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Facilitating Sustainable Professional Development through Lesson Study

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Developing sustainable professional development which facilitates teachers of mathematics to develop effective mathematics pedagogy has been a key aim in recent years. This paper examines how lesson study can be used with networks of teachers as a vehicle to promote and sustain professional development. Drawing on findings from a year-long study involving four schools, the paper highlights how through the process of collaboratively planning a lesson, observing and discussing it, teachers were facilitated to adopt approaches to mathematics teaching that are aligned with the factors identified as effective mathematics pedagogy. It also illustrates how lesson study can support teachers to engage in a collaborative network, develop their professional knowledge, and reflect on their teaching practice.

A key aim of professional development in recent years both in the United Kingdom and internationally has been to develop sustainable networks of teachers of mathematics who engage in developing effective mathematics pedagogy (Askew & Burns, 2005; Jaworski, 2006; Muir & Beswick, 2007). According to the findings of the report by Back, De Geest, Hirst, and Joubert (2009), some key indicators of the effectiveness of continuing professional development are opportunities to develop networks, a focus on student learning, and the facilitation of reflection on teaching practice. This paper considers the essential elements of lesson study as a vehicle for sustainable professional development with networks of teachers. It addresses the ways in which the post-teaching discussion draws on classroom observations of teaching practices and evidence of student learning. It illustrates how the ongoing relationships developed in the networks support the participants in sustaining their development as expert users of effective pedagogical practices in teaching mathematics. The specific questions addressed in this paper are: does involvement in the process of lesson study sustain professional development? How does that involvement sustain professional development?

Background and Theoretical Framework

The theoretical framing of this paper is based within a socio-cultural perspective on the processes of teaching and learning. In this perspective teaching and learning have a reciprocal relationship with effective teaching identified through evidence of the response to it in terms of student learning. This learning can be manifested through the changing identities, dispositions and competencies of the students involved. In addition, teachers' professional development can be identified through evidence of changes in professional identity, attitudes, and their actions in their classrooms.

There are four important elements that underlie the research described in this paper and underpin the theoretical stance. These elements are the process of lesson study, the notion of professional learning communities, the nature of effective mathematics pedagogy, and reflection on practice. The first three key elements are addressed in turn before the fourth section highlights how reflection on practice may be facilitated through the process of lesson study which integrates both professional learning communities and an examination of effective mathematics pedagogy.

Lesson Study

The research study reported in this paper involved groups of teachers participating in communities of inquiry with the methodology known as lesson study as their foci. A brief account of the lesson study process and its use as a vehicle for professional development are provided in the following section.

The process of lesson study is complex consisting of many variations. As a form of professional development, it pays attention to the key aspects of teachers' mathematical knowledge for teaching identified in the literature (Joubert & Sutherland, 2008). These key aspects include: knowledge about mathematics, knowledge about ways of teaching mathematics, and knowledge about the ways in which learners engage with and make sense of mathematics.

Lesson study as a form of continuing professional development (CPD) is to a greater or lesser degree based on Japanese models of development (Burghes & Robinson, 2010; Fernandez & Yoshida, 2004; Lewis, 1995) that particularly emphasise student learning. The process of lesson study involves a group of teachers in collaboratively planning a lesson called the 'study lesson' over a series of meetings. This lesson is then taught by one of the teachers in the group and videoed or observed by the whole team, with a particular emphasis on the student responses to the lesson. The observed lesson is then discussed at a meeting of the group where it is further developed on the basis of the student responses and consequently re-taught to a different group of students. This may then be repeated or a different lesson developed. The size of a lesson study group can vary considerably but generally involves up to five teachers with a minimum of three. In Japan, lesson study is the main form of professional development for teachers and each teacher would expect to be involved in several lesson study cycles during the course of an academic year.

A superficial view of lesson study is that it is a process centred on developing the 'perfect' lesson on a particular topic for students of a specific age; however, this is not the intention of the process. In contrast, a number of subtle aspects support the development of a process in which teachers are led to a deep engagement with the processes of teaching and learning. Consequently, engaging in a lesson study cycle prompts teachers to reflect on their own approaches to the processes of teaching and learning and to develop their own practices in ways that are meaningful to them in their working contexts. A key aspect of lesson study identified by Stepanek and Appel (2007) is the

identification of an overarching aim. This aim should be closely aligned with the broad aims and intentions of the school and may be linked to mission statements or plans for improvement. An example might be: 'Our students will become independent thinkers (learners) who enjoy working together to produce creative solutions in unfamiliar situations'. This over-arching aim would then be evident in each study lesson that the group collaboratively develops with all of the lessons contributing to its achievement in some way. In a wider sense, this may influence other lessons that are taught and therefore can lead to a wider adoption of the strategies and approaches developed for the study lesson. Another key aspect of lesson study is the development of a lesson which makes the students' learning visible to the observers (Burghes & Robinson, 2010). This can be described as an 'open approach' and involves developing tasks for the students which stimulate responses that reveal their engagement with the problem presented and their thinking as they present their solutions. Typically these open tasks may provoke a range of responses and the teacher will observe the students' responses during the course of the lesson and build an appropriate sequence in which they can be presented to the class. During the course of the presentation of the responses, the students are expected to interrogate their fellow students' work and to validate its mathematical integrity and truth.

