Lesson Study as a form of in-School Professional Development:

Case studies in two post-primary schools

Aoibhinn Ní Shúilleabháin

School of Mathematical Sciences
University College Dublin

January 2015

NCCA
An Chomhairle Náisiúnta Curaclaim agus Measúnachta
National Council for Curriculum and Assessment

Contents

Figures

Tables

Acknowledgements

This research would not have been possible without the generosity of the Mathematics teachers who gave so freely of their time, expertise, and knowledge throughout this study. Furthermore the principals, staff, and students of the two schools involved were incredibly important in welcoming this educational research to their schools and in supporting their colleagues participating in the project.

This report is based in part on my doctoral dissertation completed at the School of Education, Trinity College Dublin, under the supervision of Dr. Aidan Seery. The research reported here was assisted by the National Council of Curriculum and Assessment who supported the two post-primary schools participating in this research. This study was also sponsored by an Ussher Fellowship postgraduate award from Trinity College Dublin.

Abbreviations

KCS	Knowledge of Content and Students
KCT	Knowledge of Content and Teaching
NCCA	National Council for Curriculum and Assessment
PCK	Pedagogical Content Knowledge
PMDT	Project Maths Development Team

Introduction

This research investigated the introduction of a model of in-school professional development which would support mathematics teachers in their practices at a time of curriculum reform. Lesson study, a model of Japanese origin, was a model that would provide teachers with a structure within which they could collaborate and engage with new pedagogical practices encouraged as part of the Project Maths initiative. Twelve teachers in two post-primary schools volunteered to participate in the research which lasted for one academic year.

Qualitative data was generated in both schools through audio recordings of all teacher meetings conducted around lesson study and through interviews with participating teachers. The researcher participated in the investigation as a participant-observer in facilitating the introduction of lesson study to teachers and in participating in meetings as a former Mathematics teacher. The data was analysed thematically in iterative stages utilising a framework of pedagogical content knowledge (PCK) as suggested by Ball, Thames, and Phelps (2008).

Data analysis suggests that as a result of teachers' participation in lesson study, teachers developed their PCK and incorporated reform teaching approaches as part of their classroom practices. A number of teachers reported that their familiarity with and confidence in teaching the new mathematics syllabus improved. Furthermore, teacher communities of both schools developed through their participation in lesson study. Findings related to teacher learning and to the introduction of lesson study in two Irish post-primary schools are reported here.

This report is written as a summary of findings on research into teacher professional development which was supported by the NCCA and also as an introductory guide for teachers interested in lesson study. All references to participating teachers and schools are pseudonyms and any identifiable references have been removed from this report.

Educational Reform and Professional Development

Teachers play a key role in educational reform. Reforms typically impose new demands on the already complex work of teaching and it is therefore important that teachers are provided with professional development supports and opportunities to engage meaningfully with any reforms they are being asked to implement (Charalambos & Philippou, 2010; Hanley & Torrance, 2011; Remillard & Bryans, 2004).

This research was conducted following the introduction of Project Maths. This revised syllabus brought with it a change in content taught to post-primary mathematics students and also encouraged a change in the approach to the teaching and learning of mathematics from a commonly traditional exposition-based classroom (Lyons, Lynch, Close, Sheerin, & Boland, 2003; Oldham, 2001), to one encouraging communication of mathematical thinking with a focus on developing students' higher-order problem-solving skills. While structured in-service professional development opportunities were offered to teachers as part of this particular curriculum reform, this research investigated an alternative model of supporting teachers in their practices through school-based teacher community.

Teacher Community

A challenge in achieving sustainable reform is that most teachers teach alone in isolated classrooms without the opportunity to observe other teachers or reflect on their own practices (Remillard, 2005). While there is much recent focus on the social elements of learning for students, research increasingly refers to the importance of considering the social dimensions of learning for teachers (Grossman, Wineburg, & Woolworth, 2001; Hord, 2004) and it is widely recognised that teacher communities figure among the most important factors for promoting educational change within schools (de Lima, 2001; OECD, 2009). A key rationale for teacher community is that it provides an ongoing venue for teacher learning, provides teachers with social structures for professional collaboration and collegiality, and provides teachers with a means to engage with educational and curricular policies within the environment and realities of their own schools (Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009; Dooner, Mandzuk, & Clifton, 2008; Guskey, 2002; Louis & Marks, 1998; T. H. McLaughlin, 2004; M. W. McLaughlin & Talbert, 2006; van den Akker, 2003).

Teacher Learning and Lesson Study

Lesson study is a form of teacher professional development that is based on teacher collaboration and teacher community. The expression 'lesson study' is a literal translation from the Japanese word *Jugyokenky* where *jugyo* means lesson and *kenkyu* refers to study or research. The translation can be misleading in a sense that lesson study is more than a study of lessons, but rather is an investigation of teachers into their own practices through planning, conducting, observing, and reflecting on research lessons (Conway & Sloane, 2005; C. Fernandez, Cannon, & Chokshi, 2003; Corcoran, 2011a; Fernández & Robinson, 2006; Murata, Bofferding, Pothen, Taylor, & Wischnia, 2012; Murata & Takahashi, 2002; Takahashi & Yoshida, 2004).

A cycle of lesson study consists of the following steps portrayed in Figure 1:

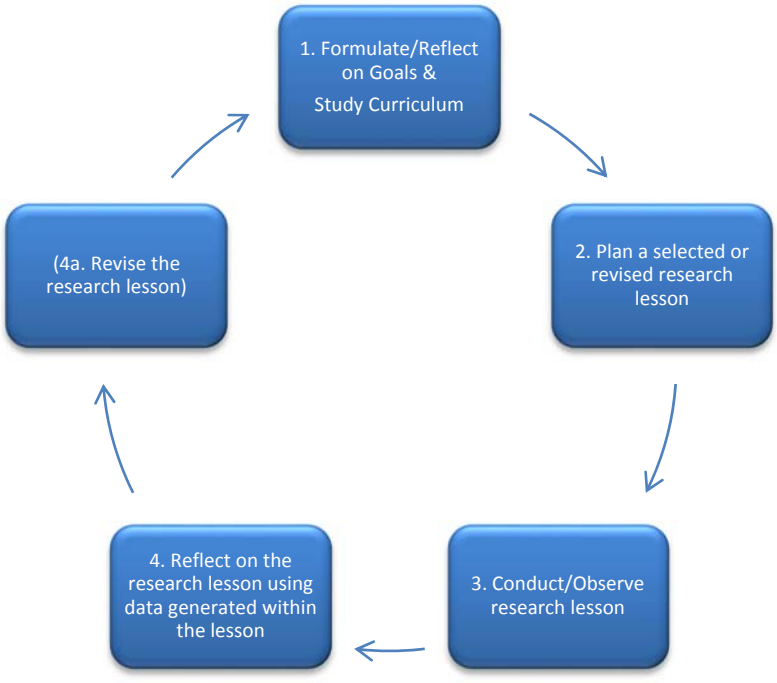


Figure 1 Lesson study cycle adapted from Lewis et al. (2009)

As part of the first step, teachers decide on an overall goal for their teaching which will guide their practices in lesson study. Teachers then directly access the curriculum, decide on a topic to teach within that cycle, and build a lesson plan around particular learning objectives (Lewis, Perry, & Hurd, 2009). Following step 2 of collaboratively planning content and materials for the lesson, one teacher conducts the research lesson while other members of the lesson study community attend and observe that lesson. This observation of the research

lesson is an important phase of the cycle which differs to other forms of teacher observation since all teachers have engaged with the planning and observation of the lesson. Teachers then collectively reflect on the lesson and may decide to alter and re-teach it or continue to another cycle of lesson study (Fernandez & Chokshi, 2004).

Since this investigation occurred during a time of reform of the post-primary mathematics curriculum, it was important to incorporate professional development practices which would support teachers in engaging with the reform and in encouraging changes to traditional classroom practices. Remillard (2000) and Hanley & Torrance (2011) note that through engaging directly with curriculum materials and through seeing a curriculum enacted, teachers are encouraged to incorporate changes to their practices as part of curriculum reform. The four stages of lesson study directly reflect these curriculum reform practices of engaging with and enacting curriculum materials. Furthermore, lesson study encompasses observation and reflection which encourages teachers to notice student mathematical thinking during research lessons and structures teachers' reflection on their own pedagogical practices (Corcoran, 2011b; Jacobs, Lamb, & Philipp, 2010; Mason, 2002; van Es & Sherin, 2008).

Previous research conducted both in Ireland and internationally suggests that participation in lesson study holds potential to develop teachers' content and pedagogical content knowledge (Corcoran, 2011b; C. Fernandez et al., 2003; Leavy, Hourigan, & McMahon, 2010; Lewis, Perry, & Murata, 2006). Murata et al. (2012) found that primary teachers developed in their understanding of student learning through conversations around planning a research lesson. Aligning with Murata et al.'s (2012) research, Cjakler et al. (2013), in their study involving four UK secondary school mathematics teachers, found that teachers began to develop less teacher-centred approaches and focused more on students' thinking through participating in lesson study. In Lewis et al.'s (2009) research they concluded that teacher participation in lesson study impacted on their teaching and learning practices and beliefs and Dudley (2013) found that teachers were more inclined to build in new approaches or take 'risks' in their teaching due to participation in lesson study. These studies suggest that through participation in lesson study, teachers are provided with opportunity to build on their understanding of teaching and learning approaches, to begin to incorporate new practices in their own teaching, and to develop in their approach to building students' mathematical understanding.

Furthermore as a form of professional development, participation in lesson study can help teachers develop a sense of community so that introduction of reforms can feel less daunting

and more manageable as a consequence of developing of collaborative pedagogy (Lewis et al., 2009).

Leading from this rich research literature, this study aimed to investigate whether lesson study could be introduced as a form of professional development within Irish post-primary mathematics departments. In addition the research questioned how participation in lesson study would impact on teachers' PCK, referencing new pedagogical approaches highlighted within the Project Maths initiative.

Pedagogical Content Knowledge

Mathematics education research has found that while teachers' subject content knowledge can be an important factor in teaching mathematics (Campbell et al., 2014; Hill, Rowan, & Ball, 2005; Krauss et al., 2008), teachers' PCK also plays a vital role in students' learning experiences (Deborah L. Ball, Thames, & Phelps, 2008; Campbell et al., 2014; Hill, Ball, & Schilling, 2008). Shulman (1976) first referenced 'pedagogical content knowledge' as the knowledge unique to teachers as an amalgam of content and pedagogy which allows teachers to represent information in a number of ways that are particular and relevant to their own students. While there are a number of frameworks of mathematical knowledge for teaching (Rowland, 2014), in this research the multi-dimensional nature of teacher knowledge is incorporated within a framework suggested by Ball et al. (2008) which encompasses teachers' knowledge of mathematics and how to teach that mathematics to their students (Figure 2).

