Staff Development: The Missing Ingredient in teaching Geometry to Year 3 Students

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The teaching and learning of Geometry has been identified in much of the literature as being problematic and the mathematics strand where many teachers feel least knowledgeable and least confident to teach. This paper describes a school-based project which sought to develop teacher knowledge and confidence in this strand via the use of Professional Learning Communities (DuFour & Reeves, 2016) and Instructional Coaching.

Introduction

Sustainable staff development in primary mathematics has been a long-term issue of concern. Here we outline and discuss a case study of site-based development in geometry that employed a *Professional Learning Community* (PLC) (DuFour & Reeves, 2016). In this paper we use the term geometry to mean the study of space and shape including spatial objects such as lines, shapes, and grids; relationships such as "equal in measure" and "parallel"; and transformations such as flips and turns (Clements, 1998). We follow Usiskin (1987) in suggesting that there are three aspects of geometry important for the early and primary years “(1) visualization, drawing, and construction of figures; (2) study of the spatial aspects of the physical world; and (3) use as a vehicle for representing nonvisual mathematical concepts and relationships. Cross-cultural research substantiates that core geometrical knowledge, like implicit basic number or quantitative knowledge, appears to be a universal capability of the human mind. Without doubt, geometry is important to young students for many reasons: the immediate understanding and interpretation of their physical environment; as a tool for understanding other mathematical concepts such as number lines or arrays; and concepts beyond mathematics including science, geography, art, design and technology (Jones & Mooney, 2003) and can thus be seen as a gateway skill to the learning of higher level thinking skills (Clements & Sarama, 2011).

This paper presents the initial findings from a school-based research and development project that foregrounded geometry in teacher professional development and student learning for a Year 3 cohort. The intent of the project was to develop a simple, successful, and sustainable model for teacher professional development and through this, to improve student learning outcomes in geometry. To support this intention, a partnership was formed between the school (through the third named author) and some university partners (the first and second named authors). The university partners supported the project by sourcing diagnostic assessments, research articles and teaching articles; developing and presenting professional development seminars; and monitoring and critiquing the measurement of outcomes. Also, a PLC model (DuFour & Reeves, 2016) was identified as the most appropriate vehicle to achieve the outcomes of the project. This decision was grounded in the research of Schmoker (2004) who stated:

> If there is anything that the research community agrees on, it is this: the right kind of continuous, structured teacher collaboration improves the quality of teaching and

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pays big, often immediate, dividends in student learning and professional morale in virtually any setting. Our experience with schools across the nations bears this out unequivocally" (p. 48).

The PLC involved participating teachers and school leaders who met on a weekly basis to address key tasks including: Collaborative Learning Cycle (CLC) for analysis of data; professional conversations around key research and teaching articles; developing formative assessment; and collaborative planning of multi-disciplinary units of work.

Literature Review

Geometry is a mandated component of the Australian Curriculum Mathematics and is to be taught to children throughout their compulsory school years. The Australian Curriculum and Reporting Authority (ACARA) (2016) indicates that connections are to be made between Geometry and other areas of mathematics and encourages that it is taught appropriately so that students come to appreciate mathematics as accessible and enjoyable. In terms of geometry content, ACARA indicates that students develop an increasingly sophisticated understanding of size, shape, position and movement of 2D and 3D objects, construct figures, and develop geometric reasoning.