This summary of lesson study constitutes the basic pattern of the approach; however, there are many variations on this both in Japan and in other contexts. These variations result in different levels of engagement with the principles underpinning lesson study. Engagement with the principles of lesson study is neither straightforward nor easy, and learning and change through engaging with this process takes prolonged time periods.

Participating in Professional Learning Communities

To consider the nature of the professional learning community in which participants were involved through the process of engaging with lesson study, the theoretical frameworks of communities of practice developed by Wenger (1998) and communities of inquiry developed by Jaworski (2004, 2006) are used. Wenger's notion of communities of practice focuses on the concepts of practice and identity and the interrelationships between them. Learning is seen as developing participation in practice and involves investigating how the participants learn to participate in the practices of the community. Application of a community of practice approach to the analysis of teachers' professional development allows exploration of the possibility that any one participant might aim to identify himself or herself in multiple ways, in the service of more than one (social) purpose. Teachers engaged in professional development within a lesson study group are involved in positioning themselves as a participant in the lesson study community in which they are engaged with social 'work' associated with developing the study lesson and developing their professional identities within the group. Use of this framework does not imply that participants are consciously aware of this work as it may be entirely tacit and embodied in the act

of participation itself. Instead, it involves the teachers in positioning themselves 'as' someone in the lesson study group which can be conceived of as a community of practice. Wenger, from a sociocultural perspective, notes that practice "is a process by which we can experience the world and our engagement with it as meaningful" (1998, p. 51). From this perspective, in the case of the teachers in the study, the focus of their participation in lesson study was on the practice of lesson study as a vehicle for developing their practice as effective teachers of mathematics. They were seeking to develop their practice as teachers of mathematics and develop meaningful approaches to that practice that increasingly developed their identities as users of effective mathematics pedagogies.

Jaworski (2004, 2006) develops Wenger's (1998) notion of communities of practice and applies it to professional development work with teachers. She sees teaching as a social process in which teachers are practitioners and in which their learning is conceptualised as developing their identities as teachers through their participation in a community of practice. In addition, Jaworski suggests that this development can perpetuate the status quo of practice within a group of teachers that settles down to conformity with classroom practices that are essentially harmonious but which are 'not necessarily providing effective learning opportunities for all students' (p. 190). Jaworski argues that for practice to develop in ways that offer improved learning opportunities for students, teachers need to be viewed as learning in practice or "learning-to-develop-learning" (2006, p. 191). This involves a conception of teachers being engaged in 'critical alignment' of practice in which they seek "to develop, improve or enhance the status quo" (2006, p. 191) through their involvement in a community of inquiry. Therefore, inquiry can develop from being used as a tool to enable teachers and educators to explore key questions and issues in practice to becoming a 'way of being' through which participants in a community develop their practice (Jaworski, 2006).

Effective Mathematics Pedagogy

Mathematics holds a key role both in terms of individuals' abilities to function in society and in the future educational and employment opportunities which are available for them (Ernest, 2010). However, many students continue both to struggle and become disaffected with mathematics. Therefore in recent years, both in the United Kingdom and internationally, research has sought to define the pedagogical practices which lead to effective mathematical learning. A large scale study by Askew and his colleagues (1997) based in the UK identified and investigated different aspects of effective teachers of numeracy. The study aimed to understand effective teachers by developing a model of their classroom practices, individual beliefs and knowledge of mathematics and mathematics pedagogy. Data were gathered through questionnaires, observations and interviews. Askew et al. identified three types of mathematics teaching and characterised 'connectionist' teaching as the most effective.

Another model for effective mathematics pedagogy was developed by Swan (2006) in conjunction with a design research project that sought to improve learning in mathematics for students at tertiary colleges who had a history of finding success in mathematics problematic. Within this study, Swan developed a professional development course for teachers which supported them in developing pedagogies valued by their students. Other research (e.g., Anthony & Walshaw, 2009; Hiebert & Grouws, 2007) on effective mathematics pedagogy includes research syntheses that draw together the findings of international research studies to develop a rich knowledge base of pedagogical practices that contribute to positive outcomes for students. Anthony and Walshaw use their findings from the synthesis to develop a framework including ten principles of effective mathematics pedagogy. These different explorations of effective mathematics pedagogy reveal some commonalities and these are used as a theoretical base for this study. The following section summarises these commonalities.