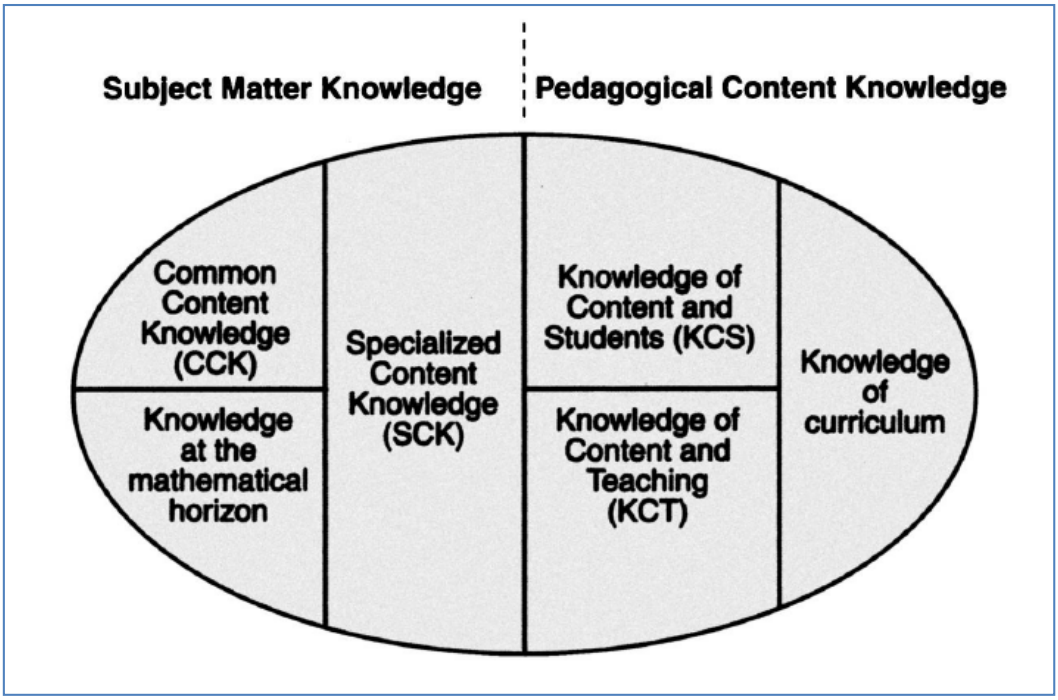


Figure 2 Framework of Mathematical Knowledge for Teaching from Ball et al. (2008)

Focusing on PCK as constructed by Ball et al. (2008), knowledge of content and students (KCS) refers to teachers' understanding of how students learn particular content and includes teachers' knowledge of common misconceptions students have. Knowledge of content and teaching (KCT) combines teachers' knowledge of various approaches and strategies which can be utilised in teaching a particular topic and the various questions which might best illuminate a topic for students. These elements of PCK will be further explored as findings in this research.

Methodology

This investigation was conducted as a double case study in two post-primary schools, Doone and Crannóg, which were involved in separate phases of the national curriculum roll-out. Twelve mathematics teachers volunteered to participate in the research and teachers taught students in all year-groups at all levels of assessment.

Qualitative data was generated in this research through audio recordings of all teacher meetings around lesson study and through individual teacher interviews held at separate stages during the research. Supplementary artefacts such as teacher notes, lesson plans, field notes, samples of student work, and a researcher log formed part of the structuring of data analysis, but were not considered as sources of data within the study. Teachers had autonomy in deciding when and how often they met as a lesson study community and had full independence in deciding the curriculum content to be taught in their research lessons.

The researcher engaged with the teachers in both schools as a participant-observer in facilitating initial phases of lesson study in participating in lesson study as a former mathematics teacher in a phase 1 school and in interviewing participating teachers using semi-structured interview guides. In order to minimise bias, analysis did not commence until all of the data had been generated. Audio files were transcribed and analysis of the data was carried out in four phases guided by a general analytic strategy as suggested by Braun and Clarke (2006). New themes and codes identified as part of the analysis were related to the literature on lesson study and teacher learning and were incorporated within a framework of mathematical knowledge for teaching as suggested by Ball et al. (2008)[1].

Participating Case-study Schools

Doone is a boy's school of approximately 550 students. Five of the nine mathematics teachers chose to participate in the research and all but one of the teachers taught more than one subject. Crannóg has a mixed gender cohort of approximately 800 students. Seven of the ten mathematics teachers at the school chose to participate in this research and of these, five teachers taught mathematics as the only subject in their time-table. These two schools had participated in different phases of the Project Maths curriculum roll-out.

[1] Further detailing of the methodology and analysis can be referenced in the doctoral thesis that is the basis for this report (Ni Shuilleabhain, 2014a)

The lesson study groups participating in both schools included teachers of varying experiences ranging from over thirty years teaching experience to newly qualified teachers. Both schools were urban based as a necessity of this research project. Referencing Ríordáin & Hannigan's (2011) study stating that approximately one half of teachers teaching mathematics at post-primary level are unqualified to do so, two of the twelve teachers were recognised as 'out-of-field'.

As discussed in their initial lesson study meetings, teachers in both schools had a number of reasons to volunteer to participate in the research ranging from feeling unsure and unconfident in teaching the revised syllabus, to wanting to investigate new ways in which they could collaborate as a Mathematics department.

Teachers had authority over when they would meet as a lesson study community, what the content of research lessons would be, what students would be taught, and how many lesson study cycles they would complete during the academic year. Research lessons were therefore developed for both a mix of junior and senior students and over a range of mathematical topics from investigation of quadratic patterns to introducing Pythagoras' Theorem. Teacher meetings were held, on average, once every two weeks and each meeting lasted on average one hour (see Table 1).

Table 1 Lesson study cycles and meeting times

School	Crannóg		Doone	
Lesson Study Cycle	**Lesson Content**	**Duration (Hr:Mins)**	**Lesson Content**	**Duration (Hr:Mins)**
1	Introducing quadratic patterns	0:36 1:19 1:44 1:08 1:23 1:03 (p-l)	Introducing the concept of x-squared	0:44 0:41 1:49 0:35 1:55 1:19 (p-l)
2	Factorising quadratic expressions utilising concrete resources	0:57 1:27 1:01 0:47 (p-l)	Multiplying Fractions: Developing a sense of measure	1:13 1:27 1:16 1:04 0:31 (p-l)
3	Factorising quadratic expressions utilising concrete resources (2)	1:01 (p-l)	Exploring quadratic expressions through application	1:13 1:16 0:30 0:23 (p-l)
4	Differentiation in Calculus: Applications	1:18 1:16 1:57 0:29 (p-l) 0:43	Introducing Pythagoras' Theorem	1:07 0:45 0:38 1:29 0:13 (p-l)

* p-l = post-lesson discussion

Teachers utilised, but were not restricted to, lesson study guidelines for the collaborative planning of research lessons (Appendix A) and to record the lesson plan (Appendix B) adapted from Lewis et al. (2011). During planning meetings resources such as syllabuses, research literature, teacher magazines, teaching and learning plans, and textbooks were utilised (Figure 3). Meetings took place in various classrooms or common teacher areas in the schools and were held during the school day at times where the majority of teachers were free, with a small number of meetings held after school.

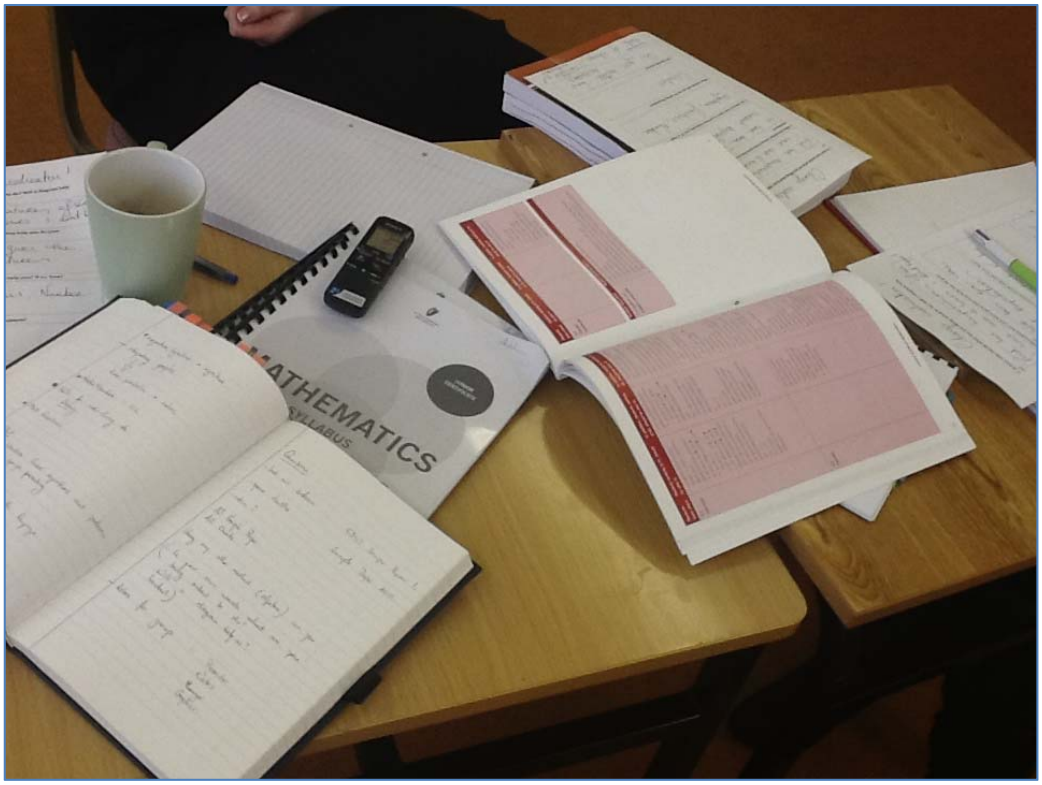


Figure 3 Resources utilised during planning meetings

In the following section lesson study processes, notable findings and items for consideration from the research are detailed.