The 3D world that that children must learn to know, explore, and conquer in developing spatial sense, demands far more of geometry than simply naming shapes and thus geometry education should develop students' spatial sense. According to Clements (1998), "Spatial sense is all the abilities we use in "making our way" in the spatial sphere" (p.18) and is related to mathematical competencies including "the manipulation of information presented in a visual, diagrammatic or symbolic form in contrast to verbal, language-based modality" (Diezmann & Watters, 2000, p. 301). Given our 3D world, much of our initial and ongoing experiences of geometry occur via visual stimulus. Clements (1998) argues that spatial visualisation is based on "understanding and performing imagined movements of two- and three-dimensional objects" (p.17), and that this requires a continually developing ability to create and manipulate mental images which assists students to explore mathematical problems without always using symbolic representation (Jones & Mooney, 2003). The second component of spatial sense is spatial orientation which, in essence, is "knowing where you are and how to get around in the world; that is, understanding and operating on relationships between different positions in space, especially with respect to your own position" (Clements, 1998, p.11). Research conducted by the Early Numeracy Research Project (ENRP) indicates that "attention to geometry in the curriculum can make a difference in children's learning and they are capable of developing in geometry beyond the expectations of the last few decades" (Horne, 2003, p. 13).

Geometric and spatial thinking are not only important in their own right but are also important in providing a foundation for learning in other areas of mathematics (Horne, 2003) and across many school subjects (Clements, 1998). Success in geometry is a strong predictor of later academic success and students studying mathematics are more likely to enter and succeed in STEM disciplines (Sinclair & Bruce, 2015). Indeed, such is the depth of research supporting the relationship between geometry and mathematical "is so well established that it no longer makes sense to ask whether they are connected" (Moss, Hawes, Naqvi & Caswell, 2015, p. 379). For example, a young child with well-developed spatial structuring abilities would be able to successfully construct and continue a triangular pattern of dots to represent triangular numbers (Mulligan, 2015) or use grids to illustrate multiplication or create drawings to model fractional amounts. This point is emphasised by Moss et al (2015) who indicate that "geometry is a special kind of language through which we communicate ideas that are essentially spatial" (p.379). The ability to use spatial representations is also highly related to the ability to solve mathematical problems, especially non-routine ones (Clements & Sarama, 2011).

Despite the correlations between mathematics performance and spatial reasoning, research suggest that geometry is often poorly taught due to a confluence of lack of teacher preparation, lack of content knowledge, and lack of interest in the area of geometry (Moss et al., 2015) with the resultant outcome being the production of "geometry deprived" students (Sinclair & Bruce, 2015, p. 321). These findings are despite curriculum authorities, such as the National Research Council in the US and ACARA in Australia, emphasising the importance of geometry in their respective national curriculums (Moss et al, 2015). Clements and Sarama (2011) note that, although curriculum documents indicate its importance, geometry is "often ignored or minimized in early education" (p. 133) and that geometry often receives the least attention of the mathematical strands (Horne, 2003; Sinclair & Bruce, 2015). In addition, where geometry is taught, it often focuses on naming geometric shapes and the use of formal symbolism for geometric concepts (Jones & Mooney, 2003) with limited emphasis on learning processes such as 'spatial sense', 'spatial reasoning', and 'geometric thinking' (Mulligan, 2015). In the UK, research by Jones and Mooney (2003) indicated that teachers spent four to eight times as much time on number than on geometry and that "average maths time on geometry was 12% but fell to 7% in Year Two as students prepared for national tests" (p. 9). This is likely mirrored in Australia as students are prepared for annual NAPLAN tests.

It is perhaps unsurprising then, that student outcomes in geometry are poor, with data from the Trends in International Mathematics and Science Study (TIMSS) research indicating poor international performance on geometry in primary or elementary schools (Clements & Sarama, 2011). For some students, this lack of emphasis in geometry, and the subsequent poor performance, can lead to dis-enchantment with geometry in particular and with mathematics more broadly (Ambrose & Falkner, 2002). This poor student performance has largely been laid at the feet of primary and early years classroom teachers in terms of both their competence and confidence to teach geometry (Moss et al., 2015). As Dindyal (2015) indicates; "at this time when children's mathematical potential is great, it is imperative that early childhood teachers have the competence and confidence to engage meaningfully with both the children and their mathematics" (p. 524). Clements and Sarama (2011) indicate that "of all mathematics topics, geometry was the one prospective teachers claimed to have learned the least and believed they were least prepared to teach" (p. 135) and further suggest that "most early childhood teachers also have not attained adequate levels of geometric knowledge" (p. 136). Although the need clearly exists, geometry remains often ignored, or at least minimised, in professional development opportunities for many teachers (Moss et al., 2015).