An important aspect of effective mathematics teaching is developing tasks and classroom activities which focus on key mathematical ideas (Anthony & Walshaw, 2009; Askew et al., 1997). In particular, tasks should be designed to engage students in furthering their understanding of important mathematical concepts and relationships. It is also important that tasks are posed in such a way that learners are able to access their prior learning and make connections between their previous experiences and important mathematical ideas (Anthony & Walshaw, 2009; Askew et al., 1997; Swan, 2006). In such a way, instruction builds on the learners' thinking, and misconceptions and mistakes are addressed and used as learning opportunities. Providing opportunities for students to explore the connections between mathematical ideas, differing strategy solutions and multiple representations also supports effective mathematics learning (Anthony & Walshaw, 2009; Askew et al., 1997; Muir, 2006; Swan, 2006).

Effective mathematics pedagogy requires both a focus on developing learners' mathematical knowledge and the development of an effective classroom community (Anthony & Walshaw, 2009; Hunter, 2009; Muir, 2006). This involves developing a learning community which is responsive to the learners' needs. Anthony and Walshaw highlight factors such as carefully structured mixed attainment grouping, providing opportunities for individual, paired and group work, and the provision of a supportive environment that develops student autonomy. Classroom discourse also has an important role in effective mathematics pedagogy. This includes the facilitation of purposeful discussion which challenges children's thinking and a focus on developing student use of explanatory justification (Anthony & Walshaw, 2009; Askew et al., 1997; Muir, 2006). Children also need opportunities to learn how to agree and disagree and how to question their peers to make sense of student provided explanations during small group work and whole class discussions (Hunter, 2009).

A critical factor in developing effective mathematics pedagogy is teacher knowledge and learning. As Anthony and Walshaw (2009) state, "how teachers

organize classroom instruction is very much dependent on what they know and believe about mathematics and on what they understand about mathematics teaching and learning" (p. 157). Sound mathematical subject knowledge is a key factor in supporting teachers in identifying the connections between different areas of mathematics. This in turn supports the teachers in assessing students' understanding of mathematical topics (Anthony & Walshaw, 2009; Askew et al., 1997; Muir, 2006). Also important is knowledge of how students learn mathematics including their expected progression and an understanding of potential obstacles to learning or misconceptions. This supports teachers to make sense of student explanations and use questioning to facilitate learning (Anthony & Walshaw, 2009; Askew et al., 1997). Another key aspect of teacher knowledge is the knowledge of teaching approaches that support students to develop rich conceptual understanding of mathematics (Askew et al., 1997). These three key factors – mathematical subject knowledge, knowledge of the ways in which students make sense of mathematics, and knowledge of ways of teaching mathematics – have also been identified in the literature as central to effective professional development for teachers of mathematics (Joubert & Sutherland, 2008).

Developing Reflective Practice

Developing reflection on practice is a key component of sustainable professional development (Back et al., 2009). This section draws together the three elements described above as central to effective professional development and examines how they may support teachers to reflect on their practice. In developing the capacity to reflect on practice the first and essential step is that of noticing and being aware of relevant phenomena. This process of noticing only develops through engaging with it and involves both knowledge of relevant aspects of a given situation and also an increasing ability to be aware of them and reflect on them in the immediate context of the classroom. In developing reflection on aspects of teaching and learning mathematics, teachers in a lesson study group need to develop understanding of the pedagogies that they are using, to have knowledge of the mathematics involved and to be aware of the ways in which the children make sense of the mathematics. Furthermore, they also need to notice how their practices resonate with, or are in conflict with, the ideas of effective mathematics pedagogies which they are seeking to adopt. This idea of noticing is captured in John Mason, Leone Burton, and Kaye Stacey's (2010) seminal text on developing mathematical thinking now in its second edition:

> None of the processes or activities I have mentioned is unusual or new. They happen spontaneously inside everyone to varying degrees, often below the level of awareness. By becoming aware of them, and seeing how effective they can be in appropriate circumstances, they should begin to happen more frequently and more intensely than before. (p. 106)

These authors equate the process of noticing thinking as similar to developing an internalised tutor who monitors that thinking for you. Involvement in the lesson

study process, in particular the reflective discussion with colleagues about the study lessons, can work in a similar way for the teachers.

To summarise, this paper draws on research literature to examine how engaging in lesson study may facilitate sustainable professional development through the development of learning communities in which both awareness of effective mathematics pedagogy and reflection on practice are promoted.

Methodology

Research Context

The overarching aims of the project were to investigate and evaluate whether lesson study could be used with teachers as a form of research-based professional development and as a form of classroom-based research. The study involved four groups of primary teachers within England and the Channel Islands who were interested in implementing the lesson study process within their schools during the 2009/2010 school year. All schools and participants involved in the study were assigned pseudonyms to ensure anonymity. The schools included a mixture of urban, rural and suburban contexts with students from a range of socio-economic and ethnic backgrounds, and the teachers had varying levels of experience. Specific details of the participants from each school are shown in Table 1.

