of the things that I picked up from the lesson was that prior knowledge of the children … that some of them are actually very au fait with that scientific knowledge … they're not afraid to impart their little bit of knowledge.*
>
> (Gwen, Pilot Cycle, Research Lesson 2, Reflection Meeting)

Teachers seemed to have a new appreciation for the potential of young children to participate in STEM activities:

Maria:	It's like that story we did, what to do with the problem, they [the children] were very insightful.
Gwen:	We were underestimating how their little minds can work – they can think outside the box at this age.

(Cycle Two, Research Lesson 1, Planning Meeting)

These insights led us to reflect on how we pitch the lessons. As STEM education was new for all teachers, we regularly questioned whether we were pitching lessons to cater for all abilites in both classes:

> *We really did underestimate their capabilities. Now there were times when we overestimated them, but that's what the lesson study was about.*
>
> (Gwen, Final Interview)

While we endeavoured to cater for children with SEN, we were also mindful of engaging children of higher ability – an area we had previously overlooked:

Researcher:	You're nearly automatically thinking about gearing your lessons towards the weaker children in your class, deliberating whether they will get it or not and then adjusting.
Gwen:	You do have to cater for the really bright sparks as well … they need to reach their potential; that is where our questioning comes out and putting that critical thinking and problem-solving back on them and getting their brains working.

(Pilot Cycle, Research Lesson 2, Reflection Meeting)

In the final interview Gwen commented on how we had underestimated some of the children and STEM's suitability for children in early years education:

> *You know, we were led to believe that, you know, science is for the upper end, and these small kids, they won't have any understanding. Oh my God, did we underestimate them. Do you remember, some of the questions and some of the ideas were fantastic? You know what, we really did underestimate their capabilities.*
>
> (Gwen, Final Interview)

The opportunity for teachers to observe is very rare in the hectic schedule of school life. LS provided teachers with a valuable opportunity to observe and reflect on children's learning. All teachers reported that their previous perspectives had been altered or tested by their observations of the children. The teachers sometimes misjudged the children's abilities, as they proved to be competent and knowledgeable STEM learners. This led teachers to pitch lessons at a more appropriate level for the children.

5.8.2 Children's engagement

LS gave the teacher participants an opportunity to focus on how children work during STEM lessons. This section discusses teachers' observations of children's engagement and the pedagogical devices they employed to optimise children's participation. Inquiry-based learning, engaging lesson triggers and adaptive teaching all merged to increase children's engagement in STEM. Through LS, teachers observed that children enjoyed the active nature of STEM, the varied investigations and the freedom to create. However, engagement proved challenging for some children with SEN, and how teachers overcame this is discussed. Generally, the children were very vocal about their enjoyment of STEM, and their reaction was very positive:

> *There was real excitement when you mentioned you were doing a STEM activity … they heard and they made a big cheer … they were really engaged.*
> (MKO, Cycle 4, Research Lesson 1, Reflection Meeting)

> *They were very engaged with the lesson, they would have loved more.*
> (Maria, Cycle 3, Research Lesson 2, Reflection Meeting)

> *STEM became a huge success in the classroom – children regarded it on par with playtime. Anytime we introduced a STEM topic in the second half of the year, the children cheered and were immediately interested. They didn't see STEM as typical work they engaged in.*
> (Researcher, Cycle 4, Reflective Diary, 8 May 2019)

Children whom teachers had perceived as difficult to engage generally were found to be extremely motivated during STEM activities:

> *Children who usually get distracted five minutes into lessons, but when they are active and constructing, they are completely absorbed in their creations.*
> (Researcher, Cycle 3, Reflective Diary, 3 Feb. 2019)

Teachers recognised that tangible learning was occurring in tandem with children's engagement:

> *You're making it very child-friendly, and the children love it. At the end of*

the day it's all about the children learning.

(Maria, Final Interview)

Although Gwen had initially found the inquiry-based approach challenging to embrace, she recognised that it encouraged children's engagement and deep learning:

> *I think their attitude changed because it was so inquiry-based, because there's so much doing and they don't realise the amount of thinking that is going on while they are doing it. Because they're active, they don't see it as academic work.*

(Gwen, Final Interview)

While all teachers noted the enthusiasm of most children during STEM activities, some children with SEN found it challenging to participate. During the pilot cycle, teachers observed all children during the research lessons. However, from cycle two onwards, teachers focused explicitly on different learning needs by utilising 'case pupils' (Dudley 2013), who characterised different attainment groups. As part of this, teachers observed children with SEN and how they accessed the knowledge and skills of the STEM lessons. In the pilot cycle, it was noted that one child with SEN habitually lost concentration if the teacher did not engage him fully, and he also found group work very difficult to participate in:

> *[Child A] was very distracted and distracted others.*

(Gwen, Pilot Cycle, Research Lesson 1, Reflection Meeting)

In contrast, another child with SEN was interested in the lesson:

> *[Child's name] was tuned in, she took charge of the recording sheet and she wasn't afraid to speak out, very well engaged.*

(Gwen, Pilot Cycle, Research Lesson 1, Reflection Meeting)

During the reflection meeting, we discussed the child's reaction to the investigation:

Gwen:	[Child's name] answered when I asked why did it float. She said it had air, so it was able to float.
Researcher:	That's fantastic – she was able to reason and explain that.

(Pilot Cycle, Research Lesson 1, Reflection Meeting)

However, the issue of engaging some children with SEN persisted. During a planning meeting for cycle four, we speculated on why these tasks were proving too challenging for children to engage in. Our opinions varied depending on the task in previous cycles, from tasks being too abstract, to the children's limited spatial awareness, to the open-ended nature of the task. We took this into account when planning the activity of building a chair in cycle four:

Researcher:	So going on from our conversation last week … I was going ask him [Child A] to make his own chair on his own. I was going to leave out the photo for him of a chair already made.
Maria:	Well, the SEN expert said set the task, give him what he needs. And don't overwhelm him, and you don't leave it very open-ended, because you're going to cause stress and anxiety … if you do limit the number of cubes and just give the exact amount that he needs, can he make the chair. … I think that would be nice to set his own individual task, because it is going to keep him focused.

(Cycle 4, Research Lesson 1, Planning Meeting)

Teachers attempted to identify tasks that would increase children's participation. Therefore, this lesson differed from the previous lessons, as child A was given different materials and a picture of the finished product; this shift in planning is evident in the Research Lessons (Appendix O and O1). Consequently, the child participated and achieved success as he constructed his chair.

> *And then you had your adjustments for one child that you were doing something different with … I thought you did that very subtly, and he was engaged too. He built the chair.*
>
> (MKO, Cycle 4, Research Lesson 1, Reflection Meeting)

For the reteach of the lesson in School 2, the same materials and picture were supplied to another child with SEN. Despite this child's Special Needs Assistant (SNA) being called away at the beginning of the lesson, he was successful in constructing his chair.

Gwen:	What about [Child 2]? I know the SNA was not with him 100% of the time, and he probably needed it; did he make the chair?
Maria:	He did, he built it himself and he found it relatively easy. I didn't think he would do it, but he did – he got his blocks and started stacking them, and off he went.
Researcher:	But needed the differentiation – the Lego wasn't working for him. So that worked very well, so we've learned that about the picture, how helpful the visual prompt is.

(Cycle 4, Research Lesson 2, Reflection Meeting)

By employing adaptive teaching, teachers differentiated the activity for some children, and this ensured that all children could participate and achieve success in the activity:

> *If you can be specific for the children who have challenges, they will then give you something back, whereas if you're more open-ended for the children who like a challenge, it's going to allow them more scope, and that can be applied across the curriculum.*
>
> (Maria, Cycle 4, Research Lesson 1, Planning Meeting)

For Gwen, reflecting on her LS experience, the importance of catering for every child's ability in the class was a prominent focus:

> *We want them to soak it up so we can give them the best possible way to teach every child that's in front of you, so that every child, whether it is the autistic child, the dyslexic child, the highly exceptional child, to get them all involved at their own level.*
>
> (Gwen, Final Interview)

The principal also noted the opportunity that LS provided for focusing on children's learning experience. She observed the context-specificity of LS as advantageous for catering for all abilities of children in the classroom:

> *I would see the children benefitting big time from it [lesson study] too, because the lesson was fairly good and structured and tight ... you're catering for the characters in your class and the abilities in your class ... their knowledge, their prior experience, so the context is huge in lesson study.*
>
> (Principal, Final Interview)

As the research progressed, teachers seemed to be most surprised by the level of engagement displayed by the children. They believed that STEM education was fundamentally motivating for children. Throughout the course of the LS cycles, most children fully embraced the hands-on, open-ended nature of STEM education. LS afforded teachers the opportunity to observe children during live lessons, and to question the understanding of case children and their ability to participate and access knowledge. Where children were not engaging, teachers participated in critical problem-solving, to find what Dudley referred to as 'pedagogic solutions' (Dudley 2008, p. 6). This research found that children with SEN can sometimes find STEM lessons over-stimulating, perhaps due to the noise level, group work or the open-ended nature of the tasks. Adaptive teaching ensured that teachers altered their approaches to aid the inclusion of children with SEN. This knowledge was applicable not just to STEM but across all subject areas, and this was a very beneficial outcome of the research study.

5.9 Summary

The focus on children's learning compelled teachers to re-examine their expectations of children and to scrutinize their engagement with STEM. LS gave teachers the rare opportunity to observe a lesson and really become attuned to children's learning. As teachers observed children, they were surprised to find that some children surpassed their expectations. Teachers realised that in pitching some lessons, they were not meeting the learning needs of all children. Teachers demonstrated their PCK and KCS as they adjusted lessons appropriately to attempt to cater for all abilities in the classroom. They recognised young children to be competent STEM learners. Overall, a strong theme emerging from the data was the children's positive experience of STEM. The children were engaged by tinkering, creating and finding solutions to the problems posed, and this proved highly motivating. Children's enthusiasm towards STEM was prevalent throughout the course of the research. This fact was reiterated in the final interviews.

5.10 Factors that Affected Teacher Engagement in LS

I have outlined the various successes of LS (see sections 5.2, 5.4, 5.6 and 5.8). This section addresses a number of factors that affected teacher engagement with LS during the research. Issues that presented challenges include teacher participation and buy-in, teachers' evolving perspectives of STEM, reluctance to being observed, time, and sustainability. How these challenges were addressed will now be outlined.

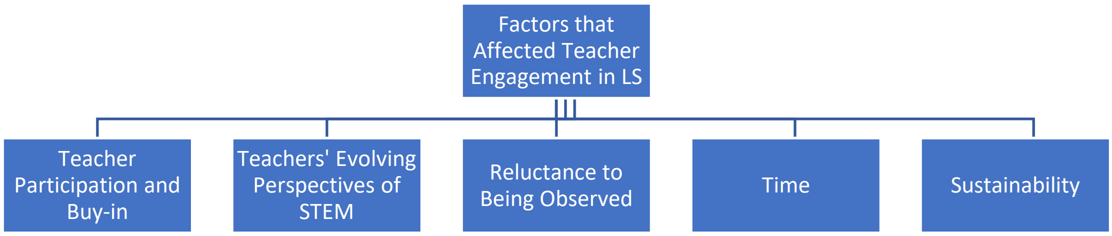

Figure 22: Factors that affected teachers' engagement in LS theme and subthemes

5.10.1 Teacher participation and buy-in

Teacher buy-in was a challenging factor when introducing the staff to LS, as LS was not well known in primary education in Ireland. The teachers had not heard of LS or partaken in any form of school-based PD. When introducing the concept of LS to the staff, I was cognisant that it would require substantial 'buy-in' from the teachers. While I had the support of the principal, and this was crucial, my colleagues were more reluctant given the practicalities. In May 2018, at a staff meeting, I introduced the teachers to LS. During this meeting the issue of the 'extra time' that LS would require emerged as an initial and persistent concern for the teachers. After the meeting, it was apparent that teacher motivation was low, and one could assume that the prospects of LS were daunting. Eventually, both teachers opted to participate, possibly levered by our relationship rather than the prospect of engaging in LS:

> *I get the feeling the teachers aren't overly enthusiastic about the prospect of LS or STEM but doing this more-so out of collegiality.*
>
> (Researcher, Pilot cycle, Reflective Diary, 29 June 2018)

As we began LS, it proved challenging to organise meeting times with the participating teachers. They were reluctant to remain in school at the end of the school day for LS meetings. This involved creating a different relationship with the SETs and forming a schedule of meetings for the pilot cycle. After that cycle I noted that teacher buy-in had been problematic, but support from leadership was imperative:

> *September was challenging, getting LS off the ground and setting up meetings with my two colleagues. There was a reluctance in giving extra time for meetings. I was frustrated initially, but it is hard for teachers to buy in to something they are so unfamiliar with; motivation is difficult. The input of the principal has been great, as she has been encouraging; unfortunately she is not one of the participants.*
>
> (Researcher, Pilot cycle, Reflective Diary, 29 Oct. 2018)

The pilot cycle was a steep learning curve for all teachers involved, for a myriad of reasons. Nationally, Irish teachers are not accustomed to school-based PD, and teachers were unfamiliar with the levels of collaboration LS required. As well as a new form of PD, teachers were also participating in an unfamiliar subject area of STEM. This added to their learning curve:

> *In hindsight, another obstacle to teachers participating in LS was the subject of STEM. None of the teachers were overly familiar with it, and perhaps when we were attempting LS for the first time, we should have attempted it in an area that teachers were familiar and confident with. Choosing the topic of STEM probably compounded teachers' apprehensiveness*.
> (Researcher, Cycle 4, Reflective Diary, 10 April 2019)

Fortunately, in cycle two, teachers were familiar with the LS cycle and what it entailed. Apprehension about LS decreased, and teachers gradually began to recognise the positive effects on their practice. An increased level of collaboration was observed, and teacher participation and engagement had grown incrementally with each cycle thereafter:

> *Teachers' reluctance seemed to decrease as they became accustomed to the new levels of collaboration and the extra time for meetings. Their participation has increased; there has been more co-operation.*
> (Researcher, Cycle 2, Reflective Diary, 11 Jan. 2019)

As I reflected at the end of the research, teacher motivation and participation at the beginning of the project might have been enhanced if the teachers had chosen the area for the focus of LS. Attempting LS in an unfamiliar subject area may have been overly arduous, in comparison to subjects with which teachers were very familiar, like numeracy and literacy. Lack of familiarity with LS and school-based PD could also explain teachers' reluctance. Teacher buy-in was initially the most challenging factor, but after the pilot cycle, teachers' engagement with LS increased with each cycle.

5.10.2 Teachers' evolving perspectives of STEM

Over the course of the four cycles of LS, teachers' attitudes towards STEM education evolved. At the outset of the research, teachers conveyed a positive outlook towards STEM and recognised the value of STEM education. During the pilot cycle, however, as the practicalities of lesson planning began, the process became mired in questions. This led to a lack of confidence. Teachers began to doubt the appropriateness of STEM for young children. However, their perspectives evolved over the course of the research.

This research took place at a time of increased national and international emphasis on STEM education. While PD sessions in STEM had become more prevalent, Maria acknowledged that most of her PD had been in 'core' subjects (maths, English and Irish), to the detriment of science:

> *No, not much in science or STEM – it wouldn't have been an area that would have particularly interested me. Because I would have maintained that if the children can read and write and do their maths and do their Irish. It was very much the core subjects with me…*
>
> (Maria, Initial Interview)

In contrast, Gwen had attended a summer course in computational thinking. This suggested that she was positively disposed towards STEM; at the very least it indicated the significance it held in the PSC. Gwen believed quite strongly that STEM was a valuable learning experience and should be integrated into primary schools:

> *It develops in the children the essential critical thinking skills to get them to think outside the box … to slow down in their approach to how they figure out the problem and maybe hoping that that would transfer to a life skill.*
>
> (Gwen, Initial Interview)

Evidently, Gwen believed that STEM had a positive effect on children's learning, and she associated STEM with developing important life skills. She saw the potential of play in providing a context for young children and teachers to engage with STEM, believing it could contribute to developing childrens' problem-solving and critical thinking skills:

> *When they are playing with a couple of blocks and you are saying, 'Right, build a house for a horse, now build a house for a pig', and you'll see the difference, I've seen it in my own house. I will ask them [her children], 'Why did you put that roof on that?' Yes, of course it should be taught at infant level; it should be coming from very, very young on. … Absolutely, because that's when they are sponges; because that's when they're not afraid.*
>
> (Gwen, Initial Interview)

The participants believed that teaching STEM to young children would provide them with an important foundation for later learning. Maria believed that STEM should be introduced in Junior Infants, as it acted as a basis for problem-solving:

> *Of course it starts the minute they start exploring; it's all about problem-solving at the end of the day, so, you know, we don't all of a sudden start problem-solving when you go into First Class.*
>
> (Maria, Initial Interview)

Like Gwen, I also believed that STEM was important for hooking children's curiosity and developing their 21st century skills:

> *Anyone who has taught this age group knows the amount of questions they ask every day – that seems to be the perfect basis of inquiry-based learning and STEM. STEM enables the children to be active in their learning and presents opportunities to utilise their skills of communication, collaboration, creativity and critical thinking.*
>
> (Researcher, Pilot Cycle, Reflective Diary, 9 Sept. 2018)

I believed that STEM education in early years laid the foundation for skills that would be beneficial for children in the future. This belief was not shared by everyone. A STEM coach, whose PD session the staff were attending, dismissed STEM for four- to seven-year-olds, advocating its use from 'First Class upwards', as 'Aistear takes care of that' in the infant classroom.

Compared with the overall feeling of positivity evident in the initial teacher interviews, a feeling of apprehension towards STEM was revealed at the outset of the research. As teachers began to partake in the pilot cycle of LS, the practicalities of planning STEM lessons became a reality. The pilot cycle provoked many questions as teachers began grappling with designing a lesson:

> *Can you teach it to 4–6-year-olds?*
>
> *Should you teach it to 4–6-year-olds?*
>
> *How will we timetable for STEM? Only science and maths are in the curriculum.*
>
> *How will we fit a STEM lesson into 30 minutes?*
>
> *What is inquiry-based learning?*
>
> *What is the level of integration of the four components of STEM?*
>
> *How can you teach engineering to infants?*
>
> *What does technology mean? We don't have enough iPads in the school*
>
> (Researcher, Pilot Cycle, Field Notes, Oct. 2018)

The prospect of introducing STEM to Junior and Senior Infants posed challenges for the teachers. As they began planning the first lesson, it was evident they lacked confidence in their competency; Gwen admitted her confidence *'would be pretty low at the moment'* (Initial Interview). In an effort to enhance the collective capacity of the staff as we grappled with questions, I organised external STEM PD sessions with different sources (section 4.5). It was hoped that this would help teachers increase their knowledge and confidence. Maria attended one external PD session and reported an increase in her confidence:

> *Well, so far, just even listening to [STEM facilitator name], you felt their approach was very much going to engage the children and that, you know, science and STEM was exciting and the children would all love it.*
>
> (Maria, Pilot Cycle, Research Lesson 1, Reflection Meeting)

Maria noted the role of the teacher as *'not being so prescriptive'*; hence, she became aware of her role as a facilitator of children's learning. This underlines the importance of the external PD in broadening the teachers' knowledge, altering mindsets and increasing confidence. Despite Maria's attendance at the first PD session, she did not attend subsequent sessions and Gwen did not attend any of the sessions. As I reflected, having both external and school-based PD was overly ambitious for teachers to 'buy into':

> *It's only after the research has concluded that I can see things from my colleagues' perspective. They were doing LS in a subject they didn't choose or didn't teach. I was expecting too much.*
>
> (Researcher, Post Research, Reflective Diary, 25 May 2019)

Teachers experienced a steep learning curve in LS and STEM during the pilot cycle. They had varying levels of interest in STEM and attached varying levels of importance to it. Importantly, all participants held a strong belief that young children should be introduced to STEM education. They believed that children would enjoy engaging with STEM and saw it as contributing to children's life skills. While teachers valued STEM, their confidence wavered when designing the first research lesson. They were apprehensive in teaching young children, and this impacted on their confidence. Teachers' lack of depth of knowledge of STEM and background knowledge of science resulted in a loss of confidence (section 5.6).