What is abundantly clear from the research are three key observations. First, geometry is under-represented in the mathematics curricula of many schools; second, it is poorly understood and therefore, poorly taught by many primary classroom teachers; and third, the emphasis on primary geometry should be the study of objects, motions and relationships within the spatial environment in which students live with the goal of developing initial intuitions regarding their world (Jones & Mooney, 2003). These three observations were a key consideration for the research and development project discussed in this paper.

The Project

The project, *Developing Deep Thinking and Problem Solving with Geometric and Spatial Reasoning*, was implemented following the successful application of a 'Science Technology Engineering and Mathematics (STEM) in Action' grant, funded by Education Queensland. The key expectation of grant recipients was to design and implement an action research project in one area of STEM that focussed primarily upon increasing teacher capacity. It was also expected that the project would document the pedagogies developed, and the processes used, to illustrate a sustainable process that would have longevity beyond the project. The project had the overarching goal of improving student outcomes in the area of geometry. This goal was chosen for two reasons, First, school data – e.g., NAPLAN and school assessment tasks, indicated that students were not performing as well in this area of mathematics as might be expected based on their performance in other aspects of mathematics. Second, in working with the teachers, it became clear that geometry was an area of mathematics they were least confident with. Therefore, this project was both an exercise in developing a sustainable model for professional development which could be sustained beyond the project and also an exercise with the explicit outcome of improved student learning and teacher pedagogy in geometry in this iteration.

The school involved was a suburban, P-6, co-educational Independent Public School and was established in 2004 in the South East Region of Queensland. The school Index of Community Socio-educational Advantage (ICSEA) is 1043 with an enrolment of 935 students (March 2016). The target group for the project was the Year 3 cohort and their teachers. This involved 126 students and nine classroom teachers, and the facilitators of the project included two middle leaders and one Deputy Principal. The range of teaching experience amongst the team varied, with one third of the group in their first four years of teaching. The nominated teacher leader for the project was one of the middle leaders whose role within the school was to support transformation in pedagogy to achieve improved student learning in the areas of literacy and numeracy. This teacher specialised in Collegial and Instructional Coaching and is in her second year of a 3 year contract.

As was noted previously, the project was sustained through the establishment of a PLC that met for 50 minutes each week before school. PLC's are grounded in the ideals of educational action research including working together in collaborative teams, data informed development, and on-going cyclic reflection on practice (DuFour & Reeves, 2016). This model was introduced to participating teachers with the clear intent to 'honour' the collaborative process and to create powerful opportunities for authentic 'co-labouring' on key tasks associated with the project. The tasks undertaken at the PLC meetings included:

- discussion of research-based articles;
- reflection upon teacher self-efficacy in mathematics, particularly in relation to teaching geometry;
- Collaborative Learning Cycle (CLC) using historical and baseline data; and,
- collaborative planning of formative assessment tasks and multi-disciplinary units of work.

To create a set of baseline data to inform the direction for supporting teachers with the project, two student assessment tasks and one teacher self-efficacy measure were developed and administered:

1. Multiple choice test – selected questions were chosen from the Graphical Languages in Mathematics (GLIM) instrument (Lowrie & Diezmann, 2011) that targeted three clusters of spatial reasoning tasks: namely, where the task involved the "subject" changing orientation; visualisation of the outcomes of a transformation; and transformations where the image and pre-image were available.
2. Individual Diagnostic interviews – specific questions were chosen from the GLIM test along with items from *First Steps in Mathematics: Space (2013).* Students completed this diagnostic individually with one of the teachers involved in the project.
3. A short questionnaire that teachers completed prior to the project where they reflected on their own experiences of mathematics and mathematics learning and on their content and pedagogical knowledge in relation to the teaching of Geometry.