Findings

A number of findings and contributions are reported here, further details of which may be found in additional research literature (Ni Shuilleabhain, 2014a, 2014b). These are categorised in this report as:

- Lesson study cycle,
- Teacher learning, and
- School-based professional development

Lesson Study Cycle

For the purposes of this report, findings of teachers' engagement in lesson study will initially be reviewed through a framework of the lesson study cycle. It is envisaged that this framework should provide the reader with greater insight into lesson study as a model of school based professional development and teacher community.

Stage 1: Formulate/Reflect on Goals & Study Curriculum

As their overall goal for lesson study, teachers in both Doone and Crannóg identified students' engagement with and attitudes towards mathematics as important classroom issues to address. Following a discussion around their pedagogical experiences, teachers in Doone highlighted that the majority of their students did not identify with mathematics as a meaningful subject and wanted to incorporate these affective issues within their teaching of research lessons during the year. Their overall goal was summarised as the following:

> *For our students to find purpose and meaning in their mathematics that leads to their enjoyment and confidence in the subject.*

In Crannóg's first lesson study meeting, teachers noted that students were often reticent in engaging in the subject and their participation in class was often prohibited by their fear of giving an incorrect answer. After brain-storming a number of ideas within the meeting (Figure 4), teachers agreed on the following over-arching goal:

> *To endeavour to create a culture which fosters independent thinking and fearlessness, leading to autonomous learning.*

These overall goals provided teachers with a philosophical basis for structuring their research lessons and, at the end of the research, teachers reported in their individual interviews that they felt these aims had been achieved through the various lesson study cycles.

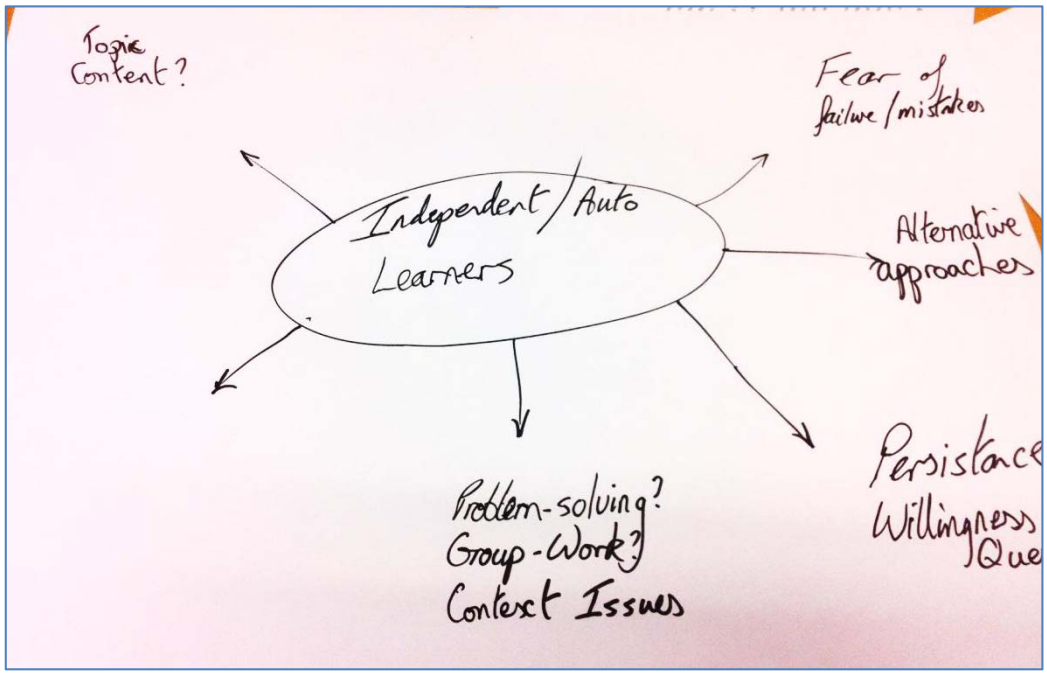


Figure 4 Brain-storm for over-arching goal

In deciding on strands of Mathematics on which to focus, teachers chose areas of the subject which they felt least confident in teaching or identified topics which they felt could be further developed for student understanding (see Table 1). As can be concluded from Table 1, the majority of research lessons were planned either for junior cycle or transition year classes. Due to the nature of the final state assessments, teachers did not wish to interrupt teaching of third year or senior cycle students as research lessons but this is not to suggest that research lessons could not also be conducted within these year groups.

Stage 2: Plan a selected or revised research lesson

In beginning the planning of lessons teachers originally referenced the lesson study guidelines given to them at the beginning of the research (Appendix A). This provided teachers with a structure through which they could collaborate with one another in deciding on the content and sequencing of activities within a research lesson. Following the initial two cycles, teachers became familiar with the processes of planning within their communities and no longer referenced the guidelines for direction.

A sample lesson template provided in the guidelines (Appendix B) was originally utilised by teachers to record their research lesson, but by the final cycles in both schools teachers had adapted these and used their own format to record the details of their research lessons.

In planning the research lessons, it was important that any work involved occurred during the meetings and that teachers did not undertake independent work outside of school. Teachers found that work undertaken outside of meetings often led to incoherence in the research lesson and therefore any activities, worksheets, or questions that were to be incorporated within a research lesson were developed during the meetings.

Materials were designed in a variety of ways during planning meetings utilising research literature, teacher magazines, on-line resources, or textbooks incorporating new and innovative ideas. In Doone, teachers developed contextualised activities through breaking into teams of two or three and devising questions to be incorporated within the lesson. Teachers then shared these questions, attempted these activities in order to anticipate students' thinking, and positively critiqued one another's work ensuring that the language, symbols, and numbers incorporated within problems were relevant to particular groups of students. Where teachers externally sourced activities these were shared with their colleagues during meetings and were modified as relevant, contextualised tasks for students. In Crannóg teachers often collectively built on one another's ideas in designing and incorporating new ideas within research lessons. Developing ideas from research literature such as articles from teacher magazines or books on mathematics education also added to the incorporation of new and innovative ideas within research lessons in both schools.

As a surprising outcome of this research, instead of planning one research lesson in isolation teachers in both schools began independently developing series of lessons within which a research lesson was included. This provided teachers with a better understanding of how students' mathematical thinking could be developed within a topic and highlighted the prior knowledge necessary for students to meet the learning objective within the research lesson (Figure 5). In their final meeting in Crannóg Eileen, an early career teacher, commented that planning a series of lessons was one of the most useful outcomes of lesson study:

Eileen *For each of them we always managed to come up with a series of lessons, we never just planned one lesson – we always had at least a week or six classes.*

Fiona *So even though you're looking at a lesson as the focus of it –*

Eileen *There was always an intro[duction] into it and the afterwards was planned as well.*

Dave *We had a topic planned as well as a lesson planned.*

Eileen *You do get more out of that than just one lesson plan. You're getting a section.*

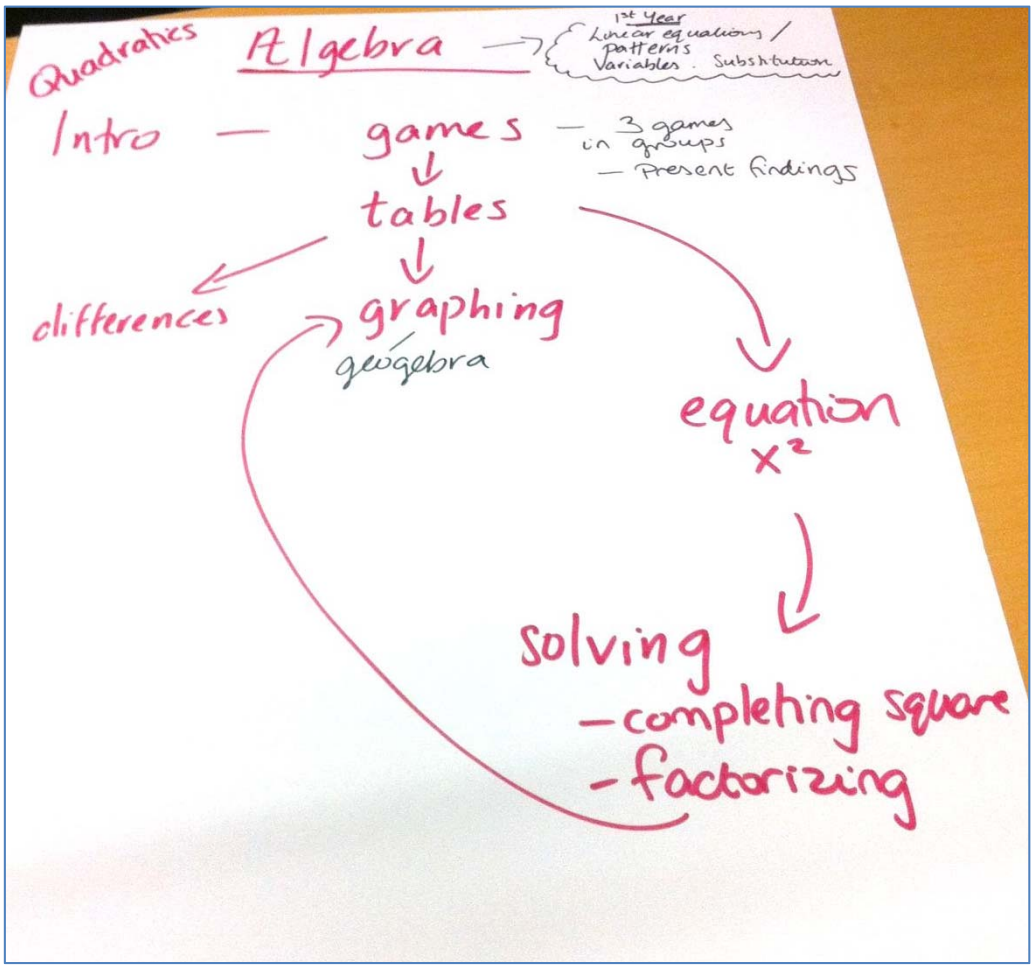


Figure 5 Planning a series of lessons

In Doone's final research cycle teachers mind-mapped their series of lessons and found this format beneficial in ordering their thinking (Figure 6).