However, as teachers began to fully embrace STEM education, they observed skill and disposition development in the children (section 5.6.2). They also observed children's enthusiasm and engagement (section 5.8.2). Certainly, challenges were identified in relation to curriculum and pedagogy. But this relatively short study reported an increase in teachers' confidence and efficacy. LS offered teachers the opportunity to collaborate with their colleagues to support each other in building knowledge together, and teachers observed the effects of this on children's engagement and learning.

5.10.3 Reluctance to being observed

At the outset of the research, teachers' participation was made even more challenging by the idea of teacher observation. During the pilot cycle, they were notably resistant and uncomfortable towards being observed by their peers:

> *Teacher discomfort was evident when the prospect of teaching in School 2 arose.*
>
> (Researcher, Pilot Cycle, Reflective Diary, 15 Sept. 2018)

Although I was surprised by the stance against lesson observation, I recognised their reluctance. Acknowledging Ireland's cultural context, teachers seemed to associate teacher observation with an inspection and having their performance evaluated:

> *As teachers we are not used to being observed; in my ten years teaching I have been observed twice, once for the Dip [Diploma] and once for the Whole-School Evaluation. Teachers have negative associations with observations. Asking teachers to open up their practice for LS is intimidating.*
>
> (Researcher, Pilot Cycle, Reflective Diary, 10 Oct. 2018)

It was evident in the pilot cycle that teachers' stance against observation perhaps indicated a vulnerablility about the idea that their practice would be criticised. They associated observations negatively with whole-school evaluations and inspections. The *Cigire* ('Inspector' in Irish) was mentioned by both the principal and Gwen when discussing teachers' reluctance towards observation. The principal recognised the problematic nature of principals observing teachers and the importance of building up a relationship of trust to lessen the feelings of apprehension:

> *Observation goes on an awful lot in big schools. The principal has the freedom to go into a class and observe, but some people see it as threatening ... you have to build up that relationship of trust ... but there's a lot of resistance to it. ... I think the younger generation are more accepting ... I think it's a generational thing.*
>
> (Principal, Final Interview)

I worked towards teachers appreciating the positive aspects of observation. I tried to alleviate their stress around observation by offering to teach four lessons, and the

SETs would teach two lessons each over the course of the research (Table 4). This served to reduce the negative feelings towards teacher observation. After the pilot cycle, resistance towards observation did not arise again.

In the final interviews, teachers described the advantages and the novelty of having the opportunity to view another teacher and observe children in a 'live lesson'. They had moved from a position of feeling apprehensive to one where they felt that observation was beneficial:

> *You have somebody who was viewing the lesson as you were up there teaching, and then that's seeing it from a different angle. Because we never get the chance to do that either, sit down and admire their skill [laughs].*
> (Maria, Final Interview)

Initially teachers associated observation negatively with an inspection or an evaluation of their performance. The sustained nature of LS allowed for trust to grow, and therefore participants learned new ways of working together. The observation of live lessons proved to be an illuminating and educational experience for the participating teachers. They had the rare opportunity to observe the idiosyncrasies of classroom practice in 'real time'. The observation of lessons also aided teachers to analyse teaching practice in order to improve it. During the observations of live lessons, teachers' agency increased as we were actively involved as researchers gathering and analysing data. We then used the data to inform our future thinking and decision making in relation to our own classroom practice.

5.10.4 Time

Time given for meetings remained a source of tension for the duration of LS. In the final interviews, teachers appreciated the specific opportunity allotted for reflection, and they recognised this time as an opportunity for learning (section 5.2.3). In the initial stages, however, apportioning the time for LS meetings proved problematic. When questioned on the possible obstacles of LS in the final interviews, participants unanimously named one obstacle: time. They felt that a constraining feature of LS was the amount of time taken for meetings outside of their teaching hours. While teachers were positively disposed to LS, this was later qualified:

> *It's a busy time trying to fit it in, time-wise, and it's just like, Phew, it's over now ... the time element would be a bit of an obstacle. Definitely. Yeah, the*

time is very hard.

(Maria, Final Interview)

I suppose you have to have people on board ... It's like everything, time is critical.

(Gwen, Final Interview)

I quickly realised in the pilot cycle that the additional time required for planning and reflection meetings would be perceived as a major drawback of LS for my colleagues. I approached the principal and asked if one Croke Park (section 2.3.5) hour could be allocated for the planning sessions for the subsequent cycles. She agreed. This arrangement proved beneficial, as the teachers perceived Croke Park as mandatory, so they were not giving 'extra' time for LS meetings. Teachers believed that using more Croke Park hours for LS would be critical for teachers participating in future LS cycles:

I think this is where our Croke Park could be used very effectively and I don't think teachers would mind too much, because if they feel it's beneficial to them, it's beneficial to their teaching. I mean if you're getting great feedback from the kids, that's really a testimony of how well you're delivering the programme.

(Gwen, Final Interview)

The principal also mentioned time as an obstacle from the perspective of the school timetable and time being allocated to teach in School 2 once a term. She indicated that LS requires a school to be adaptable:

It's your flexibility, it's the timetabling of it, but at the same time it didn't impose too much. We were lucky it didn't.

(Principal, Final Interview)

A considerable amount of timetabling was required to cater for LS in a rural school: the availability of the SETs and I, the availability of School 2, organising the resources and materials, and driving to the co-operating school. Much of this depended on the approval of the principal, who was also cognisant of rearranging teachers to cover classes while the LS cohort of teachers were in School 2. However, she seemed to believe that rearranging timetables and teacher roles was worthwhile:

To me it's timetabling, but ... it worked out good. I suppose you're conscious of a teacher being there to cover the different classes, that a number of teachers are gone today so you've an extra eye to keep down on the infant room. But no, I don't see any major drawbacks to it.

(Principal, Final Interview)

Introducing LS to a rural, multi-grade school was additionally challenging. With fewer teachers, there is more responsibility on a small number to participate. If teachers had decided not to participate, LS would not have been viable. The restricted availability of teachers in a rural school meant that the LS group of participants was limited. In this research the principal had endeavoured to participate:

> *And I would have loved more involvement in it in that sense. I would love to have been able to sit in on the lesson. ... I would love to have been more involved, but it wasn't to be with arrangements and classes.*
>
> (Principal, Final Interview)

The principal felt that LS would have been more manageable in a larger school, as there would be other cohorts of classes to reteach the lesson to, as opposed to driving to another school in the rural context:

> *I thought it was harder to be going into another school rather than another class in the same school.*
>
> (Principal, Final Interview)

LS in a rural, multi-grade school depends on the enthusiasm of a small number of teachers, and on locating a school to reteach the lessons. LS also requires participants being agreeable to teach in another school. It depends on a principal seeing LS as a worthwhile investment and prepared to make arrangements to facilitate these disruptions. This makes sustainability of LS more challenging. Undoubtedly, if adopting LS in the Irish primary school system, flexibility is required of the leadership and the school team. While teachers said they highly valued the professional collaboration and reflection on practice with their peers, giving extra time for LS meetings is not without its challenges.

5.10.5 Sustainability

As stated, this was the teachers' first time participating in school-based, long-term PD in STEM. During the final interviews, all teachers were given an opportunity to reflect on their experience of LS. They were also asked whether they would like to continue LS and STEM in the next academic year. Gwen believed that LS should be a mandatory element of PD, as it ensured that theory was translated into practice:

To focus on your own teaching and professionalism, it's absolutely invaluable. I think it should be a mandatory part of your CPD to do some lesson study. Pick an area, not necessarily STEM … then when you do a course, that you don't just park it at the education centre and you go back to the way you've always been doing it. No, you've got to take it and put it into practice.

(Gwen, Final Interview)

The principal believed the introduction of LS would have lasting effects on the staff and school:

You've done us a favour in the school by introducing it [lesson study]. You feel things should happen quicker but they don't, it happens gradually, it's slow steps, and I think this was a giant leap in the life of the school.

(Principal, Final Interview)

However, when the subject of continuing LS into the next academic year was broached, Maria and the principal were uncertain. Understandably, they felt that one cycle of LS would be more sustainable for school life:

Researcher:	But I suppose if you reduced it to one lesson study cycle for the year?
Maria:	Yeah, it's very hard, it's very hard. I don't know, Bridget, I don't know.

(Final Interview)

The principal was also reluctant:

It's something we could certainly look at ourselves doing. Not so much maybe as lesson study, but that we could do more peer teaching.

(Principal, Final Interview)

The principal felt there was a future in LS as a system of teacher evaluation instead of the system of inspectors in place at the moment:

Yes, that's probably the better model to be bringing into schools rather than somebody coming in and you teach a lesson.

(Principal, Final Interview)

Similarly, Gwen felt that LS would be a superior system to the current system of inspections and evaluations. She particularly appreciated the safe space that LS offered, with a trusted colleague to work with as opposed to an external evaluation:

The benefits as well was that you had a colleague who knew the kids and they were evaluating what was going on in the classroom. It wasn't a stranger coming in like a cigire *[inspector]…*

(Gwen, Final Interview)

Teachers were very enthusiastic at the prospect of sustaining STEM education in the school. As they engaged with STEM and trialled approaches, our understanding evolved and we gained confidence. Observing the children's enthusiasm was certainly a factor in teachers' positive experience of STEM teaching. In the final interviews, the participants were asked for any advice they would give teachers beginning STEM education:

> *Give it [STEM] a try. You know, if you're not up to speed, speak to some teacher who is, and there are so many online resources; go to CPD training and you will enjoy it. And the children will enjoy it. So it's definitely worth giving it a go. ...*
>
> (Maria, Final Interview)

The principal was committed to sustaining STEM education in the school after the research project. She believed the progress made in STEM would be maintained in the future. She did concede that the change process would take time to realise and the effects of the past year would not be evident immediately:

> *I think we see the benefits of it; we may not even be here to see the benefits of it, for instance your infants coming up, Junior, Senior Infants, by the time they get to Fifth and Sixth [Class], what kind of a gang will they be in terms of their learning and their exposure the STEM? So I would love to see the whole thing of STEM in the school in a few years' time, what momentum it has. And also what's been happening outside in the big world. What's the NCCA going to do? Where's the curriculum going to go? How is that going to change? So I think we're only at the early stages of it and we're at the cusp. It's very exciting. ... Going forward next year, how do we keep that momentum and that interest, we've done loads of CPD and bought loads of equipment and certainly we need to keep the momentum up.*
>
> (Principal, Final Interview)

In this research, LS was successful in strengthening professional collaboration, impacting classroom practice, developing teacher knowledge and increasing the focus on children's learning experience. The principal praised LS for benefiting in-class support, supporting the school vision for STEM, improved collaboration and raising the quality of teaching (section 5.2). Maria and Gwen believed LS was helpful in breaking down teacher isolation, they enjoyed the collaboration and the opportunities to reflect after a live lesson (section 5.2). As already mentioned, Gwen stated that LS 'should be a mandatory part of your CPD' (section 5.10.5). However, it should be noted that Gwen was transferring schools and I intended to job-share for the coming school year. So despite the principal and teachers commending LS as supporting collaboration, opportunities for reflection and breaking down isolation, the change in staff made ongoing sustainability challenging.

> *With you [the researcher] going job-sharing and Gwen leaving it could be difficult to run it with all the changes in staff*
>
> (Principal, Incidental conversation)

Initially, upon hearing that teachers were reluctant for LS to be continued, I was discouraged:

> *Hearing teachers' reluctance to continue LS is disappointing. However, I then reflected that LS had introduced STEM to the teachers and the children, and in this way LS had been somewhat successful. In hindsight, four cycles in the first year was far too hectic. I should have taken it much more slowly, maybe one cycle for the year. I would have also focused on an area of relevance to the SETs, maybe numeracy or literacy, or better yet, they pick the focus. However, if we are picking a problem of practice next year, I can only hope that they might do it through lesson study.*
>
> (Researcher, Post-Research, Reflective Diary, 12 May 2019)

LS required significant teacher input, time and supportive leadership. Possible reasons for teachers being disinclined to continue with LS were the upcoming change in staff. This is a challenge of sustaining LS in a rural school with limited numbers of teachers. Also, teachers were not accustomed to PD that continues from year to year, occurs in their school, without the presence of an external facilitator. Instead they believed that LS was finished and they expected to move on to the next PD experience. A cultural shift is required for teachers to change their perspective of what constitutes PD.

STEM education was introduced to the school through LS, and by the end of the research, STEM held a solid foundation in the school. Understandably, the LS process aided teachers in implementing STEM, and STEM was a strong driver for the use of LS. STEM was a new approach to science and maths which had not been attempted in the school. LS provided a safety net for the teachers as they tackled new methodologies and activities of which they had no prior experience. Overall, teachers were very satisfied with the outcomes of LS and found the experience to be beneficial in improving their practice and their learning. LS had therefore served its purpose and was perhaps deemed redundant by the teachers, as STEM had become a mainstay.

5.11 Summary

This section outlined the factors that affected teacher participation as LS was introduced, including teacher buy-in, evolving perspectives of STEM education, reluctance to being observed, lack of time and sustainability. Teachers were initially reluctant to participate, as they were completely unfamiliar with LS. Lesson observations posed a problem, as teachers negatively associated observations with evaluations. Gradually, through discussion and exposure, teachers began to recognise the benefits of observations. After the pilot cycle, teachers were decidedly more comfortable and engaged. An enduring challenge throughout the research was the additional time required for engagement. Using Croke Park (section 2.3.5) hours alleviated the demand on the teachers, giving 'extra' time. LS in a rural school included extra logistical challenges which required enthusiastic, flexible teachers. Supportive leadership was central to teacher participation and to facilitating the adjustment of school timetables. Teachers' responses to sustaining STEM were encouraging, but the outlook for sustaining LS looked dubious. A more incremental introduction of LS to schools is required.

5.12 Conclusion

The most pervasive theme revealed by the data was that the teachers highly valued the professional collaboration inherent in LS. The research found that LS built a stronger community of teachers, broke down professional isolation and created opportunities for learning. As STEM was a new approach to science and maths which had not been attempted in the school, LS supported teachers as they tackled new methodologies and activities of which they had no prior experience. Overall, teachers were very satisfied with the outcomes of LS and found the experience to be beneficial in terms of changes to their practice and their learning. Inquiry-based learning, although initially challenging, was introduced and gradually became a whole-school practice. Teachers also began to take pedagogic risks in their teaching. However, gaps in teachers' knowledge were evident in this research. Their confidence was affected by their content knowledge of STEM, and their professional knowledge base was tested on numerous occasions during the research study. Changes to teachers' knowledge and efficacy were evident as a result of their participation in LS. The process of LS led to the development of SMK and PCK as teachers navigated a path through STEM education. Teachers found that engineering naturally integrated mathematical and scientific aspects much more effectively than science. Through STEM activities, teachers observed key skills developed in children, including 21st century skills and positive learning dispositions. LS also increased teachers' focus on children's learning experience. Teachers found that they had sometimes underestimated young children and their ability to participate in STEM. The children's engagement and enthusiasm towards STEM were certainly a factor in teachers' positive experience of STEM teaching. Issues emerged with teacher buy-in, confusion around STEM, reluctance to being observed, time and sustainability. STEM and LS were initially very unfamiliar to the teachers, and this made buy-in daunting for them. While receptivity was evident for STEM, challenges were revealed as teachers began planning during the pilot cycle. Time for LS was initially difficult to carve out, but teachers welcomed the use of Croke Park (section 2.3.5) hours for this purpose. Teachers were not overly enthusiastic at the prospect of LS being used for the following school year, perhaps due to the hectic four cycles they had experienced, or their assumptions about the purpose of LS. All teachers welcomed sustaining STEM education. Teachers valued STEM, deemed it worthwhile and believed it could enrich children's learning.

Chapter 6: Discussion of Findings

The central purpose of this study was to capture teachers' perspectives of LS as a vehicle of collaborative PD in STEM education. In an attempt to answer that question, four cycles of LS were conducted in two primary schools over an eight-month period. STEM education with Junior and Senior Infants served as the focus of LS. The primary research question guiding this study was:

What are teachers' understandings of lesson study as a professional development tool?

The embedded questions associated with the overarching question are:

- In what ways does teachers' practice in STEM change (if at all) as a result of engaging with LS?
- What are teachers' learning experiences of STEM education?
- How can lesson study enhance the professional agency of teachers?
- What are the cultural adjustments made by teachers when implementing lesson study?

In this chapter the findings of the research are discussed against the backdrop of the literature. The discussion of findings relates to the five themes outlined in the findings chapter:

- LS enabled greater collaboration amongst participating teachers
- LS and the impact on teacher practice
- LS and the development of teacher learning
- LS and the increased focus on children's learning
- Factors that affected teachers' engagement in LS

6.1 LS Enabled Greater Collaboration Amongst Participating Teachers

6.1.1 Introduction

LS supported the development of a culture of collaboration by facilitating a common vision across the school. Although only three teachers formed the LS group, the effects of LS impacted the whole school community. As a result of LS, STEM education became the focus of School Self-Evaluation (section 4.5). Discussions that occurred during the LS meetings often cropped up during Croke Park (section 2.3.5) hours or staff meetings. Conversations on teachers' evolving understanding of STEM, inquiry-based learning and gaps in content knowledge opened up dialogue on practice. The long-term aims of LS complemented the aims of School Self-Evaluation, and teachers began to think of the broader purpose of education, not the narrow aims of one lesson; this aligns with research by McLaughlin and Talbert (2006). LS served as the vehicle to strengthen the focus on children's learning and how teachers across the school can improve. This reaffirmed teachers' professional purpose and is reflected in the findings from Lieberman (2009).

6.1.2 Teachers' professional capital

This research supports findings from Cajkler et al. (2014) and Dudley (2013) that LS is a vehicle for collaboration to enhance professional capital (Hargreaves and Fullan 2012). Teachers developed their professional capital through the actions they took throughout the study. In this research there were indications of growth in individual capacity as LS introduced teachers to new routines and provided a scaffold to support teachers with changes to their practice. Social capital existed in the relationships between the participants, as teachers were more enthusiastic to collaborate with colleagues and showed greater confidence in their collective capacity. They began to see the potential of their colleagues and the opportunities for learning collectively. The research also found that the principals' perception of staff capacity improved. Teachers found that their misconceptions about aspects of STEM could be remedied through collaboration and dialogue; this is similar to findings from Bagiati and Evangelou (2015). Dudley (2013) believes that LS unites its participants in a learning community as they collaborate to improve children's learning, thus building social capital, and this is reflected in the current research.

In this research, decisional capital aided teachers as they negotiated their understanding of how STEM was realised in the infant classroom. It was also evident in the changes to their pedagogical practices and in their problem-solving approach as they designed STEM lessons. Teachers questioned approaches and unreservedly shared ideas and opinions on lesson content. LS gave teachers an opportunity to collaborate on problems of practice as they implemented STEM education for the first time, and it enabled them to find creative solutions; this echoes the work of Cajkler et al. (2015). LS therefore strengthened the collective growth of the participating teachers through decision-making, sharing knowledge and practice and sharing responsibility, while focusing on children's learning.