Initial Findings regarding the geometric understanding of the students

Baseline data from the modified GLIM and the Diagnostic interviews provided rich information about the students' knowledge and capabilities related to geometry and spatial reasoning. Briefly, the data showed that students struggled with problem solving tasks involving subject orientation and visualisation. Specifically, there were common weaknesses with: ¼ and ½ turns to the left and right; drawing an object by visualising it from different positions; and, solving problems by visually manipulating information. However, the data revealed strengths in demonstrating 'flips' and 'turns', and drawing an object from different positions. As the focus on this article is on the professional development process we used, we will report on the learning attainment of students, as a result of the project, in other publications.

This data was used by the PLC to determine the direction for the professional development of teachers and to underpin shared professional learning sessions. Specific content included; developing greater knowledge of the developmental phases of geometric reasoning, increasing capacity for identifying perspectives of spatial and geometric problems and integrating geometric reasoning across the curriculum. Maintaining the project's theme of simplicity, success and sustainability was incorporated within these priorities.

Initial dispositions of the teachers in the project

The outcomes of the self-efficacy questionnaire revealed that the attitudes, content knowledge, and pedagogical knowledge of this cohort of teachers were broadly in line with the findings in much of research reported upon earlier. For the teachers involved in the project, the results revealed:

- 62.5% did not have a positive experience learning mathematics at school;
- 62.5% did not consider themselves to be good at mathematics at school; and
- 75% believed they needed to develop their understanding of spatial concepts and geometric reasoning skills to teach more effectively.

These findings, although perhaps not surprising, have obvious implications for the teaching of geometry and go someway in explaining the lower outcomes in NAPLAN and school based assessment for this strand of mathematics. They also confirmed the decision of the school leadership team and school middle leaders to focus on this aspect of mathematics as the core component of our STEM project. Further data was collected anecdotally from discussions in staff meetings; leadership team meetings, and especially from the weekly PLC. When combined with the self-efficacy measure, this data revealed the need for:

- building personal content knowledge in geometry;
- establishing a common, consistent language for geometric reasoning;
- developing pedagogical content knowledge in geometry; and,
- establishing a "safe" space for teachers to share their professional practice.

As a key component of meeting these needs it was decided that these could be best achieved through collaboratively planning lessons and units that provide opportunities for students to engage with problem solving involving geometry throughout the curriculum. As was noted earlier, this was undertaken through the PLC. These planning sessions were augmented by a full day professional development workshop that was led by the university partners. This workshop focussed on teacher attitudes towards mathematics; connecting geometry to other areas of the mathematics curriculum; working through the ten questions on the GLIM with a particular focus on common student misconceptions; classifying these errors according to subject orientation; visualisation or pre image/image type errors; and creating a rubric for assessing student performance in future geometry tasks. One of the pre-requisites of the STEM project was sustainability. The initial professional development workshop was integral in establishing the common language for geometry and in providing an impetus for the remainder of the process; however, a series of workshops by university academics was unsustainable from a financial point of view and thus, follow up workshops were supported by the university staff but led by the Pedagogy Coach guaranteeing that the model can be sustained beyond the life of the official project.

Instructional Coaching

Alongside the PLC and the professional development workshop, it was seen as vital to provide opportunities for teachers to observe the teaching practices of their colleagues and to critically reflect upon the mathematics involved. This was achieved through a coaching cycle that combined elements of both the Lesson Study Model and Instructional Coaching cycle. These 2 approaches were combined to create a cycle of instructional coaching (Knight 2007), which also included critical reflection on a lesson taught by a group of teachers. This differs from the traditional instructional coaching cycle, which is a partnership between coach and teacher. Our instructional coaching cycle was critical in providing a safe space for teachers to discuss their own pedagogy, including their limitations, and later teach lessons where their peers would observe them. For sustainability reasons it was also important that these instructional coaching episodes were led by school staff and not by university academics.