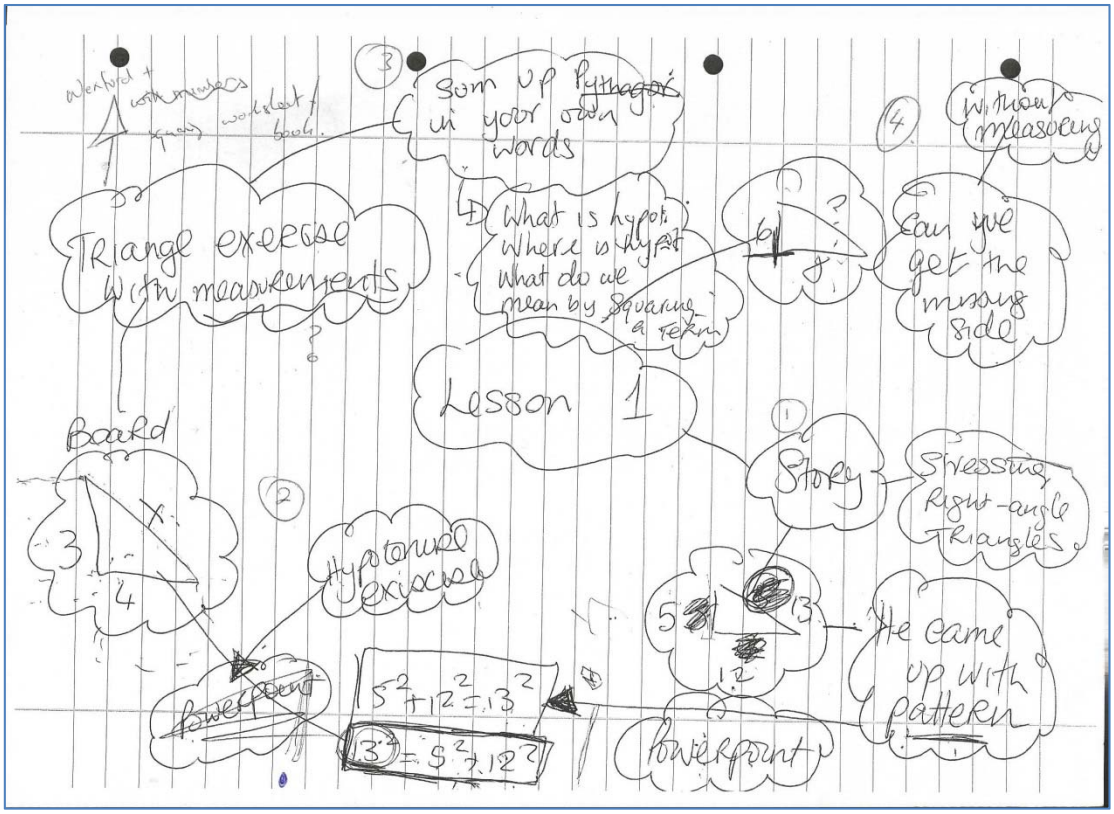


Figure 6 Mind-mapping lesson plan

In Michael's final interview, he extolled the virtues of planning and explained how he felt this stage of the lesson study cycle had benefitted the group.

> *Michael* *I'm not going to say I like planning but it's useful…It's been a very positive experience for me. I've enjoyed it and I've got a lot out of it so it's been good. It really shows me that planning is not only important but that it's productive as well and it's a very useful thing to do… It's just working in teams, working with the people that you work with, there's just so many potential benefits in it.*

Collaborative planning provided teachers with opportunities to share their teaching experiences with one another but also to build their awareness of different mathematical strategies and develop their focus on students' mathematical thinking.

Stage 3: Conduct/Observe research lesson

While the conducting teacher may, at times, have been nervous about teaching in front of their colleagues, all teachers reflected on this stage of the lesson study cycle as a very positive learning experience. While it was an unusual for teachers to invite colleagues into

their classroom to observe a lesson, the collective nature of planning led to a supportive environment for those conducting the lesson as expressed by Kate in her mid-point interview:

> *Kate* *So we were saying this actually ourselves, we were saying it's not that I'm not even nervous about it - I'll probably be a bit nervous the day I have to do it - but we planned the lesson, it's* ***our*** *lesson, so it's kind of like we're teaching it as well… I found that with Owen for instance – I was laughing at things he was saying [in the lesson]. He's just himself in the class, so is Lisa. But I wasn't really looking at them, I was more looking at what they were teaching and how it was said and how the kids were picking up…It was like we've all planned it so if it fails it's all of our faults.*

Not all teachers were free to observe each research lesson, but it was important that a majority of the group observed and reflected on how students engaged with the research lesson.

In observing the research lessons teachers found it most beneficial to track one pair or one group of students for the duration of the lesson in order to better notice and interpret how student thinking developed and how students responded throughout the lesson.

In their individual interviews teachers reported that they found observing students for the duration of a lesson to be incredibly beneficial to their practice, providing them with insight on students' thinking which encouraged teachers to reflect on their own individual classroom practices.

> *Gerald* *It's great to be able to sit there and watch that group working. They were engaged and you could follow the train of thought and give them time because you are not under pressure to run off to another group. If you are a single teacher you can't follow the train of thought around all the groups and if you are delving in and giving assistance it is quite a hard thing to do that effectively.*

Teachers originally utilised observation guides based on Lewis and Hurd's (2011) 'Lesson Study Step by Step: How Teacher Learning Communities Improve Instruction' but then developed their own observation template constructed around recording observations of students' thinking and students' activities (Appendix B). It was not necessary for teachers to maintain their observation records but these notes provided discussion points for teachers in the post-lesson discussion (Figure 7).

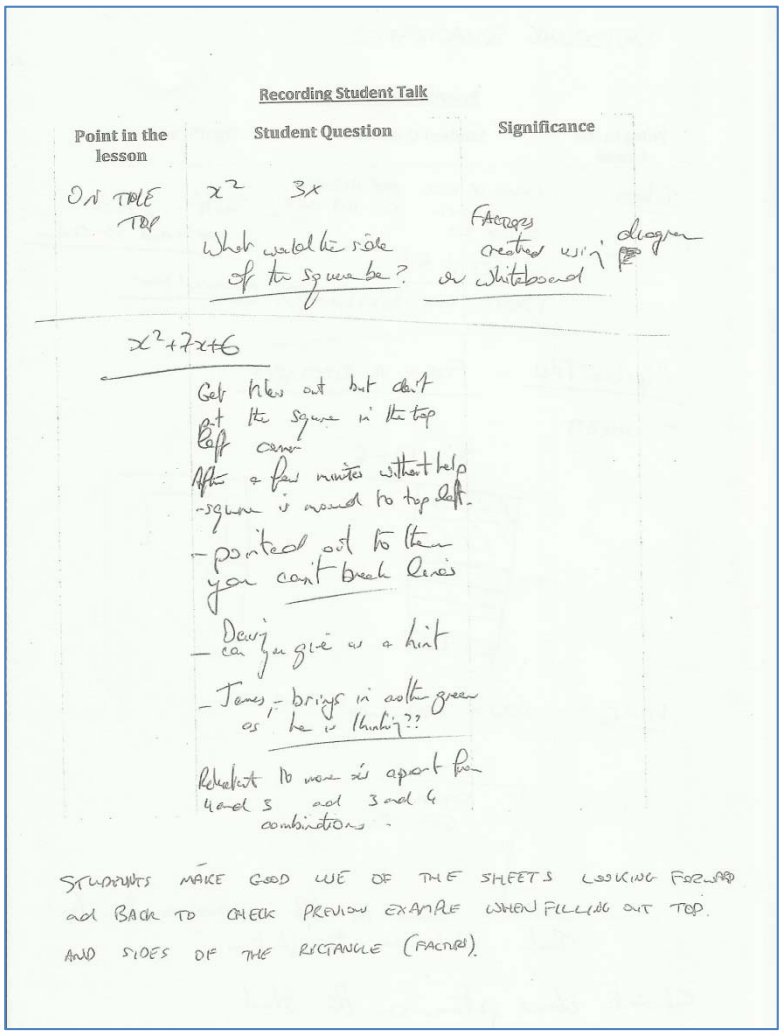


Figure 7 Sample teacher observation sheet

Teachers were initially wary of the impact of classroom observation on students' learning but reflected, in their post-lesson discussions, that the presence of a number of teachers within the classroom did not have an adverse effect on students' learning. Aside from some senior students quietly questioning why there were so many people in the room, teachers noted that students seemed surprisingly unperturbed by the larger teacher presence within the classroom.

Furthermore, observing how students communicated mathematics with one another during small group and whole class presentations provided teachers with insight into the value of such an approach in the teaching and learning of mathematics and into the features of successfully facilitating class work based around communication of mathematical thinking.

As a point of interest, in observing students during a research lesson teachers found it difficult not to intervene or engage with students while they were 'observing'. At the end of the research a number of teachers reflected that they would learn more from their

observations if they did not engage with students in this manner and resolved to maintain their distance as an observer in future research lessons as is recommended by the literature on lesson study.

Stage 4: Reflect on the research lesson

Lewis & Hurd (2011) advise that post-lesson discussions be held at as close a time following the research lesson as is possible. In this research each of the post-lesson discussions was held on the same day as the research lessons where teachers could reference their notes and accurately reflect on students' engagement, the development of the topic, the orchestration of the lesson, and many other elements within the lesson.

In post-lesson discussions teachers often referred to their observation notes but also referenced student work in interpreting how students engaged in activities and in assessing whether the lesson had met its learning objective (Figure 8).

