Facilitating inquiry based learning in mathematics teacher education

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A driving question in teacher education centers on how to help prospective teachers become expert teachers. The absence of a shared professional curriculum to prepare teachers to teach mathematics combined with the difficulty translating traditional research knowledge into forms that teachers can use in their practice have motivated this study. This paper reports on the combined efforts of teacher educators, teachers, and preservice teachers to engage in inquiry-based teaching of primary mathematics. What is innovative is the use of the classroom lesson as the unit of analysis combined with engagement in cycles of inquiry to produce exemplar mathematics lessons. Lesson Study was the primary method used to support a focus on examining teaching through the design and implementation of 'study lessons'. Insights into preservice teachers' reflections on inquiry-based teaching are presented in addition to a discussion of the benefits of efforts such as this which translate traditional research knowledge into forms preservice and practising teachers can use to improve their practice.

Inquiry-Based Learning

Inquiry based learning is often used as an approach to restructure aspects of teacher education and maximise the potential of learners. An inquiry-based approach to learning involves restructuring the manner in which the content is taught. Advocates of inquiry-based learning argue that this restructuring will provide students with more authentic experiences into the practices of mathematics and science and will increase motivation and interest in science and mathematics. The move to inquiry based approaches requires a move from didactic teaching practices toward practices that engage students in observation, experimentation, planning and culminating in the construction of knowledge and understandings of the discipline. In this study, inquiry based learning is manifested in the activities that preservice teachers engage in while planning for and teaching mathematics lessons. What emerges is a model of preservice teachers working with content (mathematics and mathematics pedagogy) in ways that encourage them to seek resolutions to questions and issues that arise when teaching.

Lesson study as a tool to promote Inquiry Based Learning

Lesson study is the vehicle used to promote an inquiry-based approach to the teaching and learning of mathematics. Lesson Study is a Japanese form of professional development involving the design and observation of live lessons, called research lessons, by a group of classroom teachers. Lesson study is becoming an increasingly popular process for improving classroom practice (Lewis & Tsuchida, 1998; Stigler & Hiebert, 1999) and its use with Irish preservice primary teachers to support the development t of mathematical understanding has been documented in a number of studies (Leavy, 2009; 2010). The central activity in lesson study is for teachers to work collaboratively on the design and implementation of a *study lesson* with the shared purpose of improving teaching. The lesson is designed by the teachers, one of whom

agrees to teach the lesson while the others observe and collect data on learning and teaching as it unfolds during the lesson. The research lesson and data detailing observations are shared at a post-lesson colloquium. A significant feature of lesson study is the cycle of inquiry within which the primary activity is located. While lesson study can be described in a number of ways, broadly speaking the cycle of inquiry consists of three phases with a number of activities occurring within each phase. Phase 1 is *Research and Preparation of the Study Lesson,* Phase 2 is the *Implementation Phase,* and Phase 3 is *Reflection and Improvement.*

Participants

The 20 participants were final year preservice primary teachers. Six were male and two were International Erasmus students. All participants had elected to enrol in a curriculum specialization in mathematics education; however the degree of confidence in teaching mathematics varied across participants. While many were confident in teaching primary level mathematics, a similar proportion lacked confidence in teaching mathematics and wished to improve their understandings of mathematics education.

Method and data collection

Algebra was the mathematics content area developed over the course of the lesson study. Four areas were identified: growing/repeating patterns, functions, equality, and variables. Participants were divided into four groups; each group focused on one topic.

During phase 1, *the research and preparation of a study lesson,* groups were observed as they worked collaboratively to design their lesson. Groups were provided with a number of reading materials relating to the algebraic topic of study. Groups met regularly to design their lesson, and met with the researcher, who acted as a mentor to the group, on at least three occasions. Artefacts arising from the collaborative planning were collected, for example the questions arising from these meetings and resources used to plan lessons. The detailed lesson plan arising from this phase was presented to the researchers and feedback on the lesson plan was provided prior to moving into phase 2.