6.1.3 LS and the enhancement of a collaborative culture

Findings from this research indicate that professional isolation was apparent before the research began. This is similar to findings in previous Irish research by Hogan et al. (2007), Smith (2014), O'Donovan (2015) and Murray (2020). Teachers in the present study embraced the collaborative aspect of LS immediately. Professional collaboration was the most powerful outcome arising from the teachers' participation in LS, and opportunities for collaboration were welcomed by teachers. Teachers felt that professional isolation was reduced through their participation in LS; this correlates with findings from Smith (2014). Interestingly, however, this is in contrast to findings from Brosnan (2014), who found that teachers did not seem ready for the level of collaboration that LS required. Years later she found there was an appetite for collaboration and called this 'a progressive gain' (2014, p. 246) of introducing LS. This suggests that the various Teaching Council initiatives promoting professional collaboration (section 1.4) may be encouraging teachers to collaborate with other professionals and that this is a prospect they view positively.

In the present study, LS provided a framework for teacher collaboration in the school, an area highlighted by Cajkler et al. (2014). Being part of the LS team had a unifying effect on the participants, as they felt part of a joint, collaborative venture. LS strengthened the relationships between the participants and gave them the opportunity to experience the affirmation of their colleagues, thus reflecting the findings of Cajkler et al. (2014) and Smith (2014). Time was required for trust to strengthen amongst participants during LS. The importance of the creation of trust as the foundation of teamwork is echoed by Lencioni (2002) (Figure 5). The reluctance of participants towards being observed by their peers at the beginning of the research indicates that trust was low. Initially, trust was built through the creation of long term aims for LS, this established a common purpose amongst the participants. Additionally, trust was created by designing lessons collaboratively, this ensured that power was shared and the voice and input of the participants was respected. As lesson observation was an area initially resisted, trust was reinforced as participants engaged with this process, eventually seeing it as beneficial to their practice. Trust was also strengthened by participants engaging in dialogue around problems of practice that occurred throughout the earlier cycles. A culture of openness was suggested as participants discovered gaps in their knowledge and expressed vulnerabilities in the area of inquiry-based teaching. Evidence of the principals' trust is apparent in the forming of an environment where agency and support were given to participants in this study. LS provided an opportunity for participants to share their ideas, knowledge, opinions, concerns and reflections. All of these elements combined as trust was built and strengthened over the course of the research.

Throughout this study the sharing of power was negotiated, and respectful relationships were nurtured, reflecting the approach taken by Pérez et al. (2010). The sustained nature of LS allowed for trust to grow, and therefore participants became more open to taking pedagogic risks and making shifts in their practice. A conclusion that can be discussed is the time taken for trust to build during collaborative PD. This has implications for the PDST, DES, the Teaching Council and also schools and teachers.

6.1.4 LS and leadership

Supportive leadership was crucial to the adoption of LS by my colleagues and this finding is reflected in the literature (Akiba and Wilkinson 2016; Ní Shúilleabháin 2016; Takahashi and McDougal 2016; Schipper et al. 2017). Distributed leadership is highlighted as particularly conducive to LS (Perry and Lewis 2009). This research indicates that the principal's beliefs and attitudes held a considerable influence on introducing LS to the school. This is supported by research that confirms principals' pivotal position in affecting the quality of teacher PD undertaken by staff (Banks and Smyth 2011). While the principal did not become directly involved in this research, its success was dependent on her willing and flexible leadership. The principal supported teachers to take a risk with LS, inquiry-based learning and STEM. Sugrue (2004) encourages principals to adopt this practice, as it creates conditions to take risks in the interests of new learning and identity formation.

6.1.5 Summary

This research developed teachers' professional capital (Hargreaves and Fullan 2012) as they conducted LS. Human capital was developed by designing and delivering STEM lessons, and social capital was built upon teachers co-operating and developing trust. Decisional capital was developed as the teachers exercised agency and decision-making on how we should drive STEM education. A negotiated learning environment was evident at all times during the LS meetings, as teachers were active learners, evaluating content and deciding how to facilitate learning. Empowering leadership to nurture the collective capacity of colleagues and the distribution of leadership also provided a foundation upon which LS grew. The collaboration experienced through LS will hopefully empower teachers to recognise the possibilities that collaboration can hold for improving their PD and their autonomy.

6.2 LS and the Impact on Teachers' Practice

6.2.1 Introduction

All teachers believed that LS had positively impacted their practice. Analysis of the findings reveal that the recurring planning, teaching, observing and analysing of children's learning caused teachers to reflect on their understanding of effective teaching practices. Through their collaboration with colleagues, teachers had the opportunity to build knowledge and introduce new practices related to teaching and learning, and this is reflected in the research (Dudley 2013; Takahashi 2014; Ni Shúilleabháin 2016). While teachers were aware of the benefits of discovery learning, child-centred learning and the teacher as facilitator in theory, LS led to the implementation of these approaches in practice. This research supports the view that LS motivated teachers to develop practice (Dudley 2013) and enabled them to experiment and move away from teacher-led approaches (Cajkler et al. 2014). Teachers began to view their teaching as experiential and to feel more confident to take risks in their teaching by adopting the inquiry-based approach to STEM lessons.

6.2.2 The role of the teacher and inquiry-based learning

In the pilot cycle the style of lesson was teacher- led. Through the SFI course participants were exposed to inquiry- based learning. Participants agreed that from cycle two to four the Framework for Inquiry lesson template would be used for the STEM lessons. Consequently, this bridged the theory-practice divide, as teachers learned about inquiry-based learning and LS provided participants with the opportunity to put this into practice during the cycles. In doing so, participants gradually moved away from a teacher- led practice to an inquiry- based approach. As explored in Chapter 3 (section 3.2.4.1), previous research revealed various challenges associated with inquiry-based learning and science at primary level (Varley et al. 2008b; Murphy et al. 2012; Roycroft 2018). It was also found in this research that inquiry-based learning remains elusive for teachers and that issues linger with its implementation. Evidence from this study reveals confusion amongst teachers over the meaning and implementation of inquiry-based learning, with teachers showing an underdeveloped understanding, thus reflecting previous research (Smith 2014; Dobber et al. 2017; Brown and Bogiages 2019). Teachers articulated inquiry-based learning poorly. They likened inquiry-based learning to discovery learning and failed to mention other characteristics of inquiry-based learning, including the children communicating their ideas and making connections between STEM and their real-life learning. In their research Brown and Bogiages (2019) found that guidance on inquiry-based learning was vague and poorly communicated to teachers. Similarly, the Irish Primary Science Curriculum (DES 1999a) does not specifically refer to inquiry-based learning methodologies.

The challenge for participant's practice as they moved away from teacher-led practice to a more facilitative role is evident through the cycles of LS. Teachers seemed to fear the loss of control in the classroom. This echoes findings from Lesseig et al. (2016) and Margot and Kettler (2019) in the STEM classroom. Discomfort with facilitation may have arisen from poor confidence in SMK. This reflects findings by Nadelson et al. (2009), in that sufficient SCK, support and feedback are required to enable teachers to change their practice and adopt an inquiry-based approach. This research found that teachers may also be reluctant to facilitate lessons because they do not fully understand the theory behind inquiry-based learning. This reflects research by Murphy et al. (2015) and Roycroft (2018), who found that Irish teachers are not familiar with inquiry-based learning, so they require knowledge and skills to support them in understanding the inquiry-based approach, why it is important and how to integrate this approach into their existing practice.

LS offered participants the opportunity to familiarise themselves with inquiry-based learning through its iterative process. Through cycles two to four participants could experiment and trial this approach. Participants collaboratively designed STEM lessons using the Framework for Inquiry lesson template. This collaboration scaffolded participant's learning about this approach. LS allowed participants multiple opportunities to teach and to observe their colleagues using the inquiry-based approach. Participants in this study recognised many of the benefits of inquiry-based teacher practices as outlined in Chapter 3 (section 3.2.4.1), including increasing children's curiosity and motivation, increasing opportunities for skill development and eliciting children's predictions and the testing of those predictions. Teachers were encouraged by the positive effects that the inquiry-based approach had on the children's learning and the development of productive learning dispositions. These conclusions on the benefits of inquiry-based learning align closely with claims made by Rocard et al. (2007), as it was found that the inquiry-based approach is easily adaptable to early years education, supports children in the development of skills such as problem-solving, critical thinking, collaborative learning and verbal expression, and engaged children of lower to higher abilities. This research indicates that LS can be successful in introducing teachers to alternative practices, namely inquiry-based education.

Guskey (2002) maintains that traditional forms of PD prove ineffective in bringing about sustainable change in classroom practice. In the present study, LS supported the teachers in the reimaging of their beliefs and in developing a deeper understanding of their practice. LS also enabled teachers to alter their practice to encompass inquiry- based learning and to pass on this new knowledge to colleagues, which helped cement their practice. These are the aspects of LS that make it a non-'traditional' form of PD, thus aligning with the point made by Guskey (2002).

6.2.3 Teacher agency

Teacher agency was promoted by LS, as each teacher made decisions to adjust their teaching and working environment when teaching STEM classes. Teachers evolved from a place of feeling uncertain and doubtful about STEM to a place of enthusiasm and engagement. Teacher agency was promoted through LS as it provided teachers with a wider variety of professional decision-making skills in their planning, assessment, integration and teaching of STEM. LS and PAR supported the teachers in reflecting on their practice, engaging in professional collaboration, experimenting with pedagogy and observing children's learning (Lieberman 2009; Dudley 2013).

LS introduced the teachers to norms of openness, collegiality and experimentation. This is supported by findings from Lieberman (2009), where instead of occupying a passive stance of technicians, participating teachers became critical evaluators of curricular materials. Despite Irish research (Dunphy et al. 2009; Shiel et al. 2011; Dooley et al. 2014; Treacy 2017) suggesting heavy reliance on textbooks and worksheets, none of the STEM lessons were acquired from a textbook or other ready-made resources. Teachers began to see themselves as 'craftspeople' (Lieberman 2009, p. 97) as they merged their prior experience with new theory in the context of the values and beliefs they used to guide their practice. As teachers were participating in PD that responded directly to their professional needs, they assumed more ownership and a great responsibility for their learning. Teachers assumed a sense of professionalism, which was a vehicle to support teacher agency.

As the research concluded, teachers' confidence and self-efficacy in their teaching of STEM education was enhanced through their participation in PD, thus echoing the findings of Lesseig et al. (2016) and Nadelson et al. (2013). Teachers were more positively disposed towards teaching STEM in the future. LS positively impacted teachers' beliefs about their ability to teach STEM lessons to young children. LS supported dialogue and trust amongst the teachers and was a restructuring of PD towards a more democratic, bottom-up sharing of knowledge and supportive pedagogies.

6.2.4 Summary

In the final interviews, teachers highlighted characteristics of LS that they identified as advantageous: collaboration with colleagues, active participation, reflective practice and the situated nature of LS. Generally, these reflect the characteristics of effective PD (Guskey 2003; Desimone 2009; Loucks-Horsley et al., 2009). LS demonstrates that PD that is situated in context, sustained and collaborative can promote positive changes in teachers' classroom practice. Teachers discovered that 'LS is not about discovering the one right way to teach a lesson, but about building knowledge of many teaching strategies and habits of observation, inquiry, and analysis of practice' (Lewis and Hurd 2011, p. 24). LS provided teachers with support to take pedagogic risks and trial new teaching approaches. However, teachers need time to engage with the meaning of inquiry-based education and their role as teacher.

6.3 LS and the Development of Teacher Learning

6.3.1 Introduction

This research indicates that LS enabled the theory-practice gap to be bridged. Prior to this study, STEM was a new approach for all teachers. Therefore, it was the teachers' responsibility to interpret their meaning of STEM and how it could be implemented practically. Challenges were revealed as teachers began planning during the pilot cycle. There were areas encountered that required several cycles of LS for teachers to understand, problem-solve and finally implement. However, LS contributed to teachers' SMK and PCK. Through observation in LS, teachers gained a better understanding of children's needs and how to differentiate their practice to meet the various needs of all children. According to Dudley (2013), this sharper focus leads to teachers seeing the children 'with new eyes' (p. 119). Teachers improved their practice by pitching lessons more accurately to children's ability and increasing the participation of children with SEN.

6.3.2 Subject-matter knowledge

Teachers' professional knowledge base of science and STEM was tested numerous times during the course of the research. This finding resonates with Irish literature, as it is suggested that many primary teachers 'have insufficient content and pedagogical knowledge of science' (Murphy and Smith 2012, p. 77). Teachers' discomfort with teaching certain STEM topics to younger children was also evident. Teachers noted that some STEM concepts were too complex and theoretical for young children to understand (section 5.6.1). Similarly, Park et al. (2017) found that a challenge mentioned by early childhood teachers was the matching of STEM concepts to children's developmental age. The present research also suggests that teachers' lack of content knowledge affected their confidence in answering questions that children may pose. This finding is in line with Eivers and Clerkin (2013), who found that Irish primary teachers' confidence was particularly low in answering pupils' questions and providing appropriately challenging activities for high-achieving pupils in their class. This reinforces the point that teachers must be responsive to children's questions and enquiries while also giving feedback to children's explanations (Van der Graaf 2019). Thus, echoing Bell (2016), robust, comprehensive content knowledge in all STEM disciplines is required, as teachers' opinions and knowledge of STEM are fundamentally tied to the effectiveness of their STEM practice in the classroom.

6.3.3 STEM integration

Teachers struggled with the transdisciplinary nature of STEM. While teachers were aware of STEM integration and had learned about it on the SFI course, putting it into practice proved challenging. The level of integration of science, technology, engineering and maths was a concern at the outset of the research which persisted for the pilot cycle and cycle two. Teachers had difficulty integrating STEM into the existing curriculum, as engineering and technology are not in the Irish curriculum. Therefore, teachers created their own objectives for technology and engineering education in the STEM lessons. Teachers were also unsure how to integrate all four disciplines into one STEM lesson, and this is a recurrent challenge in the literature (Lesseig et al. 2016; Lawrenz et al. 2017; Herro and Quigley 2017; English 2017; Stohlmann 2018; Beswick and Fraser 2019). Further inconsistency and confusion are evident in the many definitions of STEM education (Brown 2012; Tippett and Milford 2017; Akerson et al. 2018). As discussed in Chapter 3 (section 3.3.1), science was afforded a prominent status in our research, which is reflected across many literature sources (Bybee 2010; Bell 2016; Lindeman and Anderson 2015; Rosicka 2016; McGarr and Lynch 2017). Initially, it was our belief that science underpinned STEM, and this aligns with research by Akerson et al. (2018).

LS supported teachers in bridging the divide between theory and practice in relation to integrated STEM. While teachers were aware that science, technology, engineering and maths were to be integrated this proved difficult to achieve in practice. Through the recurrent LS cycles teachers gained a better understanding of how to plan and teach integrated STEM lessons. Despite their original belief of science being the keystone of STEM, the role of engineering gradually became apparent. The important role played by engineering in integrating science, technology and maths has been highlighted in the literature (Sanders 2009; Moore et al. 2014; Bagiati and Evangelou 2015; Liston 2018; Margot and Kettler 2019), and findings from this study reveal that engineering was a linchpin that successfully drew the other disciplines together in a more meaningful manner. Teachers engaged the children in scientific, mathematical and engineering practices through a simplified version of the Engineering Design Process. This is similar to Lesseig et al. (2016), as they also found that teachers had problems with STEM integration, but focusing on the Engineering Design Process enabled them to envision what STEM integration could look like. In the current research, engineering became more meaningful to teachers as they used it as a basis for their investigation.

6.3.4 Pedagogical content knowledge

This research suggests that LS facilitated teachers' development of PCK in a time of curricular change. LS supported teachers in understanding new pedagogical approaches and made new content accessible. Collaborative planning and reflection aided teachers in solving problems and finding new levels of understanding when grappling with STEM, thus aligning with research by Lewis and Takahashi (1998), Murata (2011), Takahashi and McDougal (2014), Ní Shúilleabháin and Seery (2018) and Vermunt et al. (2019). As we began to design lessons, our definition of STEM was evolving. While teachers had experience of engaging with science and maths curricula, engineering and technology seemed elusive disciplines to teach in the infant classroom. Teachers struggled to envisage how engineering could be implemented in a classroom with four to seven-year-olds, a finding reflected in the literature (Bagiati et al. 2010; Dare et al. 2014; Redman 2017). The current research found that teachers lacked confidence in implementing engineering at primary level. Similarly, Redman (2017) found that teachers' lack of confidence in the implementation of engineering resulted in a poor sense of self-efficacy and a sense of disempowerment. This research suggests that technology also requires further defining, as initially we associated this term solely with digital tools; this supports research by Sanders (2009) and Sharapan (2012). After the pilot cycle, we broadened our definition of technology to include any tools the children were using in their STEM activity, thus aligning with Sharapan's (2012) definition.

6.3.5 21st century skills

LS enabled the opportunity to focus on the goals for children's learning. In the initial interviews when participants were questioned on the importance of STEM and throughout the meetings during the pilot cycle children's skill development was mentioned frequently (section 5.6.2.1). This focus also emerged through dialogue surrounding the long-term aims for LS. In this discussion we pinpointed exactly what skills we wanted children to develop over the eight-month period of the research. While teachers did not explicitly use the term 21st century skills, their responses reflected skills which would allow children to problem-solve, develop resilience in the face of failure, explain their thinking using appropriate scientific and mathematical terms, think critically and work in groups. All participants indicated problem-solving skills should be developed, Gwen emphasised children's critical thinking skills, I felt children's ability to collaborate should be a focus and Maria highlighted the importance of children's language skills. Teachers recognised these skills as necessary life skills. These four areas became a focus for development in the research lessons from cycle two to four. Teacher's commitment to developing children's skill development was also evident in the observation checklist (Appendix P) and across the school as it was a target for School Self-Evaluation (section 4.5).

Teachers were quite attuned to developing children's 21st century skills, a finding that contrasts with research by Varley et al. (2008a) and Murphy et al. (2012). Varley et al. (2008a) stated that opportunities for children's skill development was a concern. Both studies suggest that teachers may lack confidence in how to develop children's skills. The most common skills reported were observation and using equipment (Varley et al. 2008a). A decade later, the current research suggests that Irish teachers recognise and value the development of 21st century skills in children, and they featured prominently in the STEM lessons. While teachers recognised the value of skill development through STEM they initially struggled to envisage how some of the skills could be developed in practice. Similar to findings by Varley et al. (2008a, 2008b) and Murphy et al. (2012), teachers sometimes lacked confidence in how to develop some skills through STEM. The LS process facilitated teachers in finding different strategies to support the progression of these skills throughout the cycles. However, there is scope to develop more problematic and challenging tasks and more in-depth involvement of the teacher in facilitating scientific discussion.

Promoting children's critical and creative thinking proved most problematic for teachers.

6.3.5.1 Creative thinking and critical thinking

While teachers felt that STEM education exercised and developed children's higher-order thinking skills, developing children's creativity was not an overt focus during the lessons. This was similar to findings by Cremin et al. (2015). Teachers ranked critical thinking, problem-solving, communication and collaboration as more worthwhile than creativity skills. Teachers seemed unsure of how to foster creativity, echoing Leahy's (2012) study. The opposite was the case for critical thinking. From the initial stages of the research, teachers were very positive towards adopting critical thinking skills in the children. Teachers agreed on the value of children developing their ability to reason and evaluate their thinking, a finding also evident in Portelli's (1994) research. However, in practice, teachers found the concept ambiguous and difficult to incorporate into their teaching. They eventually linked the inquiry-based approach as a means to encourage children's critical thinking.