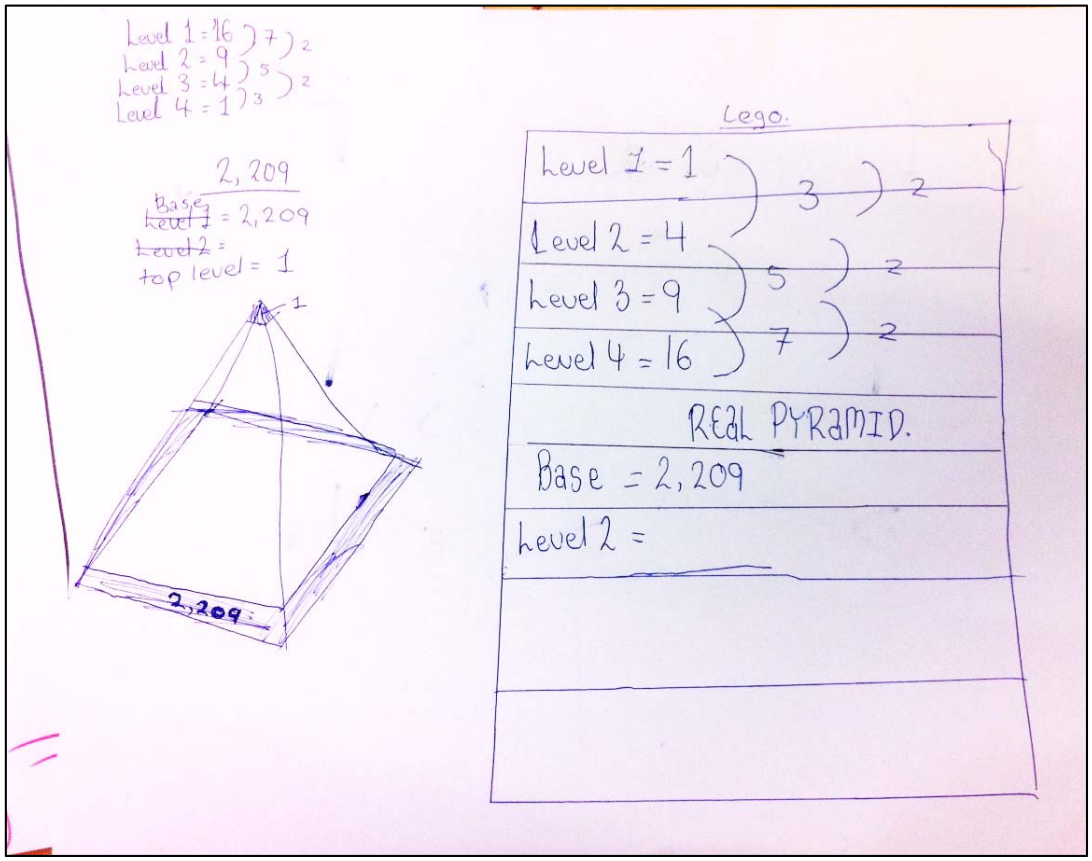


Figure 8 Sample of student work utilised for reflection

Where in their first post-lesson discussions teachers may have been wary of criticising any of the teaching approaches, as the meetings continued teachers' reflections focused more and

more on students' learning and less on the teachers' actions. This reflection of students' thinking led to teachers anticipating more of students' mathematical responses and to seeing a lesson 'from the eyes of a student' in subsequent planning meetings. This changing perspective was an important element of teacher learning where members of the lesson study community began to develop or further hone their critical student lens (Fernandez et al., 2003) in noticing and interpreting students' mathematical thinking (Corcoran, 2011b; Jacobs et al., 2010). It is also worthy to note here that early career teachers who conducted research lessons welcomed feedback on their practice from their more experienced colleagues.

These post-lesson discussions proved to be important stages of lesson study where teachers were provided with opportunity to reflect on what they had observed in terms of interpreting students' strategies, recollecting student conversations, seeing the lesson through the eyes of a student, and developing their knowledge of sequencing learning trajectories for particular mathematical content.

Re-teaching a research lesson

In cycle 2 in Crannóg, teachers decided that their lesson on factorising quadratics had not achieved their intended learning objective and they concluded that they had included too much content in one research lesson. Teachers reviewed their lesson plan and a different teacher conducted the revised research lesson with a class within the same year group. In all other cycles in both schools teachers were satisfied that the lessons had met their objectives but re-teaching a research lesson remains a viable possibility for further developing research lessons.

Teacher Learning

In this section a number of findings around teacher learning and around the wider school context will be discussed.

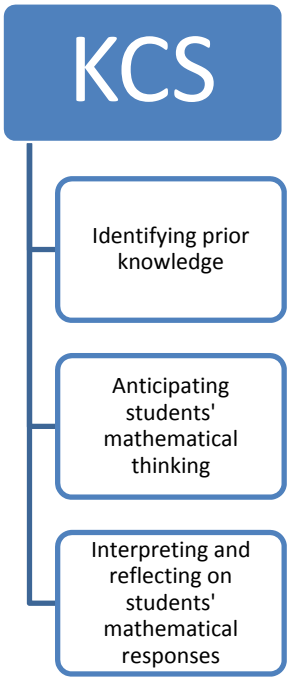
At the end of the research all teachers reported in their final interviews that they felt they had benefited, albeit in different ways, from participating in the research. All teachers felt they had an improved understanding of facilitating student group work, of holding whole class discussions, and of incorporating more communication within their mathematics classrooms. All but one teacher felt they had an improved knowledge of and understanding of the curriculum through engaging with curriculum documents throughout the planning of research lessons, that one teacher having felt that they already had a deep understanding of the curriculum prior to engaging in the research. A small number of teachers also felt their subject matter knowledge had improved.

The following section details findings of teacher learning in terms of PCK.

Developing Pedagogical Content Knowledge

Knowledge of Content and Students

A key finding of this research is the development of teachers' pedagogical content knowledge through their participation in iterative cycles of lesson study. Utilising a framework of mathematical knowledge for teaching (Ball et al., 2008), the following features of KCS emerged as developing through teachers' continued planning and reflection of research lessons:



- Identifying students' prior knowledge
- Anticipating students' mathematical thinking
- Interpreting and reflecting on students' mathematical responses

Identifying students' prior knowledge

What students learn in the classroom depends, to a large extent, on what they already know (Ball & Hyman, 2003; Holten & Thomas, 2001) and in mathematics students can be challenged by drawing

on their prior knowledge and building on the assumptions they have already made (Baumert et al., 2010). Composing a lesson from the view point of a student and identifying their prior knowledge forms an important part of teachers' KCS and within the collective planning of the research lessons, it became more and more relevant to teachers to identify the prior knowledge that was required of students for a particular topic and to incorporate this within the lesson. This was an important exercise since discussions around this issue provided teachers with a definitive starting point from which to build students' mathematical thinking in particular topics.

Anticipating students' mathematical thinking

Through their classroom experiences teachers build on their knowledge of how students are likely to understand or have difficulties with a topic (Schoenfeld, 2011). An experienced teacher will know what issues are likely to be problematic and what misconceptions are common to students (Ball et al., 2008; Krauss et al., 2008). In this research through their observation and reflection of research lessons, teachers became more aware of anticipating and articulating students' mathematical thinking within subsequent research lessons and in their own teaching.

Interpreting and reflecting on students' mathematical responses

When students construct their own mathematical understanding, there are important learning moments for teachers to interpret and gain insight into students' thinking. Lesson study provides teachers with unique opportunities to observe students' activities within a co-constructed lesson and teachers can therefore notice, interpret and reflect on students' learning (Breen, McCluskey, Meehan, O'Donovan, & O'Shea, 2014; Jacobs et al., 2010; Mason, 2002). As part of participating in iterative cycles of lesson study teachers became more aware of and began explicitly reflecting on students' strategies and conversations around mathematical activities during their post-lesson discussions. This benefitted teachers in structuring subsequent research lessons and in further identifying student thinking in their own construction and conduction of classes outside of lesson study.

Knowledge of Content and Teaching

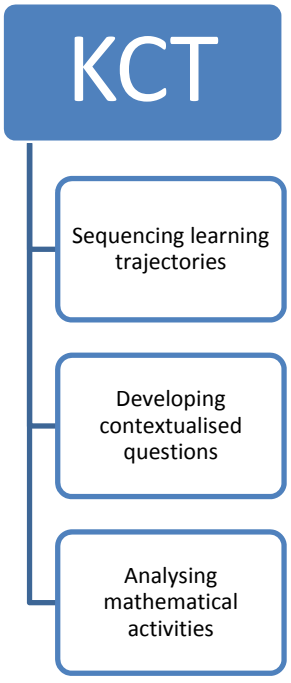
Utilising the same framework of mathematical knowledge for teaching (Deborah L. Ball et al., 2008), the following features of KCT emerged as developing through teachers' continued planning and reflection of research lessons:

- Sequencing learning trajectories
- Developing contextualised questions
- Analysing mathematical activities

Sequencing learning trajectories

Sequencing material for instruction requires teachers to make connections between the mathematics being taught and how the student can be best introduced to that topic. In order to make these connections the teacher has to be aware of the relative demands that different topics and tasks make of students (Rowland, 2007). In this research sequencing a learning trajectory over a series of lessons became a fundamental matter of planning for both lesson study communities engaged in this research and as their final output of each lesson study cycle, teachers had detailed series of lessons through which students' mathematical thinking would be developed.

Developing contextualised questions



In planning research lessons, teachers realised that traditional textbook questions did not always meet the learning objectives of the research lesson. Teachers wanted to design problems and activities that would be both relevant and contextualised for students (Schoenfeld, 1992) and developing these activities became a common element within the lesson study cycles in both schools. Teachers often sourced ideas from textbooks, PMDT curriculum materials, or education literature supplied to them by the facilitator and then modified these questions to ensure they held context for their own particular students. As an example, teachers in Doone developed a question around investigating quadratics that was

both mathematically relevant and would be of interest for their transition year group of male students (Figure 9).

During the recent Ireland v England match in the Aviva Stadium as part of the Six Nations competition, Jonathan Sexton kicked a Garryowen before he went off with an injury. A Garryowen, also known as an "Up and Under", allows the attacking team to disrupt the defensive line, take the defense's pressure off themselves and put offensive pressure on their opponents. However, the kicking team risks losing possession of the ball, after which the opposing team may counter attack.

George Hook and Brent Pope, as well as being famous for their rugby commentary are also keen mathematicians who have calculated that the height of the ball above ground during the Garryowen can be described by

$$H = 25t - 4.9t^2$$

where H gives the height of the rugby ball above the ground at any time, t, in seconds.

a) How long is the ball in the air for?

b) What is the maximum height reached by the ball?

c) If Jonathan runs at a speed of 7m/s and is not tackled or hindered in any way. The ball will land 26m away. Will he catch the ball?

Figure 9 Contextualised question designed by teachers

Similarly in Crannóg teachers developed activities and tasks that incorporated learning objectives with engaging problems. In their first research lesson teachers devised an inquiry task introducing students to quadratic patterns (Figure 10).