Table 1
Schools and teachers at each year level

	EY	R	Y1	Y2	Y3	Y4	Y5	Y6	HT
Beaumont				1	2				
Hillview					2		1		
Kingsland					2	2	2	1	
Hamilton	1			1	2		1		1

The sample was an opportunistic one of willing schools drawn from the group of schools with which the research team was involved in research and development activities.

The lesson study approach had not been used previously at any of the schools; however, two of the schools had some degree of experience in using models of collaborative practice. The teachers at Beaumont School had engaged in a paired collaborative observation approach during the previous school year. Additionally, the teachers from Hamilton School had previously worked collaboratively and across year groups in a variety of subject areas. At the other two schools, Hillview School and Kingsland School, collaborative approaches to planning or teaching had not been previously used.

Within the study, during the lesson study process each group of teachers worked as a professional learning community within their own school. The

initial step for each group was to agree on an over-arching aim which was relevant to their school context. Developing this aim was a goal of the first meeting and collaborative agreement from the group was sought. Following the initial meeting the teachers decided on an area of focus for the study lessons. This area was chosen typically as either an area in which the children at the school had difficulties, or alternatively an area which the teachers felt less confident about teaching. The group then collaboratively planned the study lesson. Following this, the lesson was taught in one classroom while the rest of the group and researchers observed. The group then engaged in an in-depth analysis and discussion of the study lesson and consequently the lesson was re-planned based on the observations from the lesson and re-taught and observed in a different classroom. The second lesson was then the subject of another in-depth analysis and discussion and the overall engagement of the teachers in the lesson study process was reflected on by them. Members of the research team were present at the majority of the planning meetings, the presentation of the study lessons, and the follow-up meetings.

Evidence of the practice that formed the focus of the study was gathered through observations of the meetings held and the study lessons taught by the teachers involved. Data were collected through field-notes and video and audio recordings. The findings of the case studies were developed through on-going and retrospective data analysis. The video and audio recordings were wholly transcribed and through an iterative process using a grounded approach, patterns and themes were identified.

The findings are presented as accounts of the learning and development in collaboration with the teachers involved and their personal reports of changes in their attitudes, identities and actions in their classrooms. Evidence of this has been triangulated from both our observations of lessons they have taught and developed and the discussion following the study lesson.

Findings and Discussion

In this section, a description of how engaging in the lesson study process is facilitated the teachers to notice key aspects of mathematics pedagogy is provided. Analysis of the data revealed five central themes that relate to the development of effective mathematics pedagogy. These were: key mathematical ideas; prior learning and misconceptions; developing connections; facilitating an effective learning community; and classroom discourse. These themes are presented as three sections in the findings due to their interwoven nature. For example, the discussions which focused on the key mathematical idea of the equal sign as equivalence were also linked to discussion of children's prior learning and misconceptions. The findings are presented in relation to the inter-linked five themes.

Focusing on Key Mathematical Ideas, Prior Learning and Misconceptions

During the post-lesson discussion it was evident that the in-depth observation of the students' responses to the classroom activity facilitated the teachers to reflect on student understanding of key mathematical ideas. During some of the discussions, the key mathematical ideas that were highlighted had been the specific focus of the lesson. For example, at Hillview School the lessons were designed to facilitate student understanding and justification of the commutative property. Following the first lesson with children aged seven and eight years, the teachers provided detailed observations of the children's responses to the task:

> Ellen: Iris and her partner were looking at subtraction without even being prompted to do it because they said straightaway 'it doesn't work for subtraction but it is working for addition'. They were very confident in the addition and less confident with the division. This group in particular were happy with the multiplying but they couldn't then..., they weren't so comfortable with the division.

Melissa also offered a specific example of how a group of students responded to the task focusing on the key mathematical idea of the commutative principle:

> Athena, Christopher and Lauren, they were doing it with the subtraction. They did four minus one equals three and one minus four [puts hand up to indicate question mark] and then they said, and Lauren said 'so that is subtraction done then, that doesn't work' and she did it for one, if it doesn't work, it doesn't work whereas she then said 'actually five times three and three times five works hmm' and then they did something with twos and then she said 'does it only work with twos though?' So then they tried with a different number, that was Lauren who said that so she had got the idea that if with one it didn't work [indicates throwing something away] she just discarded that straightaway and went straight on to the, on to the next one.

In other instances during the discussions, the key mathematical ideas were not the specific focus of the lesson but were perceived by the teachers to be influencing the children's learning. During the discussion, there was also evidence of the teachers' developing ability to notice children's misconceptions. For example, in the second study lesson at Hillview in a class of nine and ten year olds, the teachers commented on the difficulties the children had in representing the commutative principle as a number sentence (for example, $6 + 5 = 5 + 6$) due to their limited understanding of the equal sign. Ellen stated:

> They seem to find it really hard to write one continuous number sentence.

Monica further explored this commenting:

> They are still not understanding the proper meaning of the equal sign, I would say, or perhaps they are but when it comes to applying it in a context then they're not.