6.3.5.2 Problem-solving

Teachers were very aware of the importance of developing the children's problem-solving skills, as this skill had caused frequent low scoring in standardised mathematical assessments across classes in previous years. This is reflected nationwide, as problem-solving continues to be an area in which children in Ireland underperform (Dooley et al. 2014). This research found that well-meaning teachers observed children grow frustrated with a STEM problem and intervened too quickly to simplify it; this aligns with research by Schoenfeld (2017). Our conception of the teacher as facilitator was still evolving, and we realised that by stepping in too early, we were impeding meaningful learning (Schoenfeld 2017). Teachers recognised that a productive struggle allowed children to search for answers, allowed their curiosity to be elicited and their sense-making skills to be developed. Teachers appreciated that the struggle inherent in STEM activities was important to develop resilience in the children. They believed it was important for children to see mistakes as part of daily life, reflecting the findings of Rosicka (2016) and Wang et al. (2011).

In their observations, teachers noticed that succeeding in the STEM tasks also increased the children's confidence in their own abilities. Through trialling the inquiry-based approach, teachers found that children were motivated when they were presented with a problem or question. This research suggests that children were naturally and positively disposed to problem-solving, thus echoing the findings of Carpenter et al. (1993), Lind (1999) and Boaler (2009). Teachers found that STEM set a context which encouraged meaningful problem-solving as an approach to inquiry-based learning instead of children practising acquired skills and completing repetitive written problems from a maths book; this finding supports Lind (1999).

6.3.5.3 Group work

This research had similar findings to Varley et al. (2008a) and Murphy et al. (2012), as group work was a frequent feature of all lessons and children were positively disposed to collaborating with their peers. Teachers believed that children required lots of practice participating in group work to be effective in their STEM learning. This is supported by findings from Herro and Quigley (2017) in research in middle school. Like in Mercer et al. (2004) and Master et al. (2017), teachers found that group work developed children's interpersonal skills. Teachers also found that children's engagement was boosted by being a member of a group, and their self-efficacy increased. Over time, collaborative work became a routine part of practice. This is in contrast to research by Smyth (2018), who reported that individual work was the most common teaching method, with low levels of group work being implemented in infant classrooms. However, in this research, teachers became confident with collaborative group work, and it was embedded across all subjects.

6.3.5.4 Communication

Teachers believed that language played a critical role in developing young children's STEM thinking. They recognised that children should have the ability to vocalise their thinking as an important aspect to develop through STEM education. Creating opportunities for children to practise the language of STEM and promoting STEM through play were identified as key pedagogical considerations in our conception of early years education. Teachers found that children were eager to share their ideas in STEM and used appropriate vocabulary; this is in line with research by Tippett and Milford (2017).

6.3.6 Aistear and STEM

The teachers acquired PCK, as they embraced a thematic approach to encompass STEM, play and other subject areas. There was general consensus among the participants that play and STEM align naturally. The participants found that play-based learning was a very effective pedagogy for young children in STEM, thus echoing the literature (Bennett et al. 1997; Dockett and Fleer 1999; NCCA 2009; McClure et al. 2017; Tippett and Milford 2017; Simoncini and Lasen 2018). Teachers observed that Aistear supported STEM learning, in particular promoting targeted language development and positive learning dispositions.

The current study found that Aistear (NCCA 2009) and thematic planning enabled children to encounter a theme through various experiences and activities, thereby increasing their familiarity with the target STEM language. It has also been found that the teacher has a key role in teacher–child interactions in children's vocabulary development (Vygotsky 1978; NCCA 2009). In this research, teachers found that well-organised play was an appropriate context to develop positive learning dispositions amongst children (NCCA 2009). This suggests the importance of early STEM exposure for young children to build positive dispositions (Park et al. 2017). Teachers recognised that children developed 21st century skills naturally through play, supporting findings by Chesloff (2013). Children developed their interpersonal skills, collaborated with their peers in their Aistear group, solved problems meaningful to their play, designed and redesigned while learning to think critically. Children could tinker, design and create, while the teacher could shape the learning by interacting and questioning. This research found that there are many opportunities to align STEM and play, as children are encouraged to explore the world around them (Tippett and Milford 2017).

6.3.7 Children with SEN and STEM

LS made teachers more aware of the complex needs of different children. LS gave teachers the opportunity to observe children with SEN engaging with challenging activities. While most children were very engaged by STEM, some children with SEN found the active, busy nature of the STEM lessons challenging. Prior research (Herro and Quigley 2017; Park et al. 2017) has noted teachers' concern about STEM meeting students' diverse needs and cognitive abilities. During reflection meetings, teachers shared approaches and ideas of how to improve the lesson and improve children's learning. Teachers became more adept at recognising various children's needs, which led to changes in teacher behaviour; this reflects research by Dudley (2013) and Schipper et al. (2017).

LS enabled teachers to experiment with their approaches and to observe the immediate effects in the research lessons; therefore, they improved their teaching to better address the needs of the children (Schipper et al. 2017). LS gave teachers opportunities to develop their PCK and KCS as they trialled different ways to increase the inclusion of children with SEN. These strategies included teaming the child with a more competent buddy, and adding tactile materials which would draw the interest of the child to explore (Donegan-Ritter, 2017). In this research, however, both approaches failed, as the child grew frustrated by their classmate and splashed his peers with the water. Donegan-Ritter (2017) also advises that an adult should be close by, to support social interactions and participation. Unfortunately, this was not possible, as there was no special needs assistant allocated at this point. For cycle four, two children with SEN were given different materials to complete the STEM task. Differentiated questions and activities were embedded into lessons as teachers began noticing and responding to individual children's needs. This approach reflects practices advocated by both Donegan-Ritter (2017) and Lind (1999), who advise that tasks are adaptable to cater for children's strengths but also incorporate a level of challenge. This scaffolding of the activity proved most successful, as both children participated in the activity. Teachers had found an approach that facilitated the inclusion of children with SEN. This research suggests that teachers' adaptive teaching competency developed through the acute focus on children's learning and collaborative experimentation and this aligns with research from Schipper et al. (2017).

6.3.8 Summary

LS aided the development of teacher learning as PCK was constructed by teachers deliberately collaborating and engaging in dialogue on problems of practice. Implementing STEM education for the first time was a critical learning curve for teachers. As the research progressed, it was revealed that teachers' involvement in LS extended their SMK, PCK, KCS and KCT in how to design STEM lessons, deliver and teach STEM, and notice how children work, thereby increasing their confidence. Teachers addressed the learning challenges of some children by employing adaptive teaching. While some approaches failed initially, LS encouraged a thorough search of pedagogy to source more appropriate methodologies, this is also reflected in findings from Cajkler et al. (2014). LS ensures that teachers focus on children through the use of 'case pupils', and teaching methods are evaluated based on observations of the children, rather than evaluating the teacher (Dudley 2013). The four cycles of LS provided the framework that aided ongoing teachers' development and a consolidation of what STEM education was. Each cycle saw insights and progressions for teachers' learning, most likely due to progressive cycles of LS having better results than the first cycles, this is also supported by Dudley (2011).

6.4 LS and the Increased Focus on Children's Learning

6.4.1 Introduction

LS enabled a sharper focus on children's learning during STEM lessons. Dudley (2013) believes that LS helps teachers to subdue the intricacies of the classroom, leading them to observe children anew. By observing the children's learning, teachers became more responsive to various children's needs and pitched lessons more appropriately. They appreciated that the changes made in their practice influenced children's engagement.

6.4.2 Teachers' expectations re-evaluated

As LS incorporated the observation of children during STEM classes, it became apparent that teachers sometimes misjudged children's competency; this is line with research by Margot and Kettler (2019). Children whom teachers perceived as struggling generally were highly motivated during STEM lessons, a finding that supports Lesseig et al.'s (2016) research studies. This was perhaps due to the active, child-centred nature of the lessons. Close observations during LS led teachers to recognise that children frequently exceeded their expectations; this was also a finding of Cajkler et al. (2015). These observations led to changes in teachers' perspectives about learners, as teachers began pitching lessons at a more appropriate level for the children. Dudley (2018) believes that the joint planning of a lesson, prediciting a case pupil's learning and reviewing the learning observed after the lesson will lead teachers to discover 'unknowns' about children in their class.

6.4.3 Children's enjoyment of STEM

This was the first experience with STEM education for all of the children, and it proved to be a highly positive experience. Prior to the research, teachers were unanimous in believing that STEM should be taught at infant level, and this is reflected in the research (DeBacker and Nelson 2000; Chesloff 2013; Clements and Sarama 2016; McClure 2017; Rosicka 2016; Park et al. 2017; Tippett and Milford 2017; Simoncini and Lasen 2018). Teachers recognised young children's capabilities to generate mathematical and scientific ideas, while also appreciating that learning and enjoyment were occurring simultaneously. STEM education fostered multiple opportunities for children's engagement and participation, thus supporting the findings of Tippett and Milford (2017). Similarly, the research found that STEM was motivating for the children, echoing Margot and Kettler (2019). It shows the potential of children at this young age to engage with STEM once it is introduced using hooks and pedagogies that are inclusive and collaborative. Overall, this research suggests that exposing young children to STEM education is beneficial for promoting positive perceptions. There was a symbiotic relationship between the teachers and children. The children's engagement with STEM was a factor in teachers' positive experience of STEM teaching.

6.4.4 Summary

LS revealed teachers' desire to facilitate the participation of all children in STEM lessons. Through close observation of the children, this desire was realised as teachers adjusted their expectations, pitching lessons at a more appropriate level. The research also revealed that children fully embraced STEM learning in a manner that was unexpected by the participating LS teachers. The children exhibited 21st century skill development, positive learning dispositions and impressive engagement, which together show how powerful early STEM experiences can be.

6.5 Factors that Affected Teachers' Engagement in LS

Many factors affected teachers' participation in LS in this research. International research (Murata 2011; Fujii 2014a; Takahashi 2014; Akiba and Wilkinson 2016; Schipper et al. 2017; Wolthuis et al. 2020) has detailed the challenges of implementing LS outside of Japan. Through the course of the research, challenges were recognised and in most cases overcome. There were practical challenges to implementing LS in the primary school system. Cultural challenges were evident, as LS was unlike any PD that teachers had undertaken previously. Lastly, the challenge of the sustainability of LS is discussed.

6.5.1 Practical challenges

Before engaging in the research, teachers expressed concern over timetabling issues and teachers covering classes. This is line with research by Wolthuis et al. (2020), where participants found LS too time-consuming and the yields too small. Although teachers in the current research valued the collaborative meetings, time was an ongoing issue until Croke Park (section 2.3.5) hours began to be used for LS meetings. Teachers welcomed meetings scheduled in compulsory Croke Park hours; this was also found by Ní Shúilleabháin and Seery (2018). Conducting LS in a rural school involved challenges in locating another school to reteach lessons, juggling the timetables of the LS teachers and staff turnover. This was dependent on a willing and flexible principal; her openness to change enabled many practical challenges to be overcome. These findings align with Cajkler et al.'s (2014) study, as they state that while LS has potential, there are many organisational challenges to conquer. The principal in this study showed reluctance to sustain LS, instead favouring team teaching. Similarly, Dudley et al. (2013) found that school leadership is deterred from continuing with LS due to the difficulty of teacher buy-in and timetabling issues.

6.5.2 Cultural challenges

At the end of the research, the principal and one teacher failed to classify LS as PD (section 5.10.5). This suggests that teachers did not have an in-depth understanding of LS as PD. LS contains many features that are unlike traditional forms of PD to which the participating teachers were more accustomed. LS is school-based, autonomous, collaborative and reflective, includes peer observation and is sustained. This research reflects the findings of Murata (2011) and Akiba et al. (2019), who report teachers' unfamiliarity with the aforementioned features being included in their PD. Therefore, there is progress yet to be made on teachers' conceptualisations of effective PD. The current research reflects Irish research by Mulcahy-O'Mahony (2013), who found that teachers were reluctant to relinquish the one-shot workshop: 'it would seem that teachers have been enculturated into a model of professional development' (p. 323). Therefore, the findings of this research suggest that perhaps teachers expected to move on to their next PD experience in the upcoming year and did not anticipate the prospect of sustaining a model of PD year after year. Such findings collectively suggest that a cultural shift is required in how teachers perceive effective PD, echoing research by Murata (2011), Yoshida (2012) and Wolthuis et al. (2020).

6.5.3 Sustainability

The sustainability of LS in this research was questionable, and this challenge is reflected in previous studies (Yoshida 2012; Dudley 2013; Cajkler et al. 2014, 2015; Ní Shúilleabháin 2016; Dudley et al. 2019; Wolthuis et al. 2020). This study illustrates the difficulty of bottom-up PD. Initially it was challenging to ignite interest in LS; this is in line with research by Wolthuis et al. (2020). Additionally, staff turnover made the prospect of sustaining LS discouraging. The challenging practical and cultural issues that emerged as LS was implemented could have contributed to participants feeling discouraged in sustaining LS. This is similar to findings by Lesseig et al. (2016). Although Lesseig et al. (2016) did not implement LS specifically, they predicted that their collaborative, context-specific form of PD was unsustainable, as the school required changes to its practices, policies and structures. In the current research, it was felt that if LS was to be sustained in the current research setting, modifications would also be required to LS practices and school structures. Like in Cajkler et al.'s (2015) study, LS was in its infancy, and further exposure would be required before LS becomes embedded in the school culture.

In this research, the principal was supportive of LS being used, but she was not directly involved in any stage of the LS process. Perhaps if the principal had been directly involved in a cycle of LS, she would have witnessed first-hand its benefits to practice, teacher learning and children's learning and consequently may have been a stronger advocate of sustaining LS. It is documented in the research that involvement of the principal is pivotal if LS is to be sustained in a school (Dudley 2013; Ní Shúilleabháin 2016; Takahashi and McDougal 2016; Schipper et al. 2017).

6.5.4 Summary

As LS was a new form of PD for the teachers, this naturally implies that time is required for teachers to be familiar with the process. Challenges were encountered over the course of the research, and it was endeavoured, insofar as possible, to eliminate or reduce these challenges. Changes to structures and routines are required if LS is become embedded in the school culture. Also, school leadership is vital to adopting LS.

6.6 Conclusion

This chapter discussed the findings that emerged from the analyses of the data against the backdrop of the literature. The five sections of this chapter were structured to yield insights into teachers' perspectives of LS as a model of PD in STEM education. Teachers had the opportunity to use their school as the site of PD, and LS exposed teachers to context-specific, sustained PD. Teachers recognised the benefits and opportunities this gave them to observe and reflect on lessons, coupled with collegial support. Although LS boasts many advantages to teachers' learning, it was the participating teachers who contributed to the many successes of this research. Teachers created an environment of trust which boosted collaboration, and this provided the foundation to enable teacher practice and learning to thrive.

Collaborative planning, insights into practice and deepened learning facilitated the teachers in providing greater pedagogical support to the children. The next and final chapter explores the main conclusions and recommendations derived from this research.

Chapter 7: Conclusions and Recommendations

7.1 Introduction

The final chapter revisits the overarching research question and embedded questions that guided this study throughout. Additionally, it explores the implications for policy makers, teacher educators and schools in light of the recommendations. Finally, it outlines the original contribution of the research.

7.1.1 Research question and embedded questions

The research question guiding the research is:

What are teachers' understandings of lesson study as a professional development tool?

This research has yielded many significant insights regarding introducing LS to Irish primary schools. Teachers perceived LS to be a beneficial form of PD. The findings of this study demonstrate that LS, situated in context, sustained over a period of time, can promote positive changes in teachers' classroom practice. LS helped teachers bridge the gap between theory and practice, fostering collaboration, reflective practice and agency. LS provided a context for teachers to introduce STEM education to Junior and Senior Infants. LS also supported teachers as they gained confidence by placing a stronger focus on children's learning, discussing problems of practice and collectively finding solutions. Teachers reflected on their role in the STEM classes, experimenting with approaches to engage all children and developing an understanding of the importance of STEM content knowledge. The principal perceived LS to be effective in adopting STEM, changing practices and embracing collaboration.

One of the most common themes marbled throughout the findings was the value that teachers placed on collaboration. Teachers spoke of isolation prior to this research, but they recognised that the collaborative planning, dialogue and opportunities for collective reflection intrinsic to LS were beneficial. LS aided the creation of a common vision and encouraged collaborative practice as a means of achieving that united vision. The agency and the professional capital that were evident illustrated the potential of LS to support professionalism amongst teachers. It appeared that Irish teachers view the prospect of increased collaboration positively, but unfortunately they do not get sufficient opportunity to engage in it. It seems fair to conclude that school-based PD requires time – for people to build trust, nurture relationships and become accustomed to collaborative practices. This has implications for the PDST, DES and the Teaching Council and also schools, teachers and leadership.

In the final interviews, teachers highlighted the characteristics of LS which they identified as advantageous: collaboration with colleagues, active participation, reflective practice and the focus on children's learning. Generally, these are the same characteristics highlighted in the research as factors of effective PD (Desimone 2009; Loucks-Horsley et al. 2009; Borko et al. 2010). While there were challenges inherent in implementing LS in a rural multi-grade setting, the turnover of staff exacerbated the prospect of sustaining LS for next academic year. Perhaps, if the staff arrangement was remaining the same LS could have been given time to embed within the school. Despite these challenges, teachers deemed LS to be a worthwhile experience. STEM education was introduced to the school through LS, and by the end of the research, STEM held a solid foundation in the school. Overall, teachers were very satisfied with the outcomes of LS and found the experience to be beneficial in improving their practice and their learning. This finding reflects Lieberman's (2009) commentary on the progress of LS in the United States and it acknowledges that LS may not achieve all of the success it has in Japan; however, it may serve to break the norms of teaching by introducing teachers to collaboration, agency and a renewed focus on children's learning.

- In what ways does teachers' practice in STEM change (if at all) as a result of engaging with LS?

This research suggests that LS was beneficial in bringing about positive changes in teacher practice (Dudley 2013; Cajkler et al. 2014, 2015; Ní Shúilleabháin and Seery 2018). Teachers seemed to enjoy the affirmation of their colleagues as they became less self-conscious about their practice. While teachers were aware of the notion of the teacher as facilitator, LS bridged the gap between theory and practice. The PD sessions and research lessons modelled the use of inquiry-based learning, which helped the teachers expand their own understandings of the pedagogical strategies necessary for teaching STEM. Teachers started to experiment and take pedagogic risks. They removed themselves from positions of authority during the STEM lessons and began facilitating discussion. Initially, some teachers' discomfort with facilitation was evident; however, with collegial support, peer observation and the sustained nature of LS, teachers became comfortable in the facilitation inherent in inquiry-based learning. The effects of LS permeated the whole school community as teachers began to discuss their practice in STEM, resulting in all staff members adopting inquiry-based learning. A conclusion that can be drawn is that that PD over a briefer span of time and not set in the teachers' context would have had less of an impact.

- What are teachers' learning experiences of STEM education?

This study found that times of curricular change proved favourable for the implementation of LS, and this aligns with current research (Takahashi and McDougal 2014; Ní Shúilleabháin and Seery 2018). The teachers had received varying levels of PD in STEM prior to this research, and feelings of apprehension and low confidence were palpable. After teachers had participated in LS, they reported increased levels of confidence and self-efficacy in STEM. However, gaps in teachers' SMK and PCK of STEM education were revealed. To a certain extent, LS provided the vehicle for teachers to develop their understanding, and all teachers claimed they had gained SMK and PCK. Knowledge was constructed with colleagues through collaboration, dialogue and reflection. While gains were made in teacher knowledge, ways to boost teachers' SMK and PCK need to be considered.