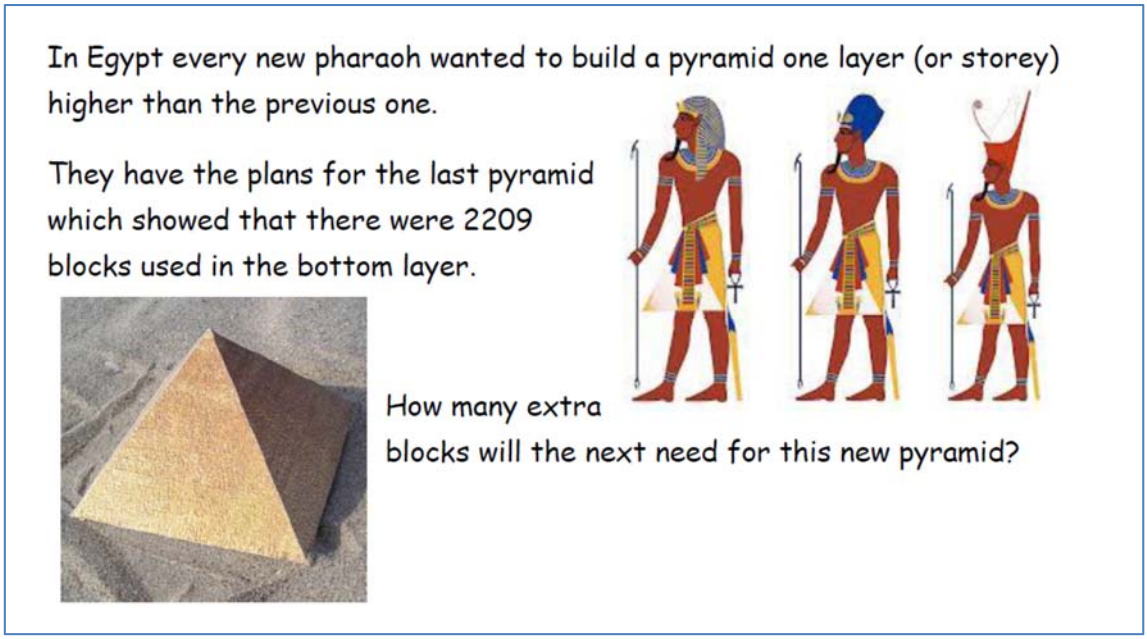


Figure 10 Contextualised student-inquiry activity

Analysing mathematical activities

Finally, teachers built on their KCT through analysing mathematics questions as a part of their planning of research lessons. Through attempting these tasks with their colleagues, teachers became aware of other solution strategies or aspects of questions that would otherwise have been unfamiliar to them (Ball et al., 2008; Borko, Jacobs, Eiteljorg, & Pittman, 2008). Furthermore, doing mathematics tasks prior to the research lesson encouraged teachers to anticipate students' mathematical responses, a feature of KCS.

In his second interview Dave reflected that in doing questions during the planning phase of lesson study he had benefitted in terms of becoming aware of different approaches to teaching that particular topic to students.

> *Dave* *I have looked at more ways of solving quadratics in the last week than I have looked at in the last ten years. I have tried more ways of solving quadratics in the last week than I have looked at in the last ten years. I had two methods, the method I used at school for ten years and the method I met with [my colleague] Fiona and I knew there were others out there. Now I am just reading different types with algebra tiles and with area models – considering more of the curriculum.*

As with any professional development intervention, not all teachers gained in exactly similar ways (Jacobs et al., 2010) but from analysis of the qualitative data the research suggests that teachers built on their PCK through participation in iterative cycles of lesson study.

Changes to Classroom Practices

The most comprehensive change to classroom practice within research lessons was in incorporating more student group work and more communication of mathematical thinking through whole-class, pair, and group activities. In including these approaches to teaching within research lessons, teachers observed the benefit of engaging students in problem solving as a collaborative effort. The following is an excerpt from a post-lesson discussion which demonstrated teachers' surprise at the learning that occurred through students' working in groups:

Walter	*It was more exciting for them than I thought it would be*
Dave	*They came up with the questions themselves!*
Walter	*Their imagination of it, they just sort of plugged into that more…*
Fiona	*It worked. Those guys over there I was watching – they really helped each other. They were listening to each other!*
Gerald	*All that dynamic is great, to watch how they are hitting off each other and when they have their own ideas. There was an excitement in there about getting stuff worked out.*

Owen reported a dramatic change in his teaching from initially despising a "noisy classroom" and considering himself as "anti Project Maths" to consciously incorporating whole class discussions and including applications of mathematics within his teaching.

Following her conduction of the first research lesson, Lisa changed the layout of her classroom from one based on individual student work to that of groups of students. When her colleagues enquired about her changed classroom Lisa was extremely positive about how it impacted on students' learning which encouraged her colleagues to also incorporate student group work in their classrooms.

Owen	*Are you happy with yours?*
Kate	*You still have that layout?*
Lisa	*Yeah! Because they can all see each other's work 'you're not doing that right'. I don't have to go as far as the group. I would never go back.*

> *Owen* *That's great...Will I change the tables in my classroom for the day [of the research lesson] to have them in group work?*

At the end of the year Lisa reflected that incorporating student communication of their mathematical thinking within research lessons led to a dramatic change in how participating teachers designed their classroom environment and activities.

> *Lisa* *I think we've all looked at the way our classrooms are set up – to facilitate cooperative learning. All of our classrooms were the traditional single look-at-the-board and everybody has used cooperative learning practices as a result of the lessons that we designed. Very little of our work was done for the kid to do on their own.*

As well as these findings generated through a thematic analysis of the data, teachers also self-reported changes to their classroom practices as a result of their participation in lesson study. Both Walter and Eileen noted that from observing their colleagues, they were beginning to consciously extend the 'wait time' in allowing students to answer during their own lessons. Teachers were also consciously reducing their exposition time, instead incorporating more opportunity for students to engage with mathematical activities within the lesson.

Furthermore, teachers in both schools were less dependent on textbooks to guide their teaching. In Crannóg, teachers were already utilising textbooks as occasional question sources and through lesson study, designed their own module on introducing calculus to Transition Year students. In Doone, teachers became more and more proficient in designing their own questions and realised that the textbook strategy did not always define a sequence of learning that was relevant to their own students.

In-School Professional Development

Complementing In-service Workshops

In both schools, teachers felt this form of professional development had particular benefit in being located within the structures and cultures of their own schools where teachers collaborated with their colleagues while focusing on their own students. Furthermore, where teachers had attended professional development workshops outside of school and utilised curriculum materials, they had not had opportunity to implement resources or ideas from such in-service days. Lesson study provided teachers with opportunity to reflect on and incorporate teaching approaches and resources which they had met in workshops and could then modify and incorporate within their own teaching, relevant to their own students.

School Management

In both schools, the support of management was key in supporting teachers to participate in this form of professional development and in this research (Fullan, 2003). Principals, vice-principals, and other staff were supportive of their colleagues throughout the year and this impacted positively on teacher learning and on the development of teacher community in both schools. The support of principals and vice-principals in organising supervision for the purposes of observation or planning was a positive influence on teachers' engagement in this form of in-school professional development.

Voluntary Professional Development

Although participation in professional development should include the majority of education professionals and should occur regularly, participation in certain modules should occur on a voluntary basis (Erickson, Minnes Brandes, Mitchell, & Mitchell, 2005). In this research, all teachers reported in their final interviews that a vital element of their participation in this research was that they had all volunteered in the intervention. Teachers felt it important that if lesson study were to be incorporated as part of a suite of professional development models, it should remain the choice of the individual teacher if they wished to participate.

In their discussions in both schools, teachers felt that they had benefitted from participating in lesson study and wanted to continue with this form of professional development as a mathematics teacher community. This was a possibility in Crannog where teachers requested

a common free period in the following academic year but was not possible to continue in Doone.

As a notable point, all teachers agreed that this form of professional development should be included in additional contract hours as a form of structured teacher collaboration in subject groups. A number of teachers expressed the wish for their participation in any professional development to be officially recognised and felt that a lack of acknowledgement of their engagement dis-incentivised teachers to continue with any form of professional development.

Scalability

While in this research there was not sufficient time to introduce teachers to lesson study prior to their engagement in the model, the introduction of teachers to a model of lesson study could be facilitated through research-based teacher education workshops mirroring Lewis et al.'s (2009) research. Such workshops would incorporate teacher participation in activities requiring facilitating of student group work and provide teachers with resources to share with their colleagues. In introducing such a model to schools, teachers should be provided with opportunity to volunteer to participate in the intervention which would necessarily adapt to the structures and cultures within individual schools and mathematics departments. A small number of well-trained facilitators would also be necessary as additional support for schools engaging in initial cycles of lesson study.

Sharing Resources

In both schools teachers were happy to share the resources created in lesson study since they were aware that their counterparts had given much of their free time in developing research lessons. It is perhaps an important finding of this research that teachers were generous in sharing the fruits of their collaboration with others who had proportionally invested time and ideas into developing such materials.

Limitations of the Research

In presenting this report it is necessary to recognise the limitations of the research.

One major limitation of this project is the sample population of the study. Only two schools were involved in this research and while both phases of the curriculum reform were represented, these two Mathematics departments cannot be stated as representative of all Mathematics departments that may exist around the country. In addition, these schools were both situated in Dublin and represented schools of large populations (over 500 students). Further research may be necessary to investigate how smaller or more rural schools with smaller populations of mathematics teachers might be impacted through participating in iterative cycles of lesson study.

In referencing the scalability of this model of professional development and referencing international research literature, I believe that lesson study can be introduced to post-primary schools on both regional and national levels. Dudley (2012) along with many other internationally based studies (C. Fernandez et al., 2003; Isoda & Katagiri, 2012; Murata et al., 2012) have demonstrated the scalability of this model in schools all over the world.

Conclusion

This research investigated lesson study as a model of school-based professional development for Irish post-primary mathematics teachers and was conducted as a double case study based in two schools. Lesson study was adopted as a model in order to structure the activities of teacher community while providing teachers with opportunity to investigate their own practices, through planning and reflection, at a time of curriculum reform.

Through planning multiple research lessons teachers collaborated in designing, conducting, observing, and reflecting on mathematics lessons that were based within the Project Maths initiative. Teachers became more aware of incorporating a critical student lens on their practice in incorporating students' prior knowledge, anticipating students' mathematical strategies, and interpreting students' classroom responses. In engaging with the processes of lesson study teachers became more comfortable in incorporating sociocultural practices within their teaching by planning and reflecting on whole class discussions, in facilitating student group work, and incorporating more communication of students' mathematical thinking. Furthermore, teachers designed their own mathematical activities and encouraged students to engage in problem solving practices during research lessons. Through engaging in iterative cycles of lesson study, all teachers of varying teaching experiences were facilitated in developing their pedagogical content knowledge.

While these schools were both Dublin based, they represented schools of differing cultures and ethos and provide evidence that lesson study may be introduced to Irish post-primary schools as a voluntary form of teacher professional development. The support of school management and teacher colleagues was incredibly important in promoting their colleagues' engagement with this research for the course of the academic year.