In some instances the discussions of children's learning of key mathematical ideas supported the teachers to reflect on how tasks could be structured to promote better learning. This also included reflection on the reasons for children's misconceptions related to classroom activity. At Beaumont School the study lessons were focused on developing children's ability to solve multi-step word problems. However, two activities again highlighted children's understanding of the equal sign. During the first activity, students were asked to make a specific number using a number sentence which was then represented as equivalent to another number sentence (for example, 45 = 20 x 2 + 5 = 20 + 25 = 45 – 0). The second activity prompted the children to correct incorrect multi-step equations some of which included balance equations (for example, 8 + 9 = 7 + __). The teachers observed the students' initial difficulties in correcting the balance equations and subsequent discussion between the students that arose. Early in the post study-lesson discussion, Zara highlighted the activities, both of which were related to understanding the equal sign:

> We still had to keep coming back to that, that the two sides of the equation had to balance, how much time we have done that, and even given that they had done that in the first part of the lesson [referring to the first activity]. They don't seem to see that as the same as being presented with one, you know because that first activity is doing the same thing, isn't it, and they see it there but they don't seem to see if you write it down for them but I think they got some good discussions out of all the correcting the mistakes.

This initial analysis of how the activities were structured to facilitate children's thinking about the key mathematical idea of equivalence led to further analysis and reflection from a different member of the group.

> Rebecca: I think maybe because we historically present children with a lot of things with the answer just being one box that sort of one where they had to look maybe provoked that thinking a little bit more. You know at the beginning where they said something, something equals and then the next child does equals, I don't know, when I look at it now I think it is a fantastic activity and a fantastic assessment thing to see where they are coming from (...) but maybe they are just seeing and the next one, and the next one, and the next one and now it's my turn and it's my turn and they don't actually see the equal sign whereas this question here and that one here in particular really made them think about the idea of balance.

These discussions highlight how observing children's responses to tasks through the lesson study process supported the teachers to notice aspects of effective mathematics pedagogy such as key mathematical ideas, the role of prior learning, and misconceptions.

Developing Connections

The teachers in this study were supported in noticing the connections between mathematical ideas, differing strategy solutions and multiple representations through the lesson study process. A common feature across all the lesson study groups was the identified need to facilitate children to make connections between physical representations or concrete materials and mathematical ideas. For example, Mark commented:

> They need lots of different representations and practical experiences of concepts.

The connections which the children developed between the concrete materials and mathematical ideas were also highlighted as supporting and deepening the children's understanding. For example, in discussion of the children's developing understanding of the commutative principle, specific examples were provided of the physical representations supporting the children's understanding:

> Ellen: I think it was Iris and Andrea, they were talking about the objects and they suddenly became sweets, if we have got three sweets we can't divide them between seven people so they were then jumping ahead and moving that relationship on, that was good.
>
> Melissa: That is really good.
>
> Ellen: I think it was the resources that prompted that.
>
> Monica: I think even with John if he hadn't seen it on the grid [referring to an array], he probably wouldn't have got it as quickly as he did.

Close observation of the students by the teachers during the study lesson also supported them to notice varying connections in student provided solution strategies. For example, in one lesson during the whole class discussion a student provided a correct solution; however, the representation and method was not linked to the problem context. This was identified by the teacher and she prompted the student to reflect on this. Another teacher in the group highlighted this as an example of good practice in terms of facilitating student learning:

> Rebecca: Afonso, you know he had done it a different way than to the actual problem because you could have just said 'yeah that is great well done' but you said 'but does that actually model what the problem was about?'

Similarly, missed opportunities in developing connections between student-provided solution strategies were also a feature of the discussions. For example, a student provided a solution that involved drawing individual flowers to solve a division problem which was critiqued by another student as inefficient. During the following discussion between the teachers this was highlighted as a possible learning opportunity:

> Rebecca: Bethany when she said 'oh that took ages', it would be nice to sort of pick up on that so you have got the halfway house, you know because it is a very inefficient method really. It's something they go through but maybe they just realise that they can just write five in each box rather than drawing each thing because that would have been a nice opportunity to pick up on what Bethany said. You know maybe some sort of race I put here, where you have someone drawing and someone finding a quicker way.

These examples suggest that through involvement in the lesson study process, teachers can be supported to notice a range of connections within the mathematics classroom.

Facilitating an Effective Learning Community and Focusing on Classroom Discourse

Discussions of effective grouping strategies were a common feature across the lesson study groups. However, there were differing levels of engagement with ideas about how to group children effectively. For example, at Hillview School the discussion touched on grouping but did not engage deeply with how children could be facilitated to work effectively within a group:

> Ellen: We keep changing the groups around trying to find the appropriate groups for them to work in and some groups work well and others I don't think will.
>
> Monica: Some people never work well in a group anyway, do they? So whichever group you put them in, they are always going to struggle.