Collaborative practices enabled teachers to access and utilise tacit knowledge. Observation in LS led to fresh insights into children's learning. Teachers gained new knowledge in optimising children's learning, thus developing their PCK. All of the teachers designed lessons encompassing more hands-on activities, with teachers becoming more mindful of including opportunities for skill development. Teachers felt that many of the STEM skills and competencies were embraced naturally by the children. However, teachers sometimes struggled to facilitate children's 21st century skills competence. Over time, and following ongoing discussion and reflection, teachers became more responsive to children's needs and trialled different approaches to engage all children, especially children with SEN. In this research, teachers felt that children would acquire life skills and competencies through STEM education. However, teachers did not anticipate the high levels of enthusiasm among children, and this motivated teachers' engagement with STEM.

- How can lesson study enhance the professional agency of teachers?

A central aim of combining LS and PAR was to enhance the agency of teachers by empowering them to take greater ownership of their PD. LS and PAR value democracy, participant voice and agency as well as learning environments that place a value on the importance of social interactions. With these values in mind, teachers had to alter their traditional approach to PD. LS and PAR offered teachers greater opportunities for collaboration where collegiality was viewed by teachers and the principal as a key aspect of teacher professionalism and a vehicle to promote teacher agency.

Both LS and PAR empowered teachers to take greater ownership of their learning in STEM. Teachers were presented with opportunities to make professional decisions encompassing: lesson content, the selection of appropriate teaching methodologies and collaboration with colleagues. LS facilitated teachers to reflect on how they learn through school-based, sustained PD. LS and PAR offered teachers the potential to see how freedom can be fostered in their learning environment and made them more aware of their voice in decision making in their own PD. This study believes that teachers should be encouraged to research their practice and identify their PD needs.

- What are the cultural adjustments made by Irish teachers when implementing LS?

Many researchers (Akiba and Wilkinson 2016; Takahashi and McDougal 2016; Wolthuis et al. 2020) report that when LS is implemented internationally outside of Japan, different adaptations are made to the procedures and practices. However, they warn that if the core elements of LS are distorted excessively, this may be fatal for its effectiveness. This study aimed, insofar as possible, to implement traditional Japanese LS. Yet, for Irish teachers, LS was a significant departure from the traditional forms of PD they were familiar with. The culture of current PD for teachers is usually an individual pursuit: attending an education centre on one or two occasions, with an external facilitator delivering material where the topics may not be based on the teacher's individual needs. Therefore, for teachers in the present study, LS proved to be a very different form of PD, and a number of factors were identified that affected teacher participation. Initially, it was challenging to ignite interest in LS; teachers needed time to adapt to the prospect of lesson observation and the recurrent LS meetings. Participating teachers identified practical constraints of LS, the most prominent being lack of time. Peer observation, collaboration, reflection, dialogue and reading research were features very separated from their perception of PD. In this study, teachers were required to adjust their expectations of PD. Teachers gradually became accustomed to collaborative lesson design, peer observation, collective reflection, MKO input and the sustained nature of LS. This experience of PD may have been a stimulus for teachers to recognise that an alternative approach – one that diverges greatly from the culture of PD they are most accustomed to – is possible. The positive outcomes of the research justify the conclusion that LS could be adapted for use in Irish primary schools.

A significant challenge for implementing LS in the Irish context was carving out time for collaborative meetings. The only time Irish teachers can engage in PD during school hours is if the principal facilitates this by arranging class supervision. In any school context there is little capacity for this, however, none more so than the rural, multi-grade context. In this research, the extra time required for LS collaborative meetings was accepted in order to meet the goals of LS. The use of one Croke Park (section 2.3.5) hour per cycle was welcomed for the planning meetings. However, participants would have been very eager for all LS meetings to have been conducted during Croke Park hours. If this arrangement was to occur, it would require schools to set aside a considerable portion of Croke Park hours to LS across the school year, this would require agreement and buy-in from a variety of stakeholders.

In this study the teachers had been teaching in the multi-grade context for a number of years and were proficient and confident in this context. Unique challenges to conducting LS in a rural, multi-grade setting were revealed in this study, one such challenge was the limited numbers of teachers. With fewer teachers, there was more responsibility on a limited number to participate. In this research if teachers had decided not to participate, LS would not have been viable. Likewise, it may not be possible for some colleagues to participate. In this research the principal had been enthusiastic to take part but as she was teaching full-time as well as occupying the leadership role she could not commit the time to the study. Therefore, the limited numbers of teachers and staff turnover were signficant challenges to sustaining LS.

Another unique challenge to rural, multi-grade schools were the arrangements involved in reteaching the research lessons. The research is divided on whether reteaching the same lesson to a different class is required. Stigler and Hiebert (1999) believe it is necessary part of LS while Chokshi and Fernandez (2004) believe reteaching is not required. In this research, the research lessons were retaught and this neccessitated the participation of a second school in the surrounding area with another cohort of Junior and Senior Infants. As teachers were travelling between two schools during school hours this involved scheduling issues and acquiring cover for teachers. This required a great deal of flexibility on behalf of the teachers and the principal.

School contextual difference may also pose a problem when conducting LS in a rural multi-grade school. In this research I taught Junior and Senior Infants and Gwen and Maria were SETs. In larger schools an LS group of teachers of the same class level are more likely to have relational PCK (Fernandez 2002). In rural, multi-grade schools teachers making up the LS group will inevitably comprise of teachers from different class levels. Therefore, teachers will have different curricular expectations and this could make choosing a topic for the research lessons and picking a class level challenging.

7.2 Recommendations for Further Research and Curriculum Change

Arising from this research, a number of recommendations are offered to contribute to the growth of LS and STEM education in Ireland. These recommendations focus on further research and policy development.

7.2.1 Lesson study in Ireland

Currently LS is not a well-known form of PD in Irish primary education. When LS was first introduced to all relevant stakeholders in School 1 and School 2, only one teacher had heard of it, on Twitter, and this was the extent of their knowledge. LS is being used in second level and in modules in pre-service education in the Colleges of Education, but this needs to expand to primary level. Further work is required to boost the profile of LS in Ireland and to inform primary teachers and leaders of this form of PD. This study was conducted over a relatively short time. How LS as a form of PD would evolve in an Irish primary setting remains to be seen. Further research could include a longitudinal study to observe the effects of LS on the schools' culture. LS could also be conducted in various primary school settings throughout Ireland. Inclusion of a number of schools from different settings would allow for comparisons of learning experiences.

While I cannot claim that traditional LS could be adopted in every school, the current educational landscape in Ireland is well situated to leverage the introduction of an adapted form of LS to primary schools. Many polices are being introduced to boost professional collaboration and teacher professionalism (section 1.4); this study situates LS as a potential vehicle to support these features. In the current research, LS and School Self-Evaluation were used in tandem. This proved to be a symbiotic relationship and is a possible avenue for introducing LS to schools. The *Looking at Our Schools* document emphasises collaborative practice:

- Teachers value and engage in PD and professional collaboration
- Teachers work together to devise learning opportunities for pupils across and beyond the curriculum
- Teachers contribute to building whole staff capacity by sharing their expertise

(DES 2016a, pp. 20–21)

LS satisfies these statements of effective practice, as 'the school is the primary locus for teachers' professional development' (ibid., p. 20). Teachers also engage in a 'collaborative review of practice' (DES 2016a), and collective practice is encouraged. Teachers plan collaboratively to 'enable pupils to make meaningful and progressively more challenging connections between learning in different subjects' (ibid.). The policy encourages teachers to build their collective skills to enable children's learning (ibid.). Considering these statements, LS has considerable potential to enhance a school's collaborative practice.

This research illustrated teachers' feelings of isolation; therefore, there is scope for LS to be introduced to Irish primary schools. More opportunities should be made for teachers to collaborate with their colleagues, thereby increasing their professional capital (Hargreaves and Fullan 2012). LS literature indicates that it is essential for school leadership to facilitate the growth of this collaborative culture, but this is a gradual process. Principals and leadership teams should be provided with PD to nurture a collaborative culture in their schools. Teams in schools need to be carefully assembled, with consideration given to different personalities and strengths. Principals are required to set up structures in schools that empower teachers to pick problems of practice which motivate them to research their practice.

Akiba and Wilkinson (2016) and Murata (2011) describe the supports and incentives at district, school and teacher level that should be utilised to assist LS practitioners (section 2.3.3). These structures could also be envisioned for Ireland. Teachers need to be provided with PD on the processes that are integral to LS, including research-based practice, research skills and reflection; these skills will provide a basis for teachers researching their practice. PD should be organised nationally by the DES. At the moment, PD in LS is run by the PDST, but it is not accessible to all schools. Education centres and external facilitators could be utilised to provide information on LS and to help set up LS in schools. All of the teachers in the current research commented on the lack of time. For LS to be sustainable, teachers need to be given the time and space for collaborative meetings and for the observation of lessons. Substitute teacher cover could be introduced as an incentive to schools to trial LS, as well as using Croke Park (section 2.3.5) hours for school-based PD. Another possible incentive would be to award teachers with EPV (extra personal vacation) days for time spent on LS throughout the year.

This research is not proposing that LS be the only approach to PD. In this research LS was but one form of it; the teachers had availed of other PD courses also. However, LS includes many features identified in effective PD that merit attention, and while it is not the panacea, it provides a powerful starting point.

7.2.2 PD in STEM

As well as boosting the platform of LS, there is also a need to boost the status of STEM education. With the current curricular changes at primary level (Primary Language Curriculum 2019, the new Maths Curriculum 2021 and the new Draft Primary Curriculum), substantial changes are imminent in Irish primary education.

The Draft Curriculum Framework (NCCA 2020) is well placed to give the warranted acknowledgement of the role of STEM education. Perhaps nodding to the desire for integrated STEM practice, science has been relocated within maths, science and technology education in the draft curriculum framework. Ideally, the inclusion of STEM education in the primary curriculum would support and guide teachers in implementing integrated STEM education in classrooms. However, it is alarming to note that neither engineering nor STEM is mentioned in the draft curriculum framework. It seems there is an intention to proceed and implement the next primary curriculum without including STEM education.

A key finding from this study is the importance of early exposure in the infant classes to STEM education. The *Irish STEM Implementation Plan* (2017b), deriving from the *STEM Education in the Irish School System* report (MacCraith 2016), assures ‘a quality assured programme of STEM PD provided to early years practitioners and teachers’ (DES 2017, p. 4). Special attention to PD for early years practitioners is required, as teachers in the current research lacked confidence in their initial implementation of integrated STEM education with young children. Teachers found planning thematically to be highly beneficial and found that STEM permeates into daily practice. Future PD and research in Irish early years settings and school settings should explore the opportunities for integrated STEM education and the synergies with Aistear, literacy, visual arts and creativity, similar to the research conducted by Cremin et al. (2015).

STEM education envisioned in the *Irish School System* report (MacCraith 2016) advocates the development of specialist teachers who assume the role of ‘STEM Champions’. Perhaps recognising primary teachers’ educational background, the DES advises that a STEM Champion should hold a postgraduate degree in a STEM discipline (McCraith 2016). A STEM Champion is envisioned as disseminating best STEM practice. However, this recommendation was not mentioned in the *STEM Implementation Plan* (2017b). This may have been revised to avoid the entire teaching and learning of a STEM programme being the responsibility of one teacher. However, similarly to this research, it would be more advantageous if the vision for integrated STEM education was introduced and driven by one teacher but became the shared responsibility of the staff and leadership of the school. The creation of a post of responsibility in STEM education or choosing STEM education as the area for School Self-Evaluation could be a means of creating and driving the school vision in STEM education.

This research indicates that teachers require comprehensive STEM teacher knowledge in order to provide challenging and motivating learning experiences for children. Similarly, policy acknowledges the need for teachers to possess sufficient content knowledge and PCK: ‘it is essential that our teachers have accessible and high-quality opportunities to facilitate them in maintaining their professional competence in a developing STEM environment’ (DES 2017a, p. 6). Teachers in the current research reported increased confidence as the research progressed, but this did not guarantee adequate PCK or SMK. Teachers require a comprehensive level of knowledge to ask children provoking questions and to support children in investigating possible answers for themselves. Teachers also require PCK to design learning experiences that promote the development of 21st century skills in children. As stated in Chapter 3 (section 3.3.3) there needs to be coherence across the educational sectors regarding the development of STEM skills and curricula. In particular, a clear and coherent policy for STEM PD would support teachers in building their PCK and SMK.

Some teachers in the current research found it challenging to adopt an inquiry-based approach. Both the *STEM Implementation Plan* (2017b) and the *Irish School System* report (MacCraith 2016) highlight the importance of inquiry-based learning. However, neither document defines the inquiry-based approach or describes how it can be made viable in the classroom with various age groups. Teachers require knowledge and skills to adopt inquiry-based learning, especially as they appear to be unfamiliar with this approach and do not know how to successfully adopt it into their practice. Teachers must also become comfortable adopting a facilitative role that allows children ‘to take the wheel and drive instruction’ (Margot and Kettler 2019, p. 14).

This research highlighted the development of teachers’ PCK with regard to children with SEN, as some found STEM lessons over-stimulating. It found that children with SEN responded to STEM differently, and no one approach is ‘best’. Teachers are required to get to know the child’s strengths, learn where challenges lie, be flexible in their approach and differentiate accordingly. Teachers require guidance in how to differentiate the STEM task, provide different materials or supply scaffolds to enable all children to access and participate in the activity. Further research is required to study effective strategies to differentiate activities for different types of abilities and learners, and this would enable teachers to facilitate all children's learning.

There was evidence in this study that children were very enthusiastic towards integrated STEM learning opportunities. Further research incorporating the children's voice would yield deeper insights into their perceptions and attitudes towards integrated STEM. A longitudinal study examining the attitudes towards STEM of children from Junior Infants to Sixth Class would produce insights into how children's attitudes evolve with age. In particular, the study could look at gender discrepancies and whether children's motivation in addition to their attitudes are affected.

This research indicates that while teachers are familiar with science and maths, they require more guidance in imagining how engineering and technology may be implemented in the primary classroom. Engineering became a focal point for our integrated STEM lessons, but this research aligns with findings from Cunningham: initially, teachers 'had a limited vision of what engineering is and a difficult time envisioning the early development of engineering skills' (2018, p. 11). Engineering requires more recognition (Moore et al. 2014), and guidance is required on how it can be supported at primary level (Redman 2017). Providing direction for teachers in STEM integration is imperative, as it is more beneficial for children's learning and engagement (Wang et al. 2011; Margot and Kettler 2019). Teachers require additional support in science, maths, engineering and technology to understand the connections between the disciplines and integrate them in a meaningful and coherent manner. This will ensure that teachers develop the best approaches and practices to plan integrated STEM approaches.

7.2.3 Participatory action research

In the current research, teachers exercised their agency by participating in bottom-up PD. It is broadly asserted that teachers should play an active role in researching their practice and identifying ways to improve their practice (Stenhouse 1975; Stenhouse

1985; Sullivan et al. 2016; Glenn et al. 2017; Elliott 2019). Currently in Ireland, there is not a tradition of teachers identifying and addressing their own professional needs. Generally, PD is mandated by the DES and offers a predetermined range of courses. The DES should consider current research and encourage teacher agency in their PD. Teachers should be encouraged and supported to identify problems in their practice and consequently identify their PD needs.

This study recommends merging PAR with LS, as the two approaches were found to be complementary. PAR coupled with LS enhanced teachers' professional capacity and in researching their practice, cooperating with colleagues, and collecting and analysing evidence to inform their work. Both PAR and LS empowered teachers to reflect on their practice and develop their appraising abilities. By utilising PAR, teachers exercised their agency, developed autonomy over their PD, researched their practice and made evidence-based decisions to improve their practice. PAR and LS enable teachers to take part in decision-making and in the development of the action that will directly affect them (Pérez et al. 2010).

As part of this research, a third-level institution linked to our primary school through the use of an MKO. Encouraging these partnerships could increase the relevance of research to teachers' practice. It could also promote the visibility of teachers as researchers by creating a supportive, inclusive culture. In Japan, teachers write up research, contribute to books, publish articles on their research lessons and may even influence curriculum design (Elliott 2019). In these situations, PCK is not the sole domain of the LS cohort; instead, the knowledge is disseminated, and 'professional learning and can instead build on each other's findings' (Elliott 2019, p. 185). This encourages teachers as authors while also increasing the relevance of research to teachers. Developing Irish teachers as researchers and publishers of their practice would be a very welcome progression of teachers' professionalism.

7.3 Original Contribution of the Research

This research adds to the growing literature of LS in Ireland. The study has identified the strengths and weaknesses of conducting LS in an Irish rural primary classroom. It details primary teachers' first experience of a form of PD that is a significant departure from the 'traditional' form of PD they normally attend. Despite a relatively short time span, LS produced compelling shifts in classroom practice, teachers' learning and children's learning. This research suggests that participating in LS can improve teachers' confidence and competence. It reveals the benefits of PD situated in the classroom, by conveying how teachers adapted their practice to suit children's needs. Time is required for teachers to develop new knowledge and make shifts in their teaching practice. The sustained nature of LS ensured that these changes could occur. As a form of development that occurs in the school context, LS has the potential to address the needs of various teachers and of the school. This has consequences for Ireland at a time when there are impending changes in various curricular areas. The new primary maths curriculum is due to be published in autumn 2021, and consultation is currently under way on the draft primary curriculum framework. These new curricula will require substantial PD.

As outlined earlier, much Irish research on PD in science is with older classes in primary school (Murphy et al. 2011; Murphy et al. 2012; Smith 2014; Murphy et al. 2016). There is little research focusing on teachers of children in Junior and Senior Infants, and similarly insufficient research on STEM practices with Junior and Senior Infants. This study explored and presented teachers' perspectives of LS in STEM education with infant classes. The findings of this research present valuable knowledge on STEM education with this young age group. This research contends that times of curriculum change create favourable conditions for LS. This study shows how LS supported teachers to adopt a new approach to STEM education with Junior and Senior Infants. Currently, research examining effective STEM practices is in the preliminary stages; thus, research-based professional learning is required to support teachers and to understand effective PD.

7.4 Concluding Reflection

Engaging in this research was a work of passion for me. The opportunity to improve my practice, collaborate with my colleagues and improve the learning experiences of the children was a privilege. The willingness of the teachers, principals, parents and children to engage in this research was inspiring. Their participation led to the many successes of the study. I learned about the characteristics of effective PD, LS, PAR and integrated STEM education. I also learned the strengths and challenges of collaboration, reflective practice and implementing a bottom-up model of PD. I have reconceptualised my own practice and encouraged others to reconceptualise theirs. I hope this research will contribute to the growth of different forms of PD, particularly LS, and that it will encourage teachers to implement integrated STEM education in their classrooms.

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Appendices

Appendix A: Information Letter to the Boards of Management

Board of Management Information Sheet

Dear Mr___________ / Members of the Board

I am currently pursuing a course of studies leading to a doctoral degree in education from Mary Immaculate College. With this in mind I now seek the consent of the Board to carry out some research in my classroom.

I would be grateful for consent and for your support. I am the focus of the research and I am to reflect on, evaluate and hopefully improve my practice. In this study I aim to investigate the effectiveness of Lesson Study as a vehicle for teachers continuing professional development in the area of STEM with junior and senior infants.

My data collection methods may include audio recording of conversations between the teachers and me, as well as the keeping of a reflective diary and field notes relevant to my research. I will seek consent from the parents for their children to become involved in the research.

I guarantee confidentiality around any information collected. I will only report information that is within the public domain and within the law. I will not reveal anything of a personal or comprising nature. There will be total confidentiality of all names and I will not name the school without consent. You are free to withdraw from the research at any time without giving a reason and without consequence.

If you have any questions about this project, contact Dr. Aisling Leavy, aisling.leavy@mic.ul.ie or Bridget Flanagan, bridget.flanagan@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

Thank you very much for you time,

Bridget Flanagan

Appendix A1: Letter of Consent to the Boards of Management

Consent Form

To whom it may concern Bridget Flanagan has the permission of this Board of Management to carry out action research in her classroom and in this school, as described above.