During phase 2, *the implementation phase,* the researchers observed the teaching of the research lesson in a local primary school. One member of each group taught the lesson and other members were responsible for observing how particular aspects of the lesson played out. Attention was focused on children's understanding of the algebraic concepts; responses to questions, activities and tasks presented; assessment issues and (any) difficulties that emerged during the lesson. In phase 3, *reflection and improvement*, researchers met with the group immediately after the lesson was taught and provided feedback to the group on the outcomes of the lesson. The group then revised the lesson in accordance with observations. Finally, the newly revised lesson was examined by the researchers prior to the lesson being taught the second time.

The revised lesson was taught in a second primary school. This second enactment of the lesson constituted the *second implementation* stage of the study. On this occasion the lesson was videotaped by a professional video crew team and observed again by the researchers. Each group then provided a written report on the process of lesson study and made an in-class presentation to the entire class. During the in-class presentation group

members shared reflections about new versions of the lesson and the development of their algebraic and pedagogical understandings of lesson study.

Case 1 - Equality

This group focused on *equality* as a foundation for algebra. An overarching purpose was to support children in moving from thinking of the equals sign as a request to 'do something' to thinking of the equals sign as expressing the relationship 'is the same as'. Based on readings of literature pertaining to children's misconceptions of equals sign, the group identified a number of approaches used to support children in thinking about equality more broadly by developing balance and equivalence notions of the equals sign.

The lesson started by examining 4th class children's current conceptions of the symbol '='. A number of problem situations (e.g. money) were used to emphasize that expressions on each side of the equals sign may look very different yet have the same value. A piece of children's literature was introduced (*Equal Shmequal* by Virginis Kroll) to help extend the concept of equals meaning the 'same value as'. In the story a seesaw is used to model the concept of 'balance'. Parallel to reading the story, children were encouraged to simulate a balance scales/seesaw and demonstrate equality in the story scenarios by adjusting the balance of their hands. Children were then encouraged to make the connection between the equals sign and their seesaws through the introduction of a pan-balance scales. Working with the pan-balance (see image 1) offered children a concrete experience of equality and an opportunity to engage physically with number sentences. Number sentences and simple linear equations were initially investigated using concrete objects on the pan-balance. Additional activities that reinforced the concepts of balance and equivalence were missing-addend problems and open-number sentences. Children worked in small groups to examine number sentences and reported back to the whole class on the outcomes of their work (see image 2).

Image 1: Using pan balances for equality

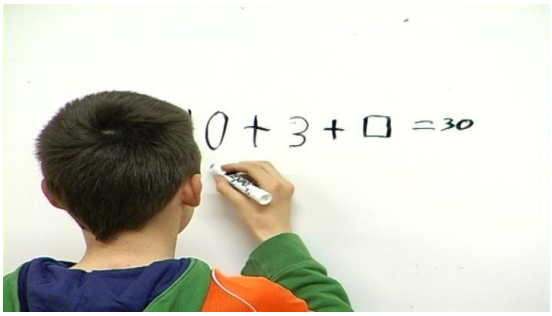

Image 2: Completing number sentences

Through teaching, observing and reflecting upon the first enactment of the lesson a number of changes were made to improve upon the initial lesson design. The primary issues pertained to the lack of challenge in the initial lesson – although the contexts were fruitful in developing notions of equality the quantities presented under challenged the children in terms of numerical reasoning. Also the operations used (primarily addition and subtraction) did not extend children's reasoning. Other pedagogical considerations

were examined and revised in relation to the nature and use of specific mathematical equipment and materials fundamental to developing notions of equality.

Case 2- Functions

The second group were given the task of introducing the concept of 'function' (rule) to 4th class pupils. On reading the relevant literature and becoming aware of the various methodologies which could be used to introduce the concept e.g. growing patterns, literature, the student teachers in this group decided to use a 'physical' function machine. The context they chose was that of a 'broken' oven (see image 3), where each button resulted in the 'input' being transformed according to a specific rule/functions e.g. doubled, increased by 15 etc. Functions (rules) were introduced developmentally from 1 step rules (e.g. x9) to 2-step rules (e.g. x2+1) by means of guided discovery. While in the initial example images of food were used, subsequently interlocking cubes were used to represent both input and output. Pupils were involved in the process of placing the input into the oven and analysing the number of items in the output. Both the teacher and pupils recorded the relevant data (see image 4). In each case, pupils were encouraged to predict the rule and to check their prediction by checking additional inputs provided.