To initiate the instructional coaching (Peita), the school pedagogy coach, taught a demonstration lesson to one of the Year 3 classes on Location. One of the university partners (Kevin) facilitated the teacher observation, feedback and reflection. This lesson focussed on the understanding of subject orientation when describing location. The classroom teachers of these students, as well as support staff, watched the Instructional Coaching lesson and were provided with a reflection sheet with prompts such as lesson successes, key observations, questions for follow-up discussion, and reflection on student learning observed. At the conclusion of the lesson the teachers, Peita and Kevin spent about 45 minutes discussing the lesson using the prompts above as discussion topics.

This was the most useful component of the process. Although initially a little reticent to comment, the teachers became comfortable critiquing the work of a colleague when prompted and supported by an 'external expert'. Initially the feedback and reflection was generic and focussed on the procedural aspects of the lesson, such as classroom organisation and behaviour management. However, with some guidance from the university partner, the group discussion progressed to a deep professional conversation regarding the mathematical learning evident in the lesson. This process was repeated with the other two Year 3 classes. Throughout the three iterations, the teacher involved (Peita) in teaching the lesson was able to apply the constructive feedback from previous lessons to further refine the mathematics content for each new lesson taught. After the process, Peita indicated that; "The last lesson looked nothing like the first lesson after repeating it multiple times. Each repeated lesson resulted in refinement of the focus of the maths content". The next component of the project will involve the teachers delivering a lesson, with their peers present, and with their teaching being the focus of the follow up discussion. This is again important for the long-term sustainability of the project.

Conclusions and Ways Forward

The primary concerns at the inception of this project were the teaching and learning of geometry in the school and an understanding that, if the project was to have longer-term impacts on student learning, it needed to be sustainable. With this in mind, the development and delivery of the professional development sessions has gradually shifted from the university partners to the school middle leaders in general, and primarily Peita as the Pedagogy Coach. This was an intentional component of the overall project design and was facilitated through the mentoring of the university partners and the Gradual Release of Responsibility (Pearson & Gallagher, 1983) to move the middle leaders from the role of participants, to co-presenters and finally to sole presenters in 2016 and beyond. Thus, the 2016 Year 4 teachers and mathematics curriculum leaders received similar professional development as provided to the initial 2015 cohort, but delivered by school middle leaders rather than university partners. Consequently, the school now has the leadership capacity to train all staff in this strand of mathematics education. The initial project funding has resulted in, amongst other things, a sustainable change in the leading capacity of the school, thus ensuring that ongoing personal and professional development, initially in geometry (but later in other areas) will continue after the conclusion of the formally funded STEM project.

Furthermore, the development of the diagnostic student assessments provides ongoing capacity for creating trend data in the area of geometric reasoning to measure changes in student achievement. Tracking of skill development from the 2015 Year 3 cohort into Year 4, 2016 has been scheduled. This will involve students completing a post-test on the same skills that were assessed for the baseline data in 2015, and this will allow teachers to identify which concepts have improved, which ones require further development, and whether initial gains have been sustained over time. This data will also form one of the data sets to determine the success of the project.

The multidisciplinary units of work that were a component of the project, Visual Arts/Mathematics and Design and Technology/Mathematics, have now been included within the whole school curriculum overview and will be delivered again in 2016. The Head of Curriculum will also co-ordinate the planning of a HPE/Mathematics unit for Year 4 to address key weaknesses with spatial reasoning, in particular those concerning subject orientation. Thus, the curriculum development that emerged through the PLC has had a sustainable impact of the teaching and learning of mathematics.

Looking forward, the school middle leaders have requested further staff and leadership professional development around the establishment of PLCs across the school. To this end, they recently attended a two-day *PLC At Work* conference. PLC meetings will be included in the staff meeting cycle to create time for teachers to participate, without the need to provide release time or expect teachers to attend additional meetings other than those within the meeting roster. Based on our learning in this STEM project, we are confident that these will be beneficial for student outcomes.

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