Signed ____

Appendix B: Information Letter to the Principals

Principal Information Letter

School name,

School address,

-- ------- 2018.

Dear Principal,

As part of my PhD research programme, I am undertaking some action research into the effectiveness of Lesson Study as a vehicle for teachers continuing professional development in the area of STEM with junior and senior infants. I am the focus of the research and I am to reflect on, evaluate and hopefully improve my practice. I would be grateful if you would grant me consent to conduct this research.

My data collection methods may include audio recording of conversations between the teachers and me, as well as the keeping of a reflective diary and field notes relevant to my research. I intend to invite you and my teaching colleagues to collaborate with me in critical evaluations of the study. I will seek consent from the parents for their children to become involved in the research. I guarantee confidentiality around any information collected, and promise not to reveal the names of the school, colleagues or children in the research report. You are free to withdraw from the research at any time without giving a reason and without consequence.

I enclose two copies of this letter, one for your files and one to be returned to me for retention in my files. I would appreciate it, therefore, if you would sign the consent slip below and return it to me at your earliest convenience.

If you have any questions about this project, contact us at Mary Immaculate College e-mail: aisling.leavy@mic.ul.ie or bridget.flanagan@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

Yours sincerely,

Bridget Flanagan

Appendix B1: Letter of Consent to the Principals

Consent Form

To Whom It May Concern:

I, principal of ………………………………… school, give permission to Bridget Flanagan to undertake research in the above-named school.

Signed………………………

Appendix C: Information Letter to the Teachers in School 1

Teacher Information Letter

Dear Teacher,

As part of my PhD research programme, I am undertaking some action research into the effectiveness of Lesson Study as a vehicle for teachers continuing professional development in the area of STEM with junior and senior infants. I intend to invite you, my teaching colleagues to collaborate with me in critical evaluations of the study. I would be grateful if you would grant me consent to partake in this research.

Participation in Lesson Study will involve the research and design of lessons in STEM (science, technology, engineering and maths). Once a lesson has been designed and evaluated by the Special Education Teachers and I, one of the team will teach the lesson as an opportunity to evaluate the adequacy of the lesson in the live classroom setting, the other teachers will observe. The main focus of the research is on the teaching processes rather than on the children. After observation of the lesson, reflection and discussion will follow and a revised lesson will be constructed. The lesson will then be retaught to a different cohort of infants. Input will be required from you at all stages of the lesson. My data collection methods may include audio recording of conversations between the Special Education Teachers and me, as well as the keeping of a reflective diary and field notes. I will seek consent from the parents for their children to become involved in the research. I guarantee confidentiality around any information collected, and promise not to reveal the names of the school, colleagues or children in the research report.

I enclose two copies of this letter, one for your files and one to be returned to me for retention in my files. I would appreciate it, therefore, if you would sign the consent slip below and return it to me at your earliest convenience. You are free to withdraw from the research at any time without giving a reason and without consequence.

If you have any questions about this project, contact us at Mary Immaculate College e-mail: aisling.leavy@mic.ul.ie or bridget.flanagan@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

Yours sincerely,

Bridget Flanagan

Appendix C1: Letter of Consent to the Teachers in School 1

Teacher Consent Form

o I have read and understood the Participant Information Letter

o I understand what the project is about

o I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason and without consequence

o I am aware that results will be kept confidential

o I have read this form completely, I am 18 years of age of older and am happy to take part in the study on Lesson Study and STEM

Signature: ___________________________

Date:__________________________

Appendix D: Information Letter to Parents

Information Letter to Parents

Mary Immaculate College

Japanese Lesson Study

Dear Parent/Guardian,

As part of my PhD research programme, I am undertaking some action research into the effectiveness of 'Lesson study', which involves the research and design of lessons in STEM (science, technology, engineering and maths). Once a lesson has been designed and evaluated, teachers are required to teach the lesson as an opportunity to evaluate the adequacy of the lesson in the live classroom setting. The main focus of the research is on the teaching processes rather than on the children. Your child's class has been selected for this project.

It is our hope that all children will benefit from participating in the research. The lessons we will teach focus on important mathematical and scientific concepts in the Irish Primary School Curriculum. In the writing up of this report I will observe the strictest confidentially – neither the school nor the children will be named.

Optimum participation is important in order to represent STEM teaching in a real classroom. Therefore we would be grateful for your support in this project. You have the right to refuse consent for your child to co-operate. Should you wish to do so, I guarantee that your refusal will not in any way affect my relationship with you or your child. If you have any questions about this project, contact us at Mary Immaculate College e-mail: aisling.leavy@mic.ul.ie or bridget.flanagan@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

Please complete the consent form on the following page and return it to your child's teacher. Retain this information page for your own records. Thank you for your cooperation.

Yours sincerely,

Dr. Aisling Leavy

Bridget Flanagan

Appendix E: Consent Form for Parents

Mary Immaculate College

MARY IMMACULATE COLLEGE
COLÁISTE MHUIRE GAN SMÁL

Japanese Lesson Study

Permission form for your child to take part in 'Lesson Study'

I give permission for my child ______________________(insert name) to collaborate in this project.

I do not give permission for my child, ______________________(insert name) to collaborate in this project.

__________________________________ ___________________

Signature of Parent or Guardian Date

Appendix F: Assent Form for Children

<u>Assent form for children</u>

I would like to find out what is important to you about learning in this school so I can tell other adults about it. Is this ok with you? If you want to stop at any time please just ask me and we will stop. If you would like to do this activity with me you can tick the smiley face (read out by the researcher).

Name:

____

Appendix G: Information Letter for the More Knowledgeable Other (MKO)

Information Letter for the More Knowledgeable Other (MKO)

Dear _____________,

As part of my PhD research programme, I am undertaking some action research into the effectiveness of Lesson Study as a vehicle for teachers' continuing professional development in the area of STEM with junior and senior infants. I intend to invite you, to collaborate with me in critical evaluations of the study. I would be grateful if you would grant me consent to partake in this research.

Participation in Lesson Study will involve you as external expert to participate in discussion with the Special Education Teachers and I to aid us our reflection on the lessons. The main focus of the research is on the teaching processes rather than on the children. My data collection methods may include audio recording of conversations between the Special Education Teachers, you and I, as well as the keeping of a reflective diary and field notes relevant to my research. I will seek consent from the parents for their children to become involved in the research. I guarantee confidentiality around any information collected and promise not to reveal the names of the school, colleagues, children or you in the research report.

I enclose two copies of this letter, one for your files and one to be returned to me for retention in my files. I would appreciate it, therefore, if you would sign the consent slip below and return it to me at your earliest convenience. You are free to withdraw from the research at any time without giving a reason and without consequence.

If you have any questions about this project, contact us at Mary Immaculate College e-mail: aisling.leavy@mic.ul.ie or bridget.flanagan@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

Yours sincerely,

Bridget Flanagan

Appendix G1: Consent Form for MKO

More Knowledgeable Other (MKO) Consent Form

o I have read and understood the Participant Information Letter

o I understand what the project is about

o I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason and without consequence

o I am aware that results will be kept confidential

o I have read this form completely, I am 18 years of age of older and am happy to take part in the study on Lesson Study and STEM

Signature: ____________________________ Date:___________________________

Appendix H: Information Letter for Teacher in School 2

Information Letter for Teacher in School 2

MARY IMMACULATE COLLEGE
COLÁISTE MHUIRE GAN SMÁL

Dear Teacher,

As part of my PhD research programme, I am undertaking some action research into the effectiveness of Lesson Study as a vehicle for teachers continuing professional development in the area of STEM with junior and senior infants. I would be grateful if you would grant me consent to partake in this research.

Lesson Study will involve the research and design of lessons in STEM (science, technology, engineering and maths). Once a lesson has been designed and evaluated by the Special Education Teachers and I, one of the team will teach the lesson as an opportunity to evaluate the adequacy of the lesson in the live classroom setting, the other teachers will observe. The main focus of the research is on the teaching processes rather than on the children. After observation of the lesson, reflection and discussion will follow and a revised lesson will be constructed. The lesson will then be retaught to a different cohort of infants. With your consent I would like to teach your class a STEM lesson once per term.

My data collection methods may include audio recording of conversations between the Special Education Teachers and me, as well as the keeping of a reflective diary and field notes relevant to my research. I will seek consent from the parents for their children to become involved in the research. I guarantee confidentiality around any information collected and promise not to reveal the names of the school, colleagues or children in the research report.

I enclose two copies of this letter, one for your files and one to be returned to me for retention in my files. I would appreciate it, therefore, if you would sign the consent slip below and return it to me at your earliest convenience. You are free to withdraw from the research at any time without giving a reason and without consequence.

If you have any questions about this project, contact us at Mary Immaculate College e-mail: aisling.leavy@mic.ul.ie or bridget.flanagan@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

Yours sincerely,

Bridget Flanagan

Appendix H1: Informed Consent Form for Teacher in School 2

Informed Consent Form for Teacher in School 2

- o I have read and understood the Participant Information Letter
- o I understand what the project is about
- o I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason and without consequence
- o I am aware that results will be kept confidential
- o I have read this form completely, I am 18 years of age of older and am happy to take part in the study on Lesson Study and STEM

Signature: ___________________________

Date:__________________________

Appendix I: Schools' Strengths, Areas for Improvement and Priorities for Action in Science / STEM

Schools strengths, areas of need and priorities for action in science / STEM

Strengths

CPD: Teachers had attended numerous courses and CPD in the area of STEM in the previous year (2017-2018)

Teacher 1	Computational thinking Play and STEM PDST STEM Conference Mata sa Rang Robotics in the primary classroom Green Screen STEM with STEM coach
Teacher 2	Mata sa Rang
Teacher 3	Computational thinking Mata sa Rang
Teacher 4	Computational thinking Green Screen STEM with STEM coach

Staff: The staff was cognisant of the promotion of STEM in education and were

enthusiastic about implementing it as part of SSE. **Pupils:** The pupils had displayed very positive attitudes to science, technology and STEM. **Resources:** The school was fortunate to be rich in resources to promote STEM. **Lesson study:** The SETs were open and enthusiastic towards participating in cycles of lesson study as a vehicle of collaborative professional development leading to impact teachers' knowledge and skills in STEM with children in Junior and Senior Infants. The principal and other staff members were willing to act as critical friends and evaluators.
Areas for improvement: Science language: Do children know appropriate and relevant scientific language? Can they explain their understanding, predictions and investigations? Timetabling: STEM should be timetabled formally. Each classroom should also be discussed to ensure there is progression from year to year. Children's critical and independent thinking
Priorities for action: Tackling gender assumptions Developing children's critical and creative thinking Whole school planning - Timetabling Teachers developing their higher order questioning Introduce inquiry-based learning
Possible goals: Encouraging students to exercise their problem-solving skills by promoting critical

thinking and independent thinking. Developing friendship and cooperation – deepening friendships while learning being considerate and kind to others. Giving specific attention to raising the participation of girls in STEM and to increasing their self-confidence.
Actions: Teachers collaborate in planning and timetabling STEM. Teachers gather data on children's perceptions of a scientist and their attitudes of STEM A focus group will be conducted with children to ascertain their attitudes and perspectives towards science, gender and STEM. Teachers collaborate and conduct lesson study. Female scientists/engineers will be invited to the school to speak to their children. Teachers will utilise the app Seesaw to document children's scientific language and their understanding of scientific concepts and investigations. Teachers will utilise higher order questioning to develop the children higher order and thinking skills.

Appendix J: Semi-Structured Interview Questions for Gwen and Maria

September

What are the important traits of professional development?
When did you last avail of professional development in Science?
How would you rate it?
What would be your level of confidence in teaching STEM?
How important is STEM? Do you think it is necessary?
Should it be taught at infant level?
Are you concerned about implementing STEM?

April
Lesson Study

What has your experience of lesson study been over the last months?

What aspects of lesson study did you find most useful? What did you gain most from your involvement in the project?

Did your teaching change as a result of lesson study and if so in what ways? What has helped you make these changes?

Did you experience the process of lesson study as an effective form of professional development? If so, in what ways?
How does this type of professional development compare to other courses you have done?

Is lesson study something you would like to continue in your school?

- If so, what are the benefits you see?
- If not, what are the obstacles?
- How do you think lesson study could be adapted to suit your particular needs/circumstances? Is it suitable to a rural school ?

STEM

From the interviews in September there were feelings of apprehension in the area of STEM. What has your involvement in this project had on your perception of teaching STEM?

Have you observed any changes in your pupils' attitudes to science/ STEM since this project began?

We changed our practice in our STEM lessons to embrace more inquiry based approaches, how did you find changing your practice? What helped you make these changes?

Do you believe your inquiry based instruction led the pupils to experience STEM and science in a different way?

What advice would you give other teachers regarding the teaching of STEM?

How did teachers construe how their participation in the process influenced their thinking about classroom teaching?

Finally, please share your any additional thoughts, feelings, discoveries, and insights from our professional development with lesson study in regard to your teaching practices, collaboration with others, or additional input you feel is relevant to this discussion.

Appendix K: Semi-structured Interview Questions for Principal

Principal Interview Schedule: End of project

As principal, what was your experience of this project?

In your opinion, was the project worth the time invested in it by you and your staff?

The project sought to implement a form of professional development, lesson study, to increase collaboration amongst the staff and introduce STEM and inquiry-based learning to teaching. How well do you think it succeeded in achieving these two objectives?

How would you compare lesson study with a summer course or the type of course you normally do?

What do you personally think are the benefits or drawbacks of lesson study? Which aspects could be improved?

Do you think this project will have any long-term lasting effect on the teaching in this school?

What next steps do you intend taking in relation to the teaching and learning of STEM?

Before we finish, is there anything else you would like to say about the project that has not come up in our conversation?

Appendix L: Research Lesson 1 – Pilot Cycle

STEM Lesson 1

Floating and Sinking

Aim / Learning Objective: Students will investigate floating and sinking with a range of materials and objects. Students should make and test predictions about objects that will sink or float and group objects based on these criteria

Objectives

Science Content Objective(s)

Forces

- investigate how forces act on objects

Maths Content Objective(s)

Comparing

- compare sets without counting
- compare objects according whether the objects floats or sinks

Skills: • Observing, Predicting, Investigating and experimenting, Estimating • Analysing: Sorting and classifying • Recording and communicating

Materials: The Gingerbread Man Story• Containers of water • A selection of different types of objects (that won't be destroyed by being placed in water) such as stones, metal spoons, wood, feather, plasticine etc. • Pencils and worksheets for recording the results.

Introduction - Recap on the story of The Gingerbread Man. Elicit from the children the dangers of the Gingerbread Man attempting to swim across the river at the end of the story.

1. Introduce the concepts of floating and sinking accompanied by images to aid understanding
2. Present the children with a range of items and a container of water. The

teacher will invite predictions whether the children think the items will float or sink

3. Tell the children that they will be conducting their own investigation on floating and sinking, recap on rules in groups and playing with water
4. Distribute sheets to the children with a different set of objects and children will draw or write their predictions on whether the objects will float or sink
5. Distribute containers of water to the children and the children will carry out the investigation, filling in their results on the worksheet
6. Invite children to discuss their results.
7. Explain that you will present two hula hoops which signify a floating set and sinking set and place each item in the water. A child will allocate it into the appropriate set. This will be repeated for all five objects.
8. Show a short video on the BBC website http://www.bbc.co.uk/schools/digger/5_7entry/8.shtml . This will recap on floating and sinking and introduce the children to the idea that objects that contain air will float.

Conclusion: Review the floating set and investigate whether these items contain air? Introduce to children a life jacket a why that works.

Differentiation: Junior Infants were asked to draw their predictions/ results object while Senior Infants were encouraged to write to develop their emergent writing skills.

Appendix L1: Research Lesson 2 – Pilot Cycle

STEM Lesson Reteach

Floating and Sinking

Aim / Learning Objective: Students will investigate floating and sinking with a range of materials and objects. Students should make and test predictions about objects that will sink or float and group objects based on these criteria

Objectives

Science Content Objective(s)

Forces

- investigate how forces act on objects

Maths Content Objective(s)

Comparing

- compare sets without counting
- compare objects according whether the objects floats or sinks

Technology Content Objective(s)

- Photos are taken on the iPad of children's investigations

Skills: • Observing, Predicting, Investigating and experimenting, Estimating • Analysing: Sorting and classifying • Recording and communicating

Materials: The Gingerbread Man Story • Containers of water • A selection of different types of objects (that won't be destroyed by being placed in water) such as stones, metal spoons, wood, feather, plasticine etc. • Pencils and worksheets for recording the results.

Introduction - Recap on the story of The Gingerbread Man. Elicit from the children the dangers of the Gingerbread Man attempting to swim across the river at the end of the story.

1. Introduce the concepts of floating and sinking accompanied by images to aid understanding
2. Present the children with a range of items and a container of water. The teacher will invite predictions whether the children think the items will float or sink.
3. Tell the children that they will be conducting their own investigation on floating and sinking, recap on rules in groups and playing with water
4. Children will discuss their predictions with their buddy and the teacher will document this on the board
5. Distribute containers of water to the children and the children will carry out the investigation, filling in their results on the worksheet
6. Invite children to discuss their results.
7. Explain that you will present two hula hoops which signify a floating set and sinking set and place each item in the water. A child will allocate it into the appropriate set. This will be repeated for all five objects.
8. Show a short video on the BBC website http://www.bbc.co.uk/schools/digger/5_7entry/8.shtml . This will recap on floating and sinking and introduce the children to the idea that objects that contain air will float.

Conclusion: Review the floating set and investigate whether these items contain air?

Differentiation: Junior Infants were asked to draw their predictions/ results object while Senior Infants were encouraged to write to develop their emergent writing skills.

Appendix M: Research Lesson 1 – Cycle 2

Research lesson title: An egg drop challenge What material will protect Humpty Dumpty when he falls from the wall?
Long-term goals: • Encourage teachers to move from dialogical and traditional teaching methodologies to the inquiry-based approach • Encourage students to exercise their problem-solving skills by promoting critical thinking
Learning outcomes of the research lesson: • Children will begin to understand the concept of fair testing • Children will describe and compare materials, noting the differences in colour, shape and texture • Children will make and test predictions • Children will carry out simple investigations set by the teacher, carry out observations and collect data
Lesson rationale: How can we design an experiment that will support the development of children's knowledge regarding the properties of materials? The lesson draws on the children's prior knowledge as new learning is connected to existing ideas. Humpty Dumpty is our stimulus, as the children are able to relate to the nursery rhyme and to the problem. We are using materials that the children have easy access to and explore the effectiveness of materials to protect the egg. Children will investigate materials for different properties i.e. ability to protect the egg Lesson Steps The teacher will discuss the nursey rhyme Humpty Dumpty with the children The teacher will record children's suggestions on the board of how Humpty could be protected when he falls from the wall S- Present the children with the materials and investigate materials for different properties i.e. which can protect Humpty from a fall. Children will make their predictions and record them on their worksheet The materials, Ziploc bags and eggs will be distributed. The children will take turns to give the eggs faces and names T- 1 senior infant from each group will record the egg drop on an I Pad, the children will then explain their recordings/ pictures at the end of the lesson E- prior to this lesson the children made a wall for Humpty as high as they could from blocks. The walls had to stand by themselves for five minutes. The children learned to make a sturdy wall, they learned the key was a wide base M- children make a set of materials that protected Humpty and a set of materials that failed to protect Humpty Children become familiar with a metre stick Children make sets of objects that protect/ do not protect the egg

How pupil's understanding of this topic is intended to develop: Children will develop their understanding of the different properties of materials i.e. What materials are better able to protect the egg
Where the lesson relates to the curriculum: Curriculum Objectives: Science: investigate materials for different properties i.e. which can protect Humpty from a fall Maths: sort and classify objects on the basis of one attribute i.e. what materials protect/ do not protect Humpty
How pupil learning will be assessed: Teacher Observation The recording of results by the pupils Teacher questioning and probing Children will discuss their pictures recorded on the iPad to the class Children will conclude by making a set of objects that protected the eggs and a set of objects that failed to protect the egg
Teaching and learning materials: Hard boiled eggs Zip lock bags Materials: water, cotton wool , shredded paper Metre sticks Prediction and results sheets Ipads

Appendix M1: Research Lesson 2 – Cycle 2

Theme	What material will cushion Humpty Dumpty when he falls from the wall? (Reteach) An egg drop challenge
Curriculum	**Strand: Materials** **Strand Unit:** Properties and characteristics of materials **Curriculum Objectives: Science:** investigate materials for different properties i.e. which can protect Humpty from breaking when he falls off of the wall **Maths:** Sets: classify objects on the basis of one attribute i.e. what material can / cannot protect Humpty **Skills Development:** Carry out simple investigations set by the teacher, carry out observations and collect data.