Pupils were provided with the challenge of predicting the 'input' if aware of both the 'output' and 'rule'. Subsequently pupils themselves had the opportunity to work in groups, with each member having an opportunity to act as 'rule generator'. A number of groups shared one of their rules with the class.

Image 3: The Function Machine

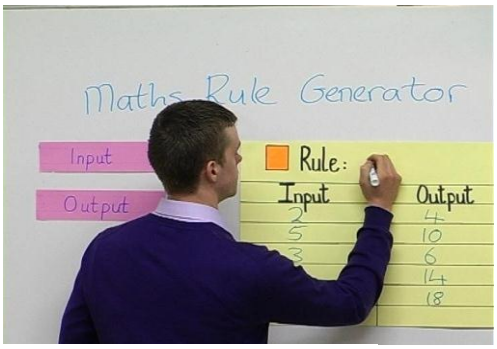

Image 4: Identifying the 'rule'

On initially implementing the lesson in the first school context, various issues arose. Firstly it became apparent to the student teachers of the need for the 'function machine' work to be streamlined i.e. to have materials (both inputs and outputs) pre-prepared. It was also decided that base ten blocks (Dienes blocks) would prove less cumbersome and more efficient in terms of counting. It was also believed that there was more potential for pupil challenge within the lesson through the provision of more time to address 2-step functions. In terms of organisation of group feedback, it was also decided that the student teachers should work with the groups during the selection and presentation of the groups' rule. In the second teaching of the lesson, pupils independently came up with both 1 and 2 step functions when acting as 'rule generators' and were eager to challenge the class to predict the rule.

Case 3 – Variables

The third group prepared a lesson on teaching variables to 4th class. Variables are symbols, e.g. letters, that take the place of numbers or ranges of numbers. According to the Primary School Mathematics Curriculum (PSMC) (1999) children should be enabled to '*explore the concept of a variable in the context of simple patterns, tables and simple formulae and substitute values for variables*' (Government of Ireland, 1999, p.96). Taking this into consideration the group decided to introduce the concept of a variable through the use of a variable wheel (see image 5). The variable wheel allowed children to explore the idea of a variable as a letter that can stand for any member of a set of numbers and also allowed children to substitute numbers for variables. The key focus in this aspect of the lesson was that children came to realise that a letter could stand for any number depending on the problem. In the initial lesson, on completing the above task, pupils demonstrated a misconception that a letter always held the same value e.g. a=1, e =5.

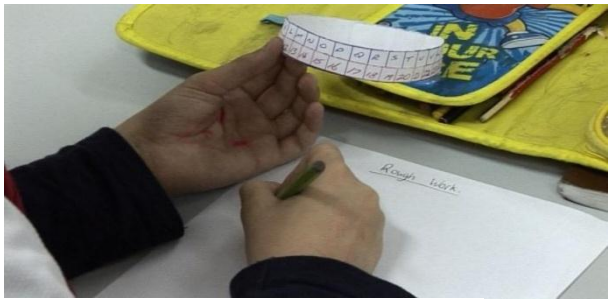

Image 5: The variable wheel used in the variable lesson

Following this the group used story problems that required a variable to solve them. In each problem there was an unknown value to be found. Children were allowed to pick any letter to represent the unknown. A simple table of what was known was drawn up. A number sentence was then written and solved. After overlooking the pupil misconception outlined above, in the second teaching of the lesson the student teachers reinforced the fact that a letter may hold different values depending on the context. This was achieved through the presentation of two problems in which the same letter was used to represent the unknown (Problem 1: F (France) = 36; Problem 2: F (France) = 45). Following this children were provided with an opportunity to create their own word problems that required a variable to solve them (see image 6).