In contrast, at Beaumont School the discussion involved consideration of how to facilitate the children to work effectively in their groups. For example, Michelle described her inclination to put the higher attaining children in a group together although she was unsure of this in terms of inclusion:

> I would be so tempted to put, because there is four in there who really do get it, to put them in one group, but I know that that really wouldn't spread it then.

Rebecca responded to this comment by suggesting pedagogical actions to support effective group work using mixed attainment groupings:

> It is how you train those other children to question, the more able so they are drawing the learning out of the less able child and that is tricky.

This was followed by an exchange which focused on how social norms could be developed for collaboration during group work and class discussions:

> Rebecca: I think it is trying to get everybody having that chance in terms of the discussion and to try and get your brighter ones, because you have got a lot of bright ones there, and how do you train them to get everybody in their group responding so you shift their role which

> broadens them wider because then they have to think okay how do I explain this in a different way? So they are trying to get others in the group of four, say Harper, to explain it and they are trying to work out what is going on in her head so they can ask the questions to draw out her explanation and giving them that as 'oh it is not sitting back and waiting for the slow person to do it' but giving them that important role.

Michelle: You can see within the whole class, it is Shaun and it is Fraser, and they are there because they are just full of it and they just want to but it is just trying to get them to hold back.

Rebecca: It is 'I know you know the answer but how can you get them to explain it really clearly, so you have to listen really carefully and work out what they are doing' so you are sort of shifting the emphasis.

This exchange exemplifies how engaging with the lesson study process can support teachers in considering factors of effective mathematics pedagogy such as carefully structuring mixed attainment grouping and facilitating the development of social norms for effective group work.

Another significant aspect during the teachers' discussion was the focus on students' developing questioning skills. The teachers' observations included questioning both during small group work and in whole class discussions. For example, Ellen identified an instance where questioning was used during small group work to resolve a mathematical disagreement:

> With Alan's group and they were working with the negative numbers, they got their addition wrong which then provoked, it certainly provoked the argument between them, well does it actually work? Does it not work? And they had to really delve deeply to work out whether it was an exception or whether it was the norm.

As the teachers were working in groups across year levels, another discussion centred on the development in questioning skills across the age groups. For example, Melissa contrasted the use of questioning from her younger seven and eight-year-old students with the questioning she observed in the class of nine and ten-year-old children during a whole-class discussion:

> When Julia was talking some of the others put their hands up and they questioned her directly and she explained her thinking back to them. I think that worked really well. (…) A number of them did that and I don't think ours have got that language, sometimes they need a bit more modelling and structuring of how to question the person who is explaining because they do sometimes say 'I don't understand' rather than asking them a specific question.

The excerpt highlights how the teachers were able to use the observations during the study lesson to reflect on their own classroom practice and further analyse how specific areas could be developed.

Another area of significance, which the teachers focused on during the post study lesson discussion, was the structuring of explanations to develop an effective whole-class discussion. This meant that the teacher had to listen carefully to children's responses during small group work and carefully select the groups to contribute to the discussion so that it would be structured in a logical manner in order to develop the children's mathematical reasoning and thinking. Through engaging in the lesson study process the teachers analysed how the whole-class discussion facilitated the children's development of mathematical concepts. For example, Ellen critiqued the choice of a group to share during the whole-class discussion as the group had concentrated on the inverse property rather than the focus of the lesson which was the commutative property:

> I think avoiding the inverse could be something to do next time so to be specific when the example came up with the group from the front there, they weren't investigating the commutative law, and they were investigating the inverse and I think what I would have tried to have done is just said that's fine and try to direct them but not bring them up to the front to make their explanation.

This also led to the teachers considering the need to think of children's possible responses to tasks in order to best facilitate a whole class discussion.

Discussion of the choice of children to share during the whole-class discussion was also an opportunity to examine how the discussion might be used to scaffold all the learners' understanding. Examination by the teachers of who was selected to share during a whole-class discussion and the reason behind this also provided opportunities to share the pedagogical actions that were used to develop inclusion and student autonomy. For example, Zara highlighted her selection of a lower attaining student to share a solution strategy and how she supported her to rehearse prior to explaining to the whole class:

Rebecca: There is still an awful lot of them doing ding, ding, ding [indicates counting on fingers].

Zara: But then that is also why I brought out Madeira because she did the five, ten, fifteen.

Rebecca: Yes and how confident was Madeira because she was one of the ones who used to need a lot of support, didn't she? It was excellent.

Zara: Yes and she still does. We rehearsed that in her place because I caught her doing it and said 'oh I want to share with everyone what you have just done'.

Michelle: So you were rehearsing it to give her the confidence?

In this way, engaging in the lesson study process offered opportunities for the teachers to notice pedagogical actions that developed a classroom environment which was inclusive and responsive to children working at different attainment levels.

Developing Reflection on Practice and Professional Knowledge

In this section, a description is provided of the teachers' awareness of their professional development as users of effective mathematics pedagogies through the process of involvement with their lesson study group. Analysis of the data revealed two central themes: firstly the teachers commented on how lesson study supported them in working collegially and reflectively and secondly they identified ways in which their professional knowledge had developed. The findings are presented in relation to these two themes.