Engage

The Trigger	Wondering	Exploring
Teacher begins by telling the children she bought in Humpty Dumpty today so that the children could help her recite her favourite nursery rhyme As they are reciting Humpty Dumpty the teacher 'accidentally' knocks Humpty and he falls to the floor and breaks.	How can we protect Humpty Dumpty from breaking when he falls from the wall? Brainstorm ideas and write materials on the whiteboard Discuss items around the room.	Explore / manipulate materials provided Cotton wool Shredded paper Marbles Leaves Discuss the materials Similarities / differences Strong, weak, hard, soft Do you know what it is? Have you seen it before?

Investigate

Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results

1. Which materials do you think will keep Humpty from breaking and why? 2. Which materials do you think will make Humpty break and why? 3. Which of these materials would work best to protect Humpty? (Include wait time between questions)	Predict which material will protect Humpty based on previous knowledge and having explored the materials provided Explain that one child per group has a job 1: Records the predictions 2: Records Results 3. Drops the bag Next, teacher fill in the predictions column on the board	Fill each ziplock bag with different materials Explore the idea of fair testing Explain the positioning of the egg in relation to the material Explain the positioning of the bag on the table Attach the A3 sheets of the mock walls to each groups table Drop each of the bags from the table and record the results for each in the results column.	Discuss and show results Compile class results. Make a set of items that protected Humpty and a set of items that did not protect Humpty	

Take The Next Step

Applying Learning	Making Connections	Thoughtful Actions

Assessment: Each group will explain their recordings to the class on the iPad

How could we improve the design?

How do you think the materials can be used in a different way to keep Humpty from cracking?

Reflection	Did we meet our learning objectives? Are the children moving on with their problem- solving skills/ critical thinking skills? Was the iPad appropriate for children to use Record their investigation Formed a good basis for assessment? What questions worked well?

Appendix N: Research Lesson 1 – Cycle 3

Theme	Making a boat for the Gingerbread Man
Curriculum	**Strand: Energy and forces** **Strand Unit:** Forces **Curriculum Objectives:** investigate how forces act on objects **Science- Working scientifically** Predicting- guess and suggest what will happen next in structured situations Investigating and experimenting- carry out simple investigations set by the teacher, make observations and collect data **Design and make** Exploring: handle and manipulate a range of materials in structured and unstructured situations. Planning: imagine a possible object to be made. Talk about the plan and communicate it to others. Making- make simple objects. Evaluating- talk about own work during design and making tasks. Report to others on what has to be done. Discuss the work of peers in a positive way. **Maths** Number- Counting- count objects Shape and space- Spatial awareness- Explore, discuss, develop and use the vocabulary of spatial awareness Shape and Space- 3-D Shapes- solve tasks and problems involving shape **Engineering** Children will engage in the engineer design process using iteration to try and create

	a boat that can float Use creative and critical thinking to design, test and evaluate their boat design and the design of others **Technology** Children will collaborate and use tinfoil to make their boat

Engage		
The Trigger	Wondering	Exploring
Recap on the story of the gingerbread man. Explain to the children that last night you tried to make a boat so that the gingerbread man could get across the river. Place the gingerbread in the tinfoil boat Watch as the gingerbread man and boat sink.	'I wonder could all of you make a boat for the gingerbread man to get across the river in...'	Explain to the children that in pairs we will explore making a boat using tinfoil Model for the children a simple design of a boat

Investigate			
Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results
Ask the children can they design a boat for the gingerbread man on the paper distributed	Tinfoil is then distributed and children design their boats in pairs. For fair testing each group will be given the same amount of tinfoil Have a short class discussion on different children's	If their boat is floating can the children take some 'passengers' (cubes)? Model this at the top of the room with the teacher's own designed boat Children then test the number of cubes the boat will hold before	Can they alter the shape so that the boat will take more 'passengers' before it sinks? Whose boat takes the most 'passengers?

	models of boats Now see if they can get their boat to float.	it sinks. Children will then draw the finished boat design	Investigate and discuss what children did to improve their design (Include wait time between questions)

Take The Next Step		
Applying Learning	Making Connections	Thoughtful Actions

Assessment: How could we improve the design?

Self -assessment- children will assess if their boat is sinking or floating?

Peer assessment- children will observe other boat designs and the success of other designs

All children will carry out the task and describe their observations using simple language

Most children will record their findings on their activity sheet

Some children will offer explanations on why their design floated or sank

Reflection	Did we meet our learning objectives? Were children able to design and make a boat that can float? Were children able to record their findings? What went well? What could I change?

Appendix N1: Research Lesson 2 – Cycle 3

Theme	Can you make a boat for the Gingerbread Man/ Woman (Reteach)
Curriculum	**Strand: Energy and forces** **Strand Unit:** Forces **Curriculum Objectives:** investigate how forces act on objects and investigate characteristics of materials **Science- Working scientifically** Predicting- guess and suggest what will happen next in structured situations Investigating and experimenting- carry out simple investigations set by the teacher, make observations, collect data and make conclusions **Design and make** Exploring: handle and manipulate a range of materials in structured and unstructured situations. Planning: imagine a possible object to be made. Talk about the plan and communicate it to others. Making- make simple objects. Evaluating- talk about own work during design and making tasks. Report to others on what has to be done. Discuss the work of peers in a positive way. **Maths** Number- Counting- count 10 cubes and make gingerbread men Shape and space- Spatial awareness- Explore, discuss, develop and use the vocabulary of spatial awareness Shape and Space- 3-D Shapes- solve tasks and problems involving shape **Engineering** Children will engage in the engineer design process to try and create a boat that can

	float Use creative and critical thinking to design, test and evaluate their boat design and the design of others **Technology** Children will use recycled materials to make a boat that can carry the Gingerbread Man/ Woman

Engage		
The Trigger	Wondering	Exploring
Recap on the story of the gingerbread man. Explain to the children that last night you tried to make a boat so that the gingerbread man could get across the river. Place the gingerbread in the tinfoil boat Watch as the gingerbread man and boat sink.	'I wonder could all of you make a boat for the gingerbread man to get across the river in...' Because we don't have a gingerbread man for everybody we are going to make one from 10 cubes. Could you count out ten cubes and make some gingerbread passengers for your boat?	Explain to the children that in pairs they will explore making a boat using recyclable materials

Investigate			
Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results
Model a boat for the children, talk about wide/ narrow, long /short Ask the children	The children can access the different materials and begin making their boat Have a short class discussion on different children's models	Once they have it floating can they get it to take some 'passengers' (cubes)? Model this at the top of the room with the teacher's own designed boat Children then test the number of	If they alter the shape so that the boat will take more 'passengers' before it sinks? Whose boat takes the most 'passengers? Investigate and discuss what children did to

to design their boat on a blueprint	of boats Now see if they can get it to float.	cubes the boat will hold before it sinks. Children will then draw the finished boat design	improve their design What did we learn about the materials? (Wait time)	

Take The Next Step		
Applying Learning	Making Connections	Thoughtful Actions

Assessment:

How could we improve the design?

Self -assessment- children will assess if their boat is sinking or floating? Peer assessment- children will observe other boat designs and the success of other designs

All children will carry out the task and describe their observations using simple language
Most children will record their findings on their activity sheet
Some children will offer explanations on why their design floated or sank

Higher- ability children- see if children can count in tens for the number of cubes for gingerbread men/ women

Reflection	Did we meet our learning objectives? Were the children able to design and make a boat that can float? Were the children able to record their findings? Were the children able to critically evaluate their boat? Could they compare their design to others? What went well? What could we change?

Appendix O: Research Lesson 1 – Cycle 4

Theme	Can you make a chair for Goldilocks?
Curriculum	**Strand: Materials** **Strand Unit:** Properties and characteristics of materials **Curriculum Objectives: Science:** investigate materials for different properties i.e. make a chair that will hold a Barbie **Skills Development:** Design and make: handle and manipulate Lego in a structured situation Observe: investigate and describe familiar objects Planning: talk about a plan and communicate it to others Making: make simple objects Evaluate: talk about own work during the design and making tasks **Curriculum Objectives: Maths:** combine 3-D shapes to make other shapes solve tasks and problems involving shape **Skills Development:** Reasoning: justify the process or results of activities Communicating and expressing: discuss and explain mathematical activities Integrating and connecting: carry out mathematical activities that involves other areas of the curriculum **Engineering** Children will engage in the engineer design process using iteration to try and create a chair from Lego

	Use creative and critical thinking to design, test and evaluate their chair design and the design of others **Technology** The children using Lego to construct their chair

Engage		
The Trigger	Wondering	Exploring
The teacher records the main event story line and engages the children in discussion What did Goldilocks do wrong? How could we help Goldilocks say sorry to the three bears? Can she un- eat the porridge? Can she un- sleep the bed? Can she repair the chair or build another? (Wait time)	ın we build a chair for Goldilocks (Barbie doll), it must have a seat, back and 4 legs.	Explore pictures of chairs on the interactive whiteboard Explain the differences and materials

Investigate			
Starter Question	Predicting	Conducting the Investigation	Sharing: Interpreting the data / results
Can we (in our groups) make a chair for Barbie using Lego?	Children get a worksheet for their group to sketch their proposed design of their chair (Differentiation of task with photo and cubes for Child A)	After the sketch children can begin building Children test their design by sitting Barbie on the chair Teacher circulates with the iPad recording in pictures and how the children describe their chair Differentiation: One child gets different	All children circulate in the classroom to observe the designs of their peers Discuss and show various chair designs and how their chair supported Barbie Revise the design and test again as needed

		resources (blocks) and an image of the finished chair Conducts build on his own	

Take The Next Step		
Applying Learning	Making Connections	Thoughtful Actions

Assessment: Each group will explain their recordings to the class on the iPad

How could we improve the design?

Could we make a chair with three legs?

Self -assessment- children will assess if their chair holds Goldilocks?
Peer assessment- children will observe other chair designs and the success of other designs

All children will carry out the task and describe their observations using simple language
Most children will record their findings on their activity sheet
Some children will offer explanations on why their chair could hold Goldilocks

Reflection	Did we meet our learning objectives? Are the children moving on with their STEM skills? Did Child A participate? Was the iPad appropriate for children to use to record their investigation Formed a good basis for assessment?

Appendix O1: Research Lesson 2 – Cycle 4

	A Chair for Baby Bear (Reteach)
Curriculum	**Strand: Materials** **Strand Unit:** Properties and characteristics of materials **Curriculum Objectives: Science:** investigate materials for different properties i.e. make a chair that will hold a Sylvanian family member **Skills Development:** Design and make: handle and manipulate Lego in a structured situation Observe: investigate and describe familiar objects Planning: talk about a plan and communicate it to others Making: make simple objects Evaluate: talk about own work during the design and making tasks **Curriculum Objectives: Maths:** combine 3-D shapes to make other shapes solve tasks and problems involving shape **Skills Development:** Reasoning: justify the process or results of activities Communicating and expressing: discuss and explain mathematical activities Integrating and connecting: carry out mathematical activities that involves other areas of the curriculum **Engineering** Children will engage in the engineer design process using iteration to try and create a chair from Lego Use creative and critical thinking to design, test and evaluate their chair design and the design of others **Technology**

<table>
<tr><td></td><td colspan="4">The children using Lego to construct their chair</td><td></td></tr>
<tr><td colspan="5">Engage</td><td rowspan="6">Considerations for inclusion:
Differentiation of task with photo and cubes</td></tr>
<tr><td colspan="2">The Trigger</td><td>Wondering</td><td colspan="2">Exploring</td></tr>
<tr><td colspan="2">The teacher begins by recapping with the children on the story of the Goldilocks and the 3 Bears

What did Goldilocks do wrong?

How could we help Goldilocks say sorry to the three bears?

Can she un- eat the porridge?

Can she un- sleep the bed?

Can she repair the chair or build another?

(Wait time)</td><td>Can we build a chair for Baby Bear, it must have a seat, back and 4 legs.</td><td colspan="2">Compare the childrens' classroom chair to the teachers' chair

Language: the legs of the chair are longer, the seat of the chair is bigger

Vocab: longer, shorter, wider and narrower

Explain the differences and materials</td></tr>
<tr><td colspan="5">Investigate</td></tr>
<tr><td>Starter Question</td><td>Predicting</td><td>Conducting the Investigation</td><td colspan="2">Sharing: Interpreting the data / results</td></tr>
<tr><td>1 Can we (in our groups) make a chair for one of the Sylvanians using Lego?</td><td>Children get a worksheet for their group to sketch their proposed design of their chair</td><td>After the sketch children can begin building

Children test their design by sitting one of the Sylvanian families on the chair

Teacher circulates and discusses with the children how they constructed their chair (10mins)</td><td colspan="2">All children circulate in the classroom to observe the designs of their peers

Discuss and show various chair designs and how their chair supported the Sylvanian

Revise the design and test again as</td><td></td></tr>
</table>

		Differentiation: One child gets different resources (blocks) and an image of the finished chair Conducts build with the Special Needs Assistant	needed

Take The Next Step

Applying Learning	Making Connections	Thoughtful Actions

Assessment:

How could we improve the design?

Could we make a chair with three legs?

Could you now make a chair for Daddy Bear, Mammy Bear and Baby Bear.

Self -assessment- children will assess if their chair holds the Sylvanian family member?

Peer assessment- children will observe other chair designs and the success of other designs

All children will carry out the task and describe their observations using simple language

Most children will record their findings on their activity sheet

Some children will offer explanations on why their chair could hold Baby Bear

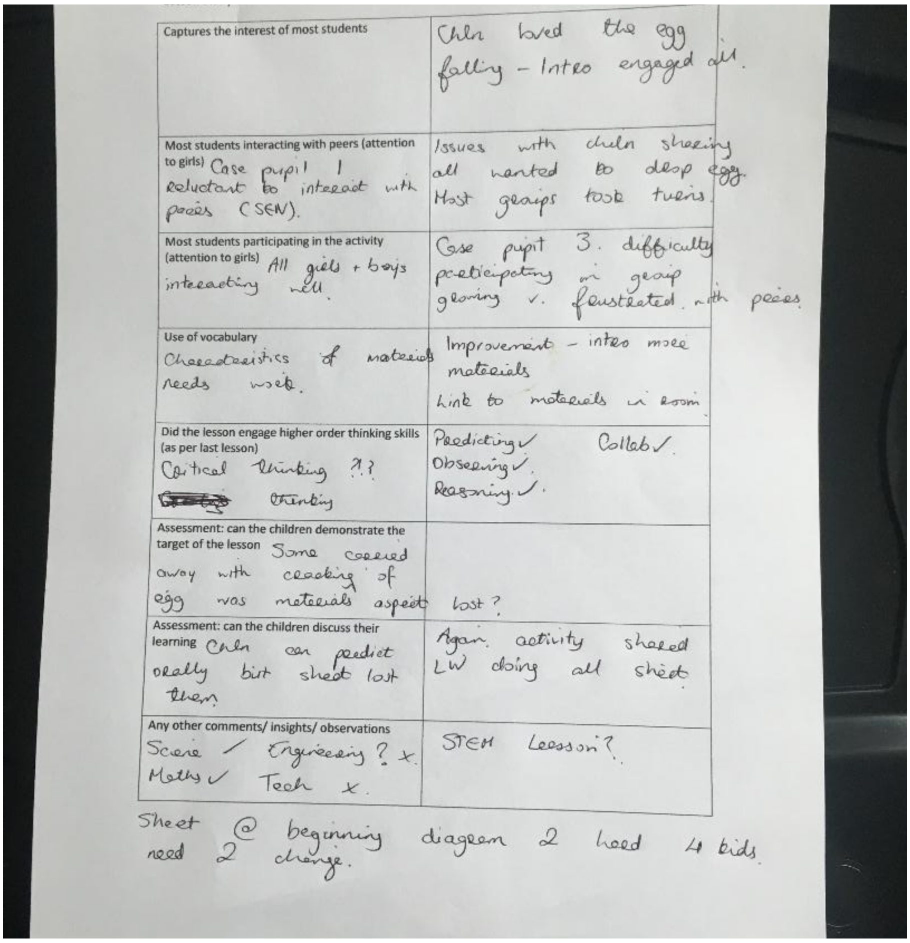
Reflection	Did we meet our learning objectives? Are the children moving on with their STEM skills? Did child with SEN succeed in building chair with the Special Needs Assistant? Was the iPad appropriate for children to use to record their investigation Formed a good basis for assessment?

Appendix P: Lesson Study Observation Checklist

Lesson Study Observation Checklist

Captures the interest of most students	
Most students interacting with peers (attention to girls, case pupils)	
Most students participating in the activity (attention to girls, case pupils)	
Use of vocabulary	
Did the lesson engage higher order thinking skills (as per last lesson)	
Assessment: can the children demonstrate the target of the lesson	
Assessment: can the children discuss their learning	

Appendix Q: A Worked Example of Lesson Study Observation Checklist



Captures the interest of most students	Chln loved the egg falling – Intro engaged all.
Most students interacting with peers (attention to girls) Case pupil 1 reluctant to interact with peers (SEN).	Issues with chdn sharing all wanted to drop egg. Most groups took turns.
Most students participating in the activity (attention to girls) All girls + boys interacting well.	Case pupil 3. difficulty participating in group growing v. frustrated with peers
Use of vocabulary Characteristics of materials needs work.	Improvement – intro more materials Link to materials in room
Did the lesson engage higher order thinking skills (as per last lesson) Critical thinking ?? [crossed out] thinking	Predicting ✓ Collab ✓. Observing ✓. Reasoning ✓.
Assessment: can the children demonstrate the target of the lesson Some carried away with cracking of egg was materials aspect	lost?
Assessment: can the children discuss their learning Chln can predict orally but sheet lost them	Again activity shared LW doing all sheet.
Any other comments/ insights/ observations Science ✓ Engineering ? x Maths ✓ Tech x.	STEM Lesson?

Sheet @ beginning diagram 2 hard 4 kids need 2 change.