Summary and conclusions

As part of the assessment of the module, student teachers were requested to reflect on their learning over the course of the Lesson study process. This was presented by means of group presentation and individual reflections. On analysis the students' learning fell into a number of broad categories. A sample of the reported learning will be presented subsequently, providing the reader with a 'taste' of the nature of this learning.

Algebraic concepts

In some cases, student teachers reported that prior to the project they possessed limited knowledge of the relevant concepts e.g. *'My understanding of the concept was lacking'* (Equality group: Eva). Many testified that through the process of partaking in the Lesson study project they had learned 'algebra' themselves i.e. they had developed their own subject matter knowledge:

'...I had a limited understanding of what the equals sign means…I understood the equals sign …as 'is' (as in 3+5 'is' 8) not as 'is the same as' or the 'same value as', so I learnt something very important myself' (Equality group: Mia)

'As a result of trial and error that I undertook in the lesson plan my own understanding of algebra and how to write equations improved' (Variables group: Rosemary)

Beliefs and perceptions about algebra and its teaching

There was evidence of improved attitudes towards the topic of algebra e.g. *' I have grown to like algebra over the last few weeks and I feel this will be reflected in my future lessons…I no longer see it as a boring topic. It was just as interesting and perhaps fun as other strand units like data'* (Equality group: Valerie). Reference was also made to changing beliefs regarding the nature of algebra:

'Algebra is not as abstract as we originally thought, once it is presented in context' (Variable group presentation)

Teaching mathematics

While some comments were quite general e.g. *'I feel the lesson studies greatest benefit was improving my understanding of teaching maths as a whole'* (Functions group: James), others referred to their increased awareness of the benefits of specific strategies:

'It offered me insight into how effective group work is. I saw…that pupils teach each other and learn from others…' (Equality group: Valerie)

'From the lesson study I have realised that if it is a new concept or topic for the class…the most important thing to do is to break the concept down into its most basic form and start from there' (Variables group: Peter)

'In all areas of maths teaching it is so important to explain the language of maths' (Variables group: Rosemary)

Teaching Algebra

Some of the student teachers reported having gained knowledge specific to the teaching of the strand of algebra:

'The lesson study has taught me that live number lines/equations can be used right up through the school in different classes and also in different strands of the curriculum' (Equality group: Valerie).

'In teaching algebra as in other areas of maths the best way to explain an abstract task to the pupils is to model exactly how it is done with the children contributing' (Variables group: Rosemary)

Increased awareness of pupil responses/misconceptions

A number of student teachers acknowledged that the lesson study highlighted the benefits of predicting and responding appropriately to pupil ideas:

'The most vital section of the lesson study was that of the expected students' reactions. This ultimately was a method of assessing the children's understanding of the lesson and required deep reflection on the way children think and learn' (Functions group: James)

'The lesson study has taught me to be open to what the children have to say. The teacher can learn how to teach from the pupil as well as the pupil learning from the teacher' (Equality group: Valerie).

The role of algebra in the curriculum

Many student teachers reported having gained increased insight into the potential for algebraic reasoning as well as opportunities for linkage within the strand of algebra and with other mathematics strands and curriculum subjects:

'I now realise that children who understand equality are well on their way to understanding relationships expressed by number sentences/equations' (Equality group: Mia)

'The lesson study has allowed me to see that variables can be used…across all strands of the curriculum once it is introduced' (Variables group: Rosemary)

Overall perspectives of Lesson study

Students found that working together on Lesson study had huge benefits in terms of working collaboratively and drawing on a variety of perspectives and ideas The group work aspect of Lesson study had challenges for the students as *'it was very time consuming'* (Variable group: Ella) and as a result it was difficult *'to meet the needs of the group'* (Functions group: Peter). However, the overall sentiment from students about Lesson study was that it was a worthwhile experience e.g. *'I had a wonderful experience and cannot stress how beneficial the lesson study was'* (Equality group: Marie)

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