Collegiality and Reflection

Teachers from all the groups commented on how the process of lesson study gave them opportunities to work together with other teachers. This broadened their insights into the topic, its teaching, and the sense that children might make of the learning opportunities involved. For instance, Monica commented:

> I think it gave me an insight as well and I think, you know when you are planning a lesson on your own and it is all in your head, it is one thing but when you are verbalizing it in a group and discussing it, there is so much. It gives you a depth that I don't feel I achieve when I am planning a lesson on my own necessarily.

And also:

> Michelle: We are also having more of an understanding of the development of learning these concepts which has been good, it has been great to see that development today and it can only be beneficial.
>
> Zara: It shows you more of that journey and you are picking up things from other people which you think I could take that, I could adapt that, and that is another way of doing what I am doing or it's another idea of something I have not tried.

These features of collaboration often led them to reflect on their own teaching as Zara is beginning to say in the quote above. Once again, all the groups made reference to how involvement in the lesson study process facilitated them to reflect on their own teaching. For example:

> Orla: I think it definitely makes you look at other aspects of maths, not just fractions [the topic of the study lesson] and it has made me think every time I've planned lessons since like how could I do this differently this time, like look into different ways of exploring a lesson that I've done before so again maybe looking into research based on that concept.

Similarly, one of the teachers from Hillview commented:

> Ellen: We are constantly analysing what we do anyway and I think it has just given more of a focus for that because Melissa and me we could

take a step back and look at what somebody else is doing. I think that always then makes you reflect on what you are doing yourself.

Other comments indicated that the reflective process facilitated by engagement in the lesson study prompted the teachers to engage in deep reflection on their practice and begin to develop teaching practices which align more closely with effective mathematics pedagogy:

Monica: It has made me think about my practice, I have to say and it has made me more aware of what I can improve and it has made me more aware of what I need to be including in my lessons and kind of working within a broader structure. Whereas I was always good at questioning and pitching different questions to different children and whereas now I think I am doing it in a deeper and broader way. It has kind of widened out a lot and I am much more receiving, although I always wanted to get things out of the children but now it is a bit more different. Whereas before I saw things as right or wrong, I am much more focused on the process now rather than whether it is right or wrong.

This shows a teacher who is giving considerable thought to her practice and ways in which to change it in order to support her students to learn mathematics.

Professional Knowledge

As previously stated, the literature identifies three aspects of professional knowledge that support teachers in their endeavour to teach mathematics effectively. These are the teachers' own knowledge of mathematics as a subject, their knowledge of ways of teaching mathematics, and their knowledge of the ways in which children make sense of mathematics (Joubert & Sutherland, 2008). All three aspects are crucial to effective mathematics pedagogies and all three were mentioned by the teachers in the course of their discussions after the lessons they observed.

Teachers' knowledge of mathematics is not dealt with directly in the lesson study approach to professional development; nonetheless, each of the groups mentioned how much they felt they had learnt about the mathematics through the process of their engagement. As one of the teachers said:

Judith: It certainly raises your awareness about the importance of mathematical subject knowledge and relevant terminology and how much you should be using and what you should be using and why. It means that instead of making some glib comment about something that you think is mathematically correct, you would take the time to make sure and get your maths dictionaries out, check those, build that in.

This was supported further on in the discussion by another member of the group who said:

Mark: It's raising your awareness that you might not know, there are things

> you don't know that you don't know, that you might teach without even knowing you're teaching them which means you can teach misconceptions which can be tricky … so if you've got a different attitude to think maybe I don't know then that immediately opens it up.

The focus of lesson study on the teaching of a specific lesson on a specific topic results in an in-depth consideration of the ways of teaching mathematics. This was an aspect highlighted and discussed by all the groups within the study in relation to their developing professional knowledge. In many cases this led them to more general discussion about how to teach mathematics. For example, Ellen reached some general principles about using resources to support the teaching and learning of mathematics from her group's use of resources in the study lesson:

> How much the resources are very useful and how I don't generally think I use them enough. … I would like to have supplies of resources which the children could then choose to use, not to impose them on them but to at least have access.

In another group, one of the teachers became interested in the connections that were being made between the work they did with the children on fractions and other mathematical topics, especially measures. As she said:

> Judith: And it shows you more of that journey and you are picking up things from other people which you think I could take that, I could adapt that, and that is another way of doing what I am doing or it's another idea of something I have not tried. For me making sure that we had a range… that we looked at grams, that we looked at millilitres and we looked at centimetres and so we were trying to draw together lots of areas of mathematics to build on the previous knowledge, to really think about the application, … skills that are notoriously quite difficult and our children find most challenging.