Lesson study, while seemingly simple to describe, holds much power in how it can engage teachers in investigating their own practices and in providing an environment within which mathematics teachers can be creative in their teaching. It also provides teachers with unique opportunities to access how students respond to and engage within mathematics lessons and, as identified in this research, participation in iterative cycles of lesson study can build teachers' pedagogical content knowledge.

This is a model of professional development which holds great potential as a structure within which teachers can enjoy, learn from, and reflect on their practices of teaching mathematics.

References

Ball, D. L., & Hyman, B. (2003). *Toward a Practice-Based Theory of Mathematical Knowledge for Teaching.* Paper presented at the 2002 Annual Meeting of the Canadian Mathematics Education Study Group, Edmonton.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content Knowledge for Teaching: What Makes It Special? *Journal of Teacher Education, 59*(5), 389-407.

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., . . . Tsai, Y.-M. (2010). Teachers' Mathematical Knowledge, Cognitive Activation in the Classroom, and Student Progress. *American Educational Research Journal, 47*(1), 133-180. doi: 10.3102/0002831209345157

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education, 24*(2), 417-436. doi: http://dx.doi.org/10.1016/j.tate.2006.11.012

Breen, S., McCluskey, A., Meehan, M., O'Donovan, J., & O'Shea, A. (2014). A year of engaging with the discipline of noticing: five mathematics lecturer's reflections. *Teaching in Higher Education, 19*(3), 289-300.

Cajkler, W., Wood, P., Norton, J., & Peddar, D. (2013). Lesson Study: towards a collaborative approach to learning in Initial Teacher Education? *Cambridge Journal of Education*. doi: DOI: 10.1080/0305764X.2013.834037

Campbell, P. F., Nishio, M., Smith, T. M., Clark, L. M., Conant, D. L., Rust, A. H., . . . Choi, Y. (2014). The Relationship Between Teachers' Mathematical Content and Pedagogical Knowledge, Teachers' Perceptions, and Student Achievement. *Journal for Research in Mathematics Education, 45*(4), 419-459. doi: 10.5951/jresematheduc.45.4.0419

Charalambos, C., & Philippou, G. (2010). Teachers' concerns and efficacy beliefs about implementing a mathematics curriculum reform: integrating two lines of inquiry. *Educational Studies in Mathematics, 75*(1), 1-21. doi: 10.1007/s10649-010-9238-5

Conway, P., & Sloane, F. (2005). *International trends in post-primary mathematics education*. National Council for Curriculum and Assessment.

Corcoran, D. (2011a). Learning from Lesson Study: Power Distribution in a Community of Practice. In L. Hart, A. S. Alston & A. Murata (Eds.), *Lesson Study Research and Practice in Mathematics Education* (pp. 251-268). New York: Springer.

Corcoran, D. (2011b). Lesson Study in practice: Staff ownership of mathematics teacher professional development. In T. Dooley, D. Corcoran & M. Ryan (Eds.), *Fourth Conference on Research in Mathematics Education MEI 4* (pp. 130-142). St. Patrick's College, Drumcondra, Dublin 9.

Darling-Hammond, L., Chung Wei, R., Andree, A., Richardson, N., & Orphanos, S. (2009). Professional Learning in the Learning Profession: A status report on teacher development in the United States and Abroad. US: National Staff Development Council & Stanford University.

de Lima, J. Á. (2001). Forgetting about Friendship: Using Conflict in Teacher Communities as a Catalyst for School Change. *Journal of Educational Change, 2*(2), 97-122. doi: 10.1023/a:1017509325276

Dooner, A.-M., Mandzuk, D., & Clifton, R. A. (2008). Stages of collaboration and the realities of professional learning communities. *Teaching and Teacher Education, 24*(3), 564-574. doi: 10.1016/j.tate.2007.09.009

Erickson, G., Minnes Brandes, G., Mitchell, I., & Mitchell, J. (2005). Collaborative teacher learning: Findings from two professional development projects. *Teaching and Teacher Education, 21*(7), 787-798. doi: http://dx.doi.org/10.1016/j.tate.2005.05.018

Fernandez, C., Cannon, J., & Chokshi, S. (2003). A US-Japan lesson study collaboration reveals critical lenses for examining practice. *Teaching and Teacher Education, 19*(2), 171-185.

Fernandez, C., & Chokshi, S. (2004). Challenges to Importing Japanese Lesson Study: Concerns, Misconceptions, and Nuances. *Phi Delta Kappa International, 85*(7), 520-525.

Fernández, M. L., & Robinson, M. (2006). Prospective teachers' perspectives on microteaching lesson study. [Article]. *Education, 127*(2), 203-215.

Fullan, M. (2003). *The Moral Imperative of School Leadership*. USA: Corwin Press, Inc

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *Teachers College Record, 103*(6), 942-1012.

Guskey, T. R. (2002). Professional Development and Teacher Change. *Teachers and Teaching: theory and practice, 8*(3), 381-392.

Hanley, U., & Torrance, H. (2011). Curriculum Innovation: Difference and Resemblance. *Mathematics Teacher Education and Development, 13*(2), 67-84.

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking Pedagogical Content Knowledge: Conceptualizing and Measuring Teachers' Topic-Specific Knowledge of Students. *Journal for Research in Mathematics Education, 39*(4), 372-400. doi: 10.2307/40539304

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of Teachers' Mathematical Knowledge for Teaching on Student Achievement. *American Educational Research Journal, 42*(2), 371-406. doi: 10.2307/3699380

Holten, D., & Thomas, G. (2001). Mathematical Interactions and Their Influence on Learning. In D. Clarke (Ed.), *Perspectives on Practice and Meaning in Matheamtics and Science Classrooms*. Netherlands: Kluwer Academic Publishers.

Hord, S. M. (2004). Professional Learning Communities: An Overview. In S. M. Hord (Ed.), *Learning Together, Leading Together: Changing Schools Through Professional Learning Communities* (pp. 5-14). New York: Teachers College

Isoda, M., & Katagiri, S. (2012). *Mathematical Thinking: How to Develop it in the Classroom* (Vol. 1). Singapore: World Scientific Publishing.

Jacobs, V. R., Lamb, L. L. C., & Philipp, R. A. (2010). Professional Noticing of Children's Mathematical Thinking. *Journal for Research in Mathematics Education, 41*(2), 169-202.

Krauss, S., Brunner, M., Kunter, M., Baumert, J., Blum, W., Neubrand, M., & Jordan, A. (2008). Pedagogical content knowledge and content knowledge of secondary mathematics teachers. *Journal of Educational Psychology, 100*(3), 716-725. doi: 10.1037/0022-0663.100.3.716

Leavy, A. M., Hourigan, M., & McMahon, A. (2010). Facilitating inquiry based learning in mathematics teacher education *Third Science and Mathematics Education Conference*. Dublin City University

Lewis, C., & Hurd, J. (2011). *Lesson Study Step by Step: How Teacher Learning Communities Improve Instruction*. USA: Library of Congress Cataloging-in-Publication Data.

Lewis, C., Perry, R., & Hurd, J. (2009). Improving mathematics instruction through lesson study: a theoretical model and North American case. *Journal of Mathematics Teacher Education, 12*(4), 285-304. doi: 10.1007/s10857-009-9102-7

Lewis, C., Perry, R., & Murata, A. (2006). How Should Research Contribute to Instructional Improvement? The Case of Lesson Study. *Educational Researcher, 35*(3), 3-14.

Louis, K. S., & Marks, H. M. (1998). Does Professional Community Affect the Classroom? Teachers' Work and Student Experiences in Restructuring Schools. *American Journal of Education, 106*(4), 532 - 575.

Lyons, M., Lynch, K., Close, S., Sheerin, E., & Boland, P. (2003). *Inside Classrooms: The Teaching and Learning of Mathematics in Social Context*. Dublin: Insitute of Public Administration.

Mason, J. (2002). *Researching Your Own Practice: The Discipline of Noticing*. London: RoutledgeFalmer.

McLaughlin, M. W., & Talbert, J. E. (2006). *Building School-Based Teacher Learning Communities: Professional Strategies to Improve Student Achievement*. New York: Teachers College Press.

McLaughlin, T. H. (2004). Teaching as a Practice and a Community of Practice: The Limits of Commonality and the Demands of Diversity. In J. Dunne & P. Hogan (Eds.), *Education and Practice: Upholding the Integrity of Teaching and Learning* (Vol. 1, pp. 48-60). UK: Blackwell Publishing.

Murata, A., Bofferding, L., Pothen, B. E., Taylor, M. W., & Wischnia, S. (2012). Making Connections Among Student Learning, Content, and Teaching: Teacher Talk Paths in Elementary Mathematics Lesson Study. *Journal for Research in Mathematics Education, 43*(5), 616-650. doi: 10.5951/jresematheduc.43.5.0616

Murata, A., & Takahashi, A. (2002). *Vehicle to Connect Theory, Research, and Practice: How Teacher Thinking Changes in District-Level Lesson Study in Japan*. Paper presented at the North American Chapter of the International Group for the Pyschology of Mathematics Education, Athens.

Ni Shuilleabhain, A. (2014a). *Developing Mathematics Teachers' Pedagogical Content Knowledge through Lesson Study.* (Doctor of Philosophy Ph.D.), Trinity College Dublin, Trinity College Dublin Library.

Ni Shuilleabhain, A. (2014b). Lesson study and Project Maths: A Professional Development Intervention for Mathematics Teachers Engaging in a New Curriculum. In S. Pope (Ed.), *8th British Congress of Mathematics Education* (pp. 255-262). Nottingham University.

OECD. (2009). Creating Effective Teaching and Learning Environments: First Results from TALIS.

Oldham, E. (2001). The culture of mathematics education in the republic of Ireland: Keeping the faith? *Irish Educational Studies, 20*(1), 266-277. doi: 10.1080/0332331010200121

Remillard, J. T. (2005). Examining Key Concepts in Research on Teachers' Use of Mathematics Curricula. *Review of Educational Research, 75*(2), 211-246. doi: 10.2307/3516049

Remillard, J. T., & Bryans, M. B. (2004). Teachers' Orientations toward Mathematics Curriculum Materials: Implications for Teacher Learning. *Journal for Research in Mathematics Education, 35*(5), 352-388. doi: 10.2307/30034820

Ríordáin, M. N., & Hannigan, A. (2011). Who teaches mathematics at second level in Ireland? *Irish Educational Studies, 30*(3), 289-304. doi: 10.1080/03323315.2011.569117

Rowland, T. (2007). Developing Knowledge for Mathematics Teaching: A Theoretical Loop. In S. Close, D. Corcoran & T. Dooley (Eds.), *Second National Conference on Research in Mathematics Education: MEI2* (pp. 14-27). St. Patrick's College, Dublin.