Appendix R: Sample List of Raw Codes

Children's motivation

Value of inquiry- based learning for children's learning

Children's language

Value of play

Underestimated children's learning

Children being active in their learning

Challenge of time for STEM lessons

Integrating all four elements into a STEM lesson

Teacher Isolation- collaboration

Value of observation

Confidence with science

Wait time- thinking about children's learning

Promoting children's resilience through STEM

Promoting children's reflection and thinking time

Gap in science knowledge in density

Surprised by childrens thinking

Teacher insecurity about science knowledge

Importance of critical thinking in children

Difficulty of buy- in of teachers

Apprehension surrounding STEM

Appendix S: A Worked Example of Thematic Analysis from an Initial Interview with Maria

Data Extract	Code
What are the important traits of CPD?	
Well that they would be relevant is the starting thing, but I suppose I wouldn't have signed up for them if they weren't relevant. And that they are that they gave you food for thought on teaching skills and maybe even to how we can approach children, how we get insights into how children learn. I guess from my point of you now it is a lot of focus on children with difficulties and needs because you know you often hear that the children who are bright will learn anyway. But it's the children who are struggling, and you keep trying different methods and you know they have to over- learn everything. And that's something that we need, the children aren't retaining, but yet you just keep going and going and maybe try different approaches. So, yes, CPD anything to do with maths and, you know, literacy, I find if it opens up new insights great	Relevance of professional development important Focus on children's learning Focus on children with needs Differentiation of learning for children Different teaching approaches Importance of maths and literacy
When did you last avail of CPD in science or STEM?	Ambivalent towards science and STEM
I guess like that science or STEM it wouldn't have been an area that would have particularly interested me. Because I would have maintained that if the children can read and write and do their maths and do their Irish. It was very much the core subjects with me. And then I said if they have all those skills everything is all okay. Everything is opened them once they can read it and they can access it once they have the basic skills.	Importance of 'core subjects' Life skills

Appendix T: Grouping Initial Codes under 'Candidate Themes'

Theme: LS enabled greater collaboration amongst the participating teachers

Subtheme 1: LS contributed to the collective vision of the school and to a stronger community of teachers

Stronger community of teachers/ leadership perspective /long term result – benefit to team teaching
Principal: I think it [lesson study] benefits in- class support, it's definitely a benefit in terms of we've gone from total withdrawal whereas now were an awful lot more comfortable with people coming into our rooms. So that's a huge benefit that has gone hand in hand and it seems to be naturally going on. So I mean in the morning if you said 'look you teach that and I'll do that' that would happen an awful lot easier (Final Interview)

Maria: And the other thing was its was a whole school approach so that meant everybody was on board and everybody was trying to set up targets and achieve them. So it was kind of a whole school effort rather than somebody coming along and saying you know what .... I did a great course and somebody is really enthusiastic about it but you aren't ... So that was good from that point of view. And it was a positive thing working together and knowing that yeah we're going to implement this (Final Interview)

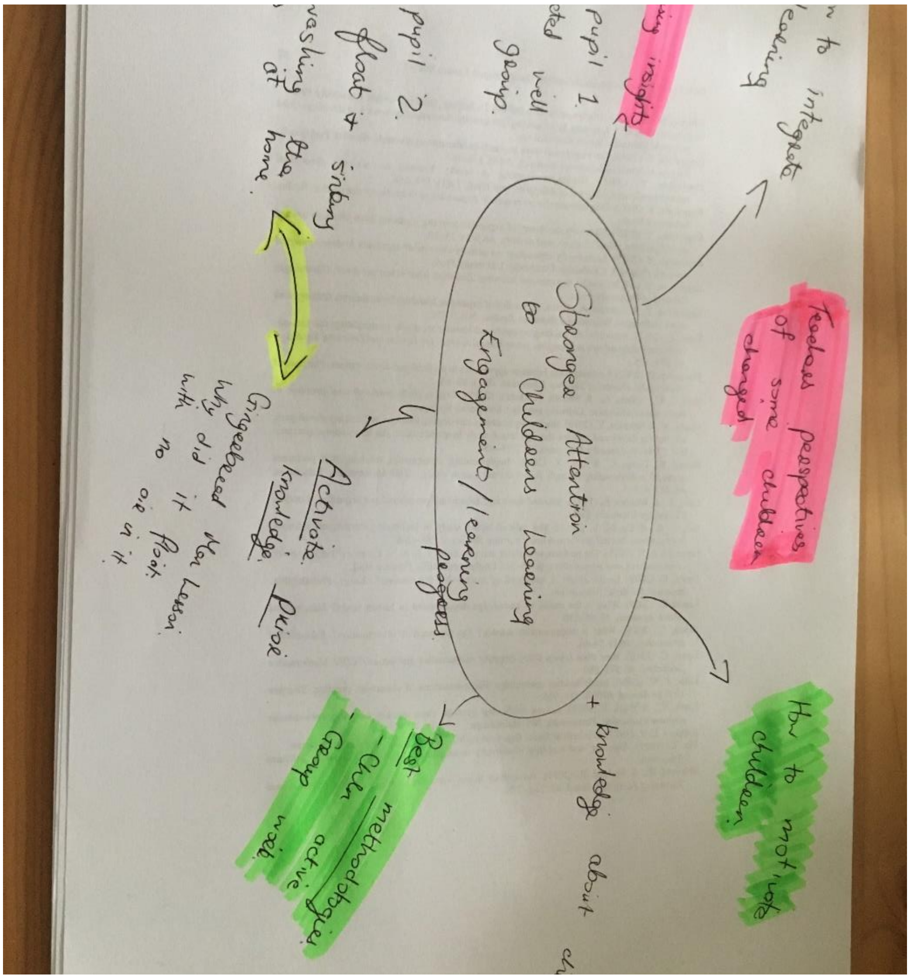
Benefits of LS to collective vision of stem
Principal; 'It [lesson study] definitely drove it on'
'LS certainly drove it us on for us here at school' (Final Interview)

LS and professional dialogue, confidence, leadership perspective/ problem solving staff
Principal: You know at the start of the year and our apprehension 'what is stem? How did you teach it?' And even our planning in the school is STEM through maths or science? All of that debate and conversation was brilliant (Final Interview)

Leadership perspective - benefiting the whole school- collaborating and professional dialogue

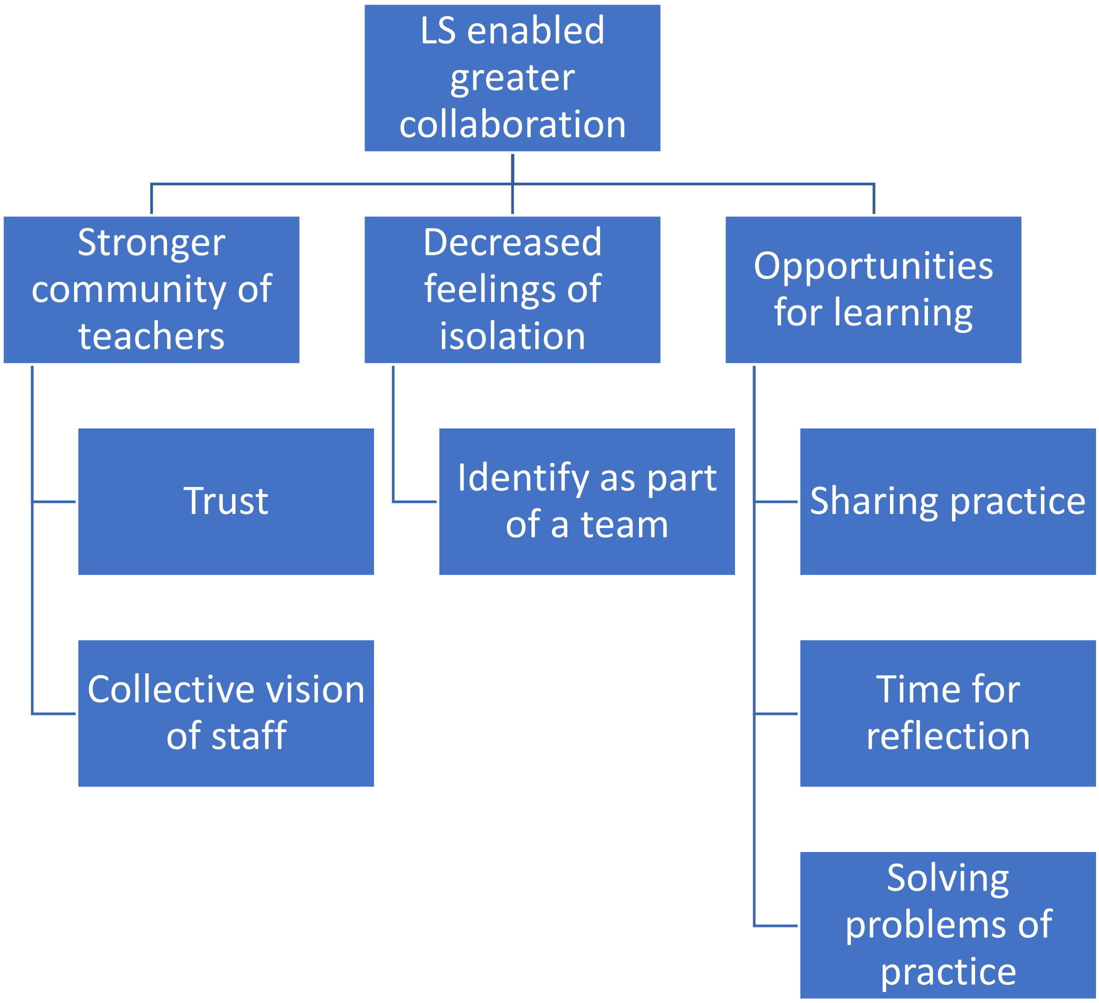
Principal: 'It's lovely to hear what's gone on in other classrooms like it's even with you and the Lego and making the chairs and then you find they couldn't join the blocks... that's fascinating because we are talking and that's the collaboration and generating more knowledge' (Final Interview)

Appendix U: Mind-Map of Initial Codes and Candidate Themes

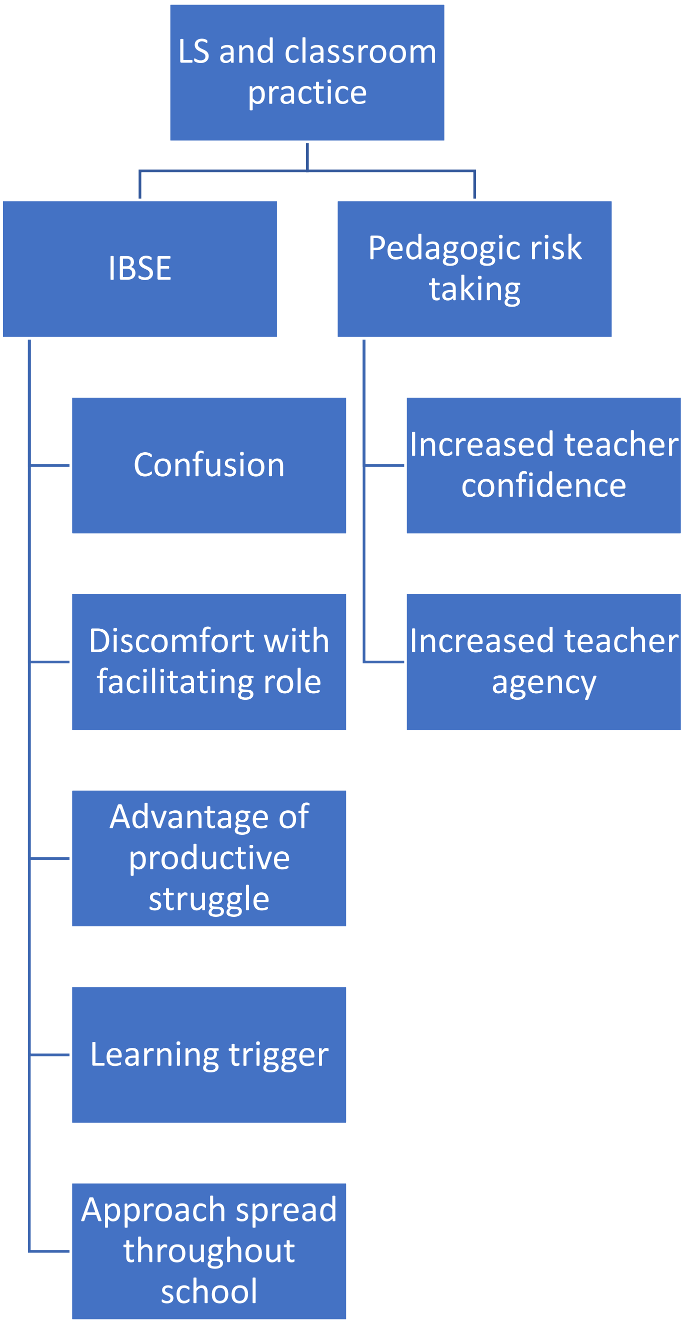


Appendix V: Developing the Themes, Subthemes and Codes

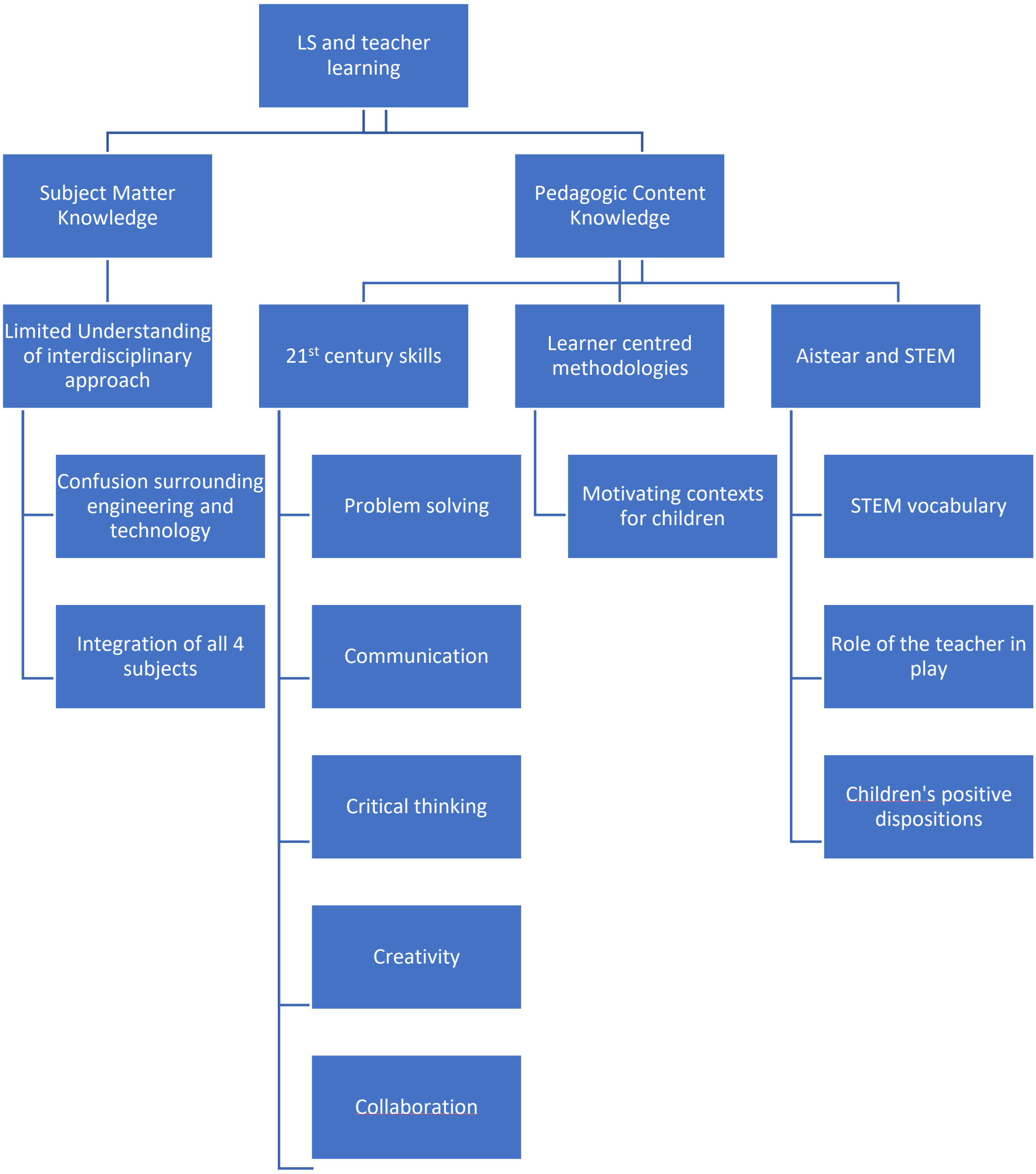
Theme 1: LS enabled greater collaboration amongst the participating teachers



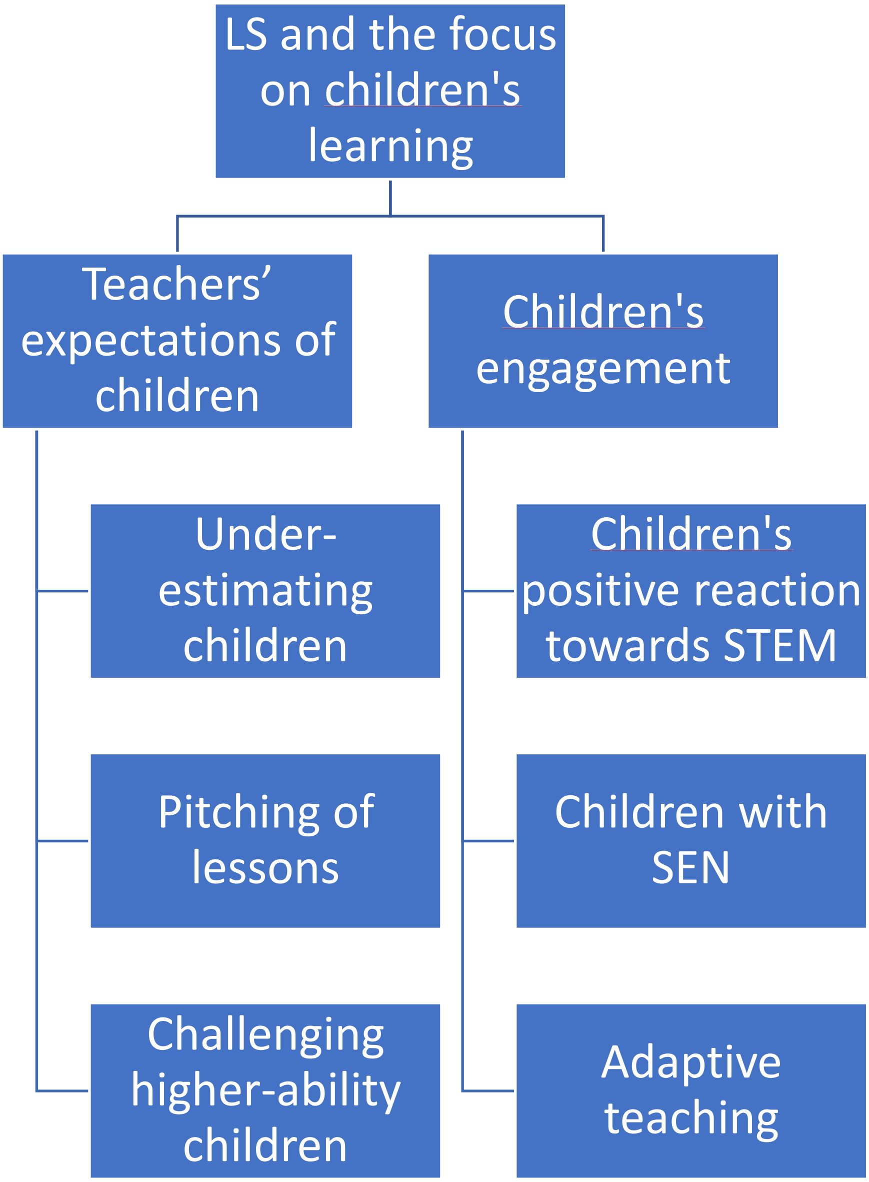
Theme 2: LS and the impact on classroom practice



Theme 3: LS and the development of teacher learning



Theme 4: LS and the increased focus on children’s learning



Theme 5: Factors that affected teacher engagement in LS