This statement is also linked to developing teacher knowledge of how children make sense of mathematics. This was also a feature that was apparent across the groups during the discussions. As the groups of teachers were involved in teaching children of different age groups, this led to some discussion about the progression of understanding of mathematical concepts. This is illustrated by the following excerpt which looks at the differences in understandings of multiplication between a class of 7-year-old children and another class of 9-year-old children:

> Melissa: I think I would discuss with them what they actually thought multiplication was to get them to go right back and kind of …
>
> Monica: Going back to 'lots of'…
>
> Melissa: Seeing it as lots of and seeing it as repeated addition and spending a little bit of time looking and representing multiplication in different ways.

> Monica: I think there is a bit of a similar problem as Ellen's class that they probably at some level have an understanding that it's 'lots of' and at some level because we have done arrays and they can see it somehow but when it comes to applying it at an everyday level, it's not secure enough to solve the problems that they need to solve.

However, this was most evident in the teachers' focus on predicting the children's responses to the learning opportunities that were offered in the study lessons. As Melissa said:

> Melissa: We spent some time trying to predict how the children were going to perform and true to form they always perform. You know we did anticipate a lot of it but there is always something that you haven't anticipated which then you have to think on your feet and look through and change your original plan. For me it was just fascinating to see somebody else do it.

In addition to predicting the children's responses to the tasks, the teachers developed knowledge of the learners from in-depth observation of the children's work on the mathematical tasks during the study lessons. Another common feature highlighted by each group during the discussion was the value of observing the learners. As Ruth said:

> The thing with observing which is really helpful is that you kind of put yourself in the position of the child whereas when you're teaching, yeah, you are thinking about their learning but you've also got to think about what you're doing and how you're sort of delivering it. With observing you listen to the teacher as if you were that child and so you really see how they are learning.

Ruth also commented on the value of having other teachers as observers when she taught the study lesson:

> It's useful though having people at the tables listening because you obviously can't listen to every single child and then having that feedback, I mean that amazing talk in your classroom to learn from.

In response to this, Mark added:

> Very useful I know. You've got one person in every group, no child can escape, the ideas they have are going to be captured which is fantastic.

In several of the groups this level of observation proved very encouraging to the teachers who were impressed by the focus of the children's talk on the mathematics of the lesson.

This section has illustrated how through the process of engaging with lesson study, teachers are provided with opportunities to work collegially to reflect on their own practice and develop their professional knowledge.

Conclusion and Implications

The results discussed in this paper support the argument that engaging teachers in lesson study is an effective way to support them in sustaining their professional development through facilitating awareness of effective mathematical pedagogies and the teachers' use of these pedagogies in their teaching practice. Research studies (Anthony & Walshaw, 2009; Askew et al., 1997; Swan, 2006) investigating effective mathematics pedagogy highlight the key factors of tasks which: focus on important mathematical ideas; link to prior learning and draw out misconceptions; develop connections; focus on effective discourse; and establish a learning community which is responsive to learners' needs. The teachers in this study demonstrated increasing understanding of strategies that supported their students' learning of mathematics, both in the lessons that they prepared as a group and in their reflections on the lessons that they taught and observed. The discussion that formed an important part of the lesson study process gave the teachers opportunities to articulate their observations about these issues and so helped them to notice relevant phenomena. They became the drivers of their own development as they increasingly sought to adopt strategies that encouraged more of their pupils to engage meaningfully with mathematics. This led them to try to engage all the children with mathematics whatever their attainment levels and to adopt strategies that encouraged discussion and mathematical reasoning. In this way, they began to adopt more approaches to their mathematics teaching that reflected the common attributes identified in the literature as effective mathematics pedagogies.

A key indicator of effective sustainable professional development is the development of networks of teachers that focus on student learning and facilitate reflection on practice (Back et al., 2009). Evidence from the study indicates that engaging in the lesson study process supported the teachers to work in a collegial manner through developing the lesson plan, observing the lesson and engaging in in-depth discussion which followed the study lesson. This collaboration also supported them to reflect on their own teaching practice. In this way, as Jaworski (2006) argues, inquiry developed from being used as a tool to enable the teachers and educators to explore key questions and issues in practice to being a 'way of being' through which participants in a community developed their practice. As the communities of practitioners engaged in lesson study through the process of developing the study lesson and its following evaluation, the members of the community addressed: issues related to the mathematics involved in the lesson; ways of teaching mathematics; ways of developing their practices; and ways of developing their identities as mathematics teachers in order to address the issues they had identified. Therefore, as the teachers engaged with the practice of lesson study in order to develop the meaning of the processes of teaching and learning mathematics, they also developed their own identities as teachers of mathematics and members of a community of inquiry engaged with lesson study.

Engaging with the process of lesson study is time intensive and requires significant contribution from the teachers involved in the groups. However, the findings of this study indicate the potential benefits of engaging in lesson study through the facilitation of awareness of effective mathematics pedagogy and the development of professional knowledge and reflection on teaching practice. Analysis of further cases of teachers engaged in the lesson study process would support further investigation into its potential as a vehicle for professional development.

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