Rowland, T. (2014). Mathematics Teacher Knowledge. In P. Andrews & T. Rowland (Eds.), *Masterclass in Mathematics Education* (pp. 87-100). London: Bloomsbury Publishing.

Schoenfeld, A. H. (1992). Learning to think Mathematically: Problem Solving, Metacognition, And Sense-Making in Mathematics. In D. Grouws (Ed.), *Handbook for Research on Mathematics Teaching and Learning* (pp. 334-370). New York: MacMilan.

Schoenfeld, A. H. (2011). *How We Think: A theory of goal-oriented decision making and its educational applications.* New York: Routledge.

Takahashi, A., & Yoshida, M. (2004, May). Ideas for Establishing Lesson-Study Communities. *Teaching Children Mathematics,* 436-443.

van den Akker, J. (2003). Curriculum Perspectives: An Introduction. In J. v. d. Akker, W. Kuiper & U. Hameyer (Eds.), *Curriculum Landscapes an Trends* (pp. 1-10): Springer Netherlands.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education, 24*(2), 244-276. doi: http://dx.doi.org/10.1016/j.tate.2006.11.005

Appendices

Appendix A: The Lesson Study Cycle

1. Study Curriculum and Formulate Goals

During the first meeting of the community of practice the following agenda is suggested:

A. Choose roles for the initial meeting: time keeper, note taker, facilitator etc.
B. Examine everyone's ideas about professional development and lesson study
C. Consider long-term goals and/or lesson goals
D. Build a timeline for the lesson study cycle
E. Review the curriculum and areas or topics which may be of interest
F. Review key decisions and/or insights made during the meeting
G. Agree upon assignments to be completed or followed up in the next meeting.

Facilitator: The facilitator's role is to aim to ensure that the preceding steps are met during the meeting or will agree with the group that they will be addressed at the next meeting. It is important that while an agenda is adhered to, the facilitator's role should be fluid and allow conversations to run freely.

Long term goals

In considering long-term goals teachers may ask themselves:

- What is a gap between the ideal and the actual that you would really like to work on as a teacher?
- Think about the students you serve. What qualities would you like these students to have in 5 or 10 years from now?
- What qualities do they have now and what could be improved upon?

Teachers should agree on the phrasing and terminology of their long term goal particular to their own set of students. This goal should remain a focus for all of the lesson study cycles throughout the year.

Examples:

For our students to find purpose in their mathematics and meaning that leads to their enjoyment and confidence in the subject.

Creating a culture which fosters independent thinking and fearlessness leading to autonomous learners.

2. Planning a Research Lesson

Planning Meetings

A. Choose roles for the planning meeting: note takers, lesson plan recorder, time keeper, facilitator, etc.
B. Decide on the class group and curriculum area on which to focus.
C. Select the lesson you will focus on.
D. Write a teaching and learning plan over a number of meetings (You may wish to use and/or modify resources already available to you).
E. Devise an observation strategy for collecting data.
F. Review key decisions and/or insights made during the meeting.
G. Agree upon assignments to be completed or followed up in the next meeting.

Teaching and Learning Plan

The teaching and learning plan should include:

- Long term goals
- Anticipated student thinking
- Data collection plan
- A sequence of learning
- The rationale for this chosen approach

In creating the teaching and learning plan teachers may wish to ask themselves:

(Note: These questions are only a guide)

1. What do students currently understand about this topic?

2. What do we want them to understand at the end of the unit or sequence of lessons?

3. What's the sequence of experiences (lessons) that will propel students toward the learning objective?

4. What will make the unit/sequence of lessons and each individual lesson motivating and meaningful to students?

5. Which lesson in the unit will be selected as the research lesson?
6. What will students need to know before this lesson?
7. What will they learn during this lesson?
8. What is the sequence of experience through which they will learn it?
9. How will students respond to the questions and activities in the lesson?
10. What problems and misconceptions will arise and how will teachers respond to them?
11. What evidence should we gather and discuss about student learning, motivation, and behavior?
12. What data collection forms are needed to do this?

Each member of the planning team should independently do the activity intended for students within the research lesson. Usually in a group of teachers, there will be a variety of strategies in attempting an activity and each teacher should have an opportunity to share how they approached the activity. It will be important to discuss the successes and difficulties the students will encounter and also the successful process(es) and outcomes for this task.

The point of anticipating student responses is not to design the activity so that student's won't struggle or so that misconceptions won't emerge, but rather to give teachers an opportunity to plan how they will respond and to think about what kind of struggles and misconceptions may be an intentional element of the lesson. It is important to discuss the instructional strategies and options that might facilitate the student learning as struggles and misconceptions emerge. Record the anticipated student responses and teacher responses in the lesson plan.

Approximate Time Guide	Student Learning Activities	Anticipated Student Responses	Anticipated Teacher Responses	Points to notice & evaluate

Figure 11 Suggested headings for a Teaching & Learning plan

Collecting Data

It will also be important for teachers to reflect on what data collected during the lesson will assess the learning and engagement of students.

NB: It may be useful for observing teachers to have both a copy of the lesson plan and seating map of the room with students' names during the lesson.

In designing and observation sheet teachers should ask:

1. What data will help you understand your students' progress on your lesson goals and long-term goals?
2. Would a prepared data collection form facilitate observation or should conversations between students be recorded?
3. What student work (if any) will be collected at the end of the lesson?
4. How will material that is presented on the board or in other locations be captured? (Photographs etc.)
5. What are the individual assignments of the lesson study team? Will one person transcribe the lesson and keep a timeline of lesson events? Will observers be assigned to observe specific students or groups?
6. If the lesson is to be video-recorded, who will be in charge of the video equipment during the lesson?

It is not necessary to write an answer for every question but it is important to discuss the questions within the meeting. You may wish to write your Lesson Plan as a mind map but it is important that there is a written record for you and your colleagues to return to for the reflection and following the Lesson Study cycle.

3. Conducting and Observing the Research Lesson

Teaching the Lesson

The teacher who will be instructing the lesson should follow the Teaching & Learning plan or may construct a condensed Lesson Flow for themselves. The teacher may introduce the class to the observing teachers but otherwise should not interact with his/her colleagues during the lesson. This teacher is conducting the lesson that all members of the group have designed.

Recommendations for observing teachers

- Minimise side conversations during the lesson

Remain in the classroom during the entire lesson to capture how the lesson is set up, its flow, and its conclusion

- Do not block the students' view of the blackboard or any area where the teacher is writing and posting materials or demonstrating an activity
- Minimise interactions with students. Refrain from teaching or assisting the students. Occasional interaction is permissible if done discreetly and with the purpose of understanding student thinking.

Observing teachers should choose specific behaviours or actions to focus on during the lessons. Teachers may wish to address specific research questions during the lesson and/or use observation forms.

Note: The observing teachers are explicitly focusing on students' engagement and learning during the lesson and not on their colleague's teaching.

Suggested Observations to Note

- Comments that come to your mind as you observe.
- Critical things that are happening in the classroom.
- Types of questions the students ask.
- Types of questions the teacher asks.
- Evidence of higher-order thinking.
- Evidence of confusion.
- Number of times students refer to and build on classmates' comments.
- Evidence of engagement.

4. Reflect on the Research Lesson

Reflection Meeting

A. Choose roles for the planning meeting: time keeper, note taker, facilitator etc.
B. The lesson teacher should first share their reflections on the lesson.
C. Observing teachers should share data and reflections from the lesson (each person should have an opportunity to share their opinions and provide evidence for their observations).
D. Use the data to highlight student learning, lesson design, and any broader issues in the teaching & learning.
E. Reflect on any changes that should/not be made to the Teaching & Learning template and decide whether or not to teach this adjusted plan or embark on a new cycle.
F. Record any changes to the Lesson Study plan and make note of new ideas that have resulted from the observation of the lesson.
G. Review key decisions and/or insights made during the lesson study meeting.
H. Agree upon assignments to be completed or followed up in the next meeting.

Note: If the group agrees to revise and re-teach the lesson, what changes affected the student learning? How was the learning affected?

Appendix B: Materials for use during lesson study

Long-term Goals and Objectives

Personal Objectives	
Teaching Objectives	
Classroom Objectives	
Objectives for Students	

Teaching-Learning Plan

Participating Teachers	
Instructor	
Date	
Intended Class & Year Group	

Lesson Title	
Research Theme/ **Subject Matter Goals/** **Lesson Goals**	
Lesson Rationale • Why focus on this topic? • What is difficult about learning or teaching this topic? • What is currently noticed about students learning this topic? • Why we have designed the lesson as shown.	
What do students already know about this topic? **How does students' understanding of this topic develop?**	
Where does this lesson relate to the curriculum?	
How will the learning be assessed?	

Approximate Time Guide	Teaching/ Learning Activities	Anticipated Student Responses	Anticipated Teacher Responses	Points to notice & evaluate

Lesson Flow for Instructing Teacher

Lesson Flow	Role of Teacher (s)

Observing the Research Lesson

Observers may wish to take some of the following actions:

1. Make notes on individual student comments and conversations, noting the names of students
2. Note situations in which students are collaborating or choosing not to collaborate
3. Look for examples of how students construct their understanding through their discussions and activities
4. Document the variety of methods that individual students use to solve problems, including errors.
5. Decide on pairs or groups of students on which to call on when students are asked to present their work.

The following are a number of options you may wish to follow during your observations. You and your colleagues may amend/use as you feel best impacts your own research on students' engagement.

Observer Questions	Notes
Was the goal clear? Did the supporting activities contribute effectively to achieving the goal?	
Was the flow of the lesson coherent and did it support students' learning of the concept?	
Were the activities and the materials helpful in achieving the goal of the lesson?	
Did the classroom discussions help promote student understanding?	
Was the content of the lesson appropriate for students' level of understanding?	
Did students apply their prior knowledge to understand the content of the lesson?	
Did the teacher's questions engage and facilitate student thinking?	
Were student ideas valued and incorporated into the lesson? Did the lesson summary refer to student theories or ideas?	
Was the lesson summary consistent with the lesson goal?	
How could the teacher reinforce what the students learned during the lesson?	

Recording Student Talk

Point in the lesson	Student Comments/Conversations	Significance