

## The explicitness of teaching in guided inquiry

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Guided inquiry pedagogy is gaining recognition for promoting deep learning as students connect concepts, understandings and meanings to defend and justify their mathematical ideas. Research describes how it promotes the development of deep understandings, yet the approach can seem at odds with explicit teaching pedagogies that show potential for a rapid rise in mathematical achievement in solving simple, routine tasks. Additional pressure from timed, standardised tests can contribute to confusion about choice when teachers consider implementing pedagogies with which they are less familiar. This paper illustrates what explicit teaching looks like in inquiry as year five students explore angles in polygons.

Planned inquiry teaching and learning experiences in mathematics, as teacher resources, are becoming more available as classroom teachers seek to know more about the approach to try with their own students. Presentations amongst mathematics education researchers at MERGA, sharing research on inquiry pedagogy, raise further interest in the pedagogy and institutions such as The Australian Academy of Science have invested time and money through the ReSolve project, to draft, trial and publish a large number of mathematical inquiries for classrooms around Australia. As classroom teachers conduct trial inquiries in their classroom for the first time, surprise about the levels of difficulty or challenge for students and an unsure feeling about how to facilitate such high levels of intellectual quality are expected reactions by teachers. There has been an emphasis placed on explicit classroom pedagogy to raise the academic standards of students quickly and many teachers have become comfortable using this approach. Explicit teaching, in a sense, does take place in guided inquiry yet practically, it is not quite clear what this entails. An experienced inquiry teacher will recognise teachable moments as a moment of struggle and engineer a way forward to support learners to recognise the significance of knowing and understanding such a new concept. This paper will illustrate teacher engineering in inquiry pedagogy and how it is explicit, as students learn and make conjectures about measurement and geometry concepts.

The students in the Year 5 classroom highlighted in this paper needed to know how to use a protractor to measure angles (ACARA, 2017). Their classroom teacher engineered an inquiry that would provide opportunities to repeatedly create angles and measure those using protractors. Illustrated below are some of the teachable moments in this inquiry that reflect a sense of explicit teaching, including the teacher recognising teachable moments, their students' perturbations, an illustration of how the teacher moved forward, and the students' reactions/learning. This paper adds to an extensive body of work exploring inquiry pedagogy in primary classrooms, building on iterative phases of Design Research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The teacher-researchers and authors of this paper were interested in capturing the 'explicitness' of teaching in inquiry pedagogy to illustrate to other teachers new to this approach, what explicit teaching entails in the inquiry *How can I accurately predict the sum of the internal angles of any polygon?*

2018. In Hunter, J., Perger, P., & Darragh, L. (Eds.). *Making waves, opening spaces (Proceedings of the 41<sup>st</sup> annual conference of the Mathematics Education Research Group of Australasia)* pp. 306-313. Auckland: MERGA.

## Literature

Although this paper explores the teaching of mathematics through inquiry pedagogy, the authors are focused on recognising how teachers navigate with students through their moments of unsurety, towards sense making about mathematics. Guided inquiry presents an investigation approach to teaching and learning mathematics through four phases: Discover, Devise, Develop and Defend. (Makar, 2012). The authors of this paper argue that guided inquiry pedagogy provides multiple opportunities for explicit teaching within and between these phases, often identified as a Checkpoint in the inquiry process. The Checkpoint helps teachers to recognise difficulties (and successes) students are having and to evaluate whether explicit teaching is required. Explicit teaching may be required in guided inquiry due to a number of reasons. The exploration may have become too large (e.g. students may have collected a large number of data and are unable to see relationships between the data), or a roadblock to a new topic presents and exploration is not necessary to move learners forward (e.g. students need to know how to use a protractor to measure angles. This coming to know process for students has previously been translated by one of the authors as a process whereby learners traverse a complicated series of emergent and concomitant potentialities, engineered by the teacher (Fry, 2016). In guided inquiry, the teacher encourages emerging complex connections students make as potentialities and includes these as problems to solve, concomitant to the inquiry question. Valuing potentialities and including them as pathways to explore in guided inquiry contributes to developing a learning community in the classroom and there is much research reporting on such a classroom culture (Fielding-Wells, Dole & Makar, 2014; Goos, 2004; Makar, Bakker & Ben-Zvi, 2015). The teacher's role to challenge and scaffold teaching and learning in inquiry mathematics classrooms has been explored in terms of providing mathematical evidence, scaffolding reasoned discourse and in creating socially productive classrooms (Anthony & Walshaw, 2009; Hunter, 2012; Hunter, Hunter, Jorgenson & Choy, 2016; O'Brien, Makar, Fielding-Wells & Hillman, 2015). This paper builds on this research to illustrate how one year five teacher makes teaching and learning about angles in polygons explicit, with her students.

Teachers have been surprised about the levels of difficulty or challenge for students when implementing inquiry pedagogy in their mathematics classroom. Student mathematical learning in inquiry has often exceeded teacher expectations and student confidence is enabled when they achieve success in overcoming such mathematical challenge (Hunter, et. al, 2016). In inquiry, the intellectual quality of lessons can improve significantly over time with specific gains in higher order thinking and the problematising of knowledge (Makar, 2016). Guided inquiry presents contextualised investigations that include ambiguity to open pathways for solving the problem and to open up ways to answer the question with students making decisions about how they navigate the problem-solving process (Makar, 2012). Since the early to mid-2000s, Australian teachers have heard the effectiveness of explicit instruction for particular students (Rowe, 2006; Hattie, 2008; Melony, 2015). On the other hand, Hunter (2012) provided evidence that when a teacher taught lessons procedurally, student disengagement increased. It was reported that explicit teaching also limits students' opportunities to exercise conceptual agency (Anthony, 2013). In a problem-solving sense, explicit teaching approaches such as direct instruction strive to minimise misinterpretations by presenting carefully planned problems to suit guided practice of the process being taught (Hattie, 2008). The challenge for teachers new to inquiry is to navigate ambiguity in the mathematics classroom which is less apparent in an explicit teaching approach, to facilitate

high levels of intellectual quality and success in mathematical learning without explicitly stating how to work things out.

## Method

Although non-interventional, the illustrations of teaching in inquiry analysed in this paper aim to contribute to a growing body of knowledge of inquiry pedagogy to teach mathematics. As the classroom teachers and authors of this paper become interested in teacher-led research themselves, and an interest generally in understanding how to engineer meaningful learning experiences through inquiry, the type of research begins to reflect a more participationist focus (Sfard, 2005). Part of a larger study to understand teaching and learning mathematics through inquiry, design research methodology allows the authors to build on previous iterations of study to understand the learning ecology, contributing to subsequent phases of testing and revision (Cobb, et al., 2003). The research presented here is qualitative in nature with analysis based on grounded theory methodology (Corbin & Strauss, 2008), through qualitative content analysis (Flick, 2009).

### *Context and participants*

The year five classroom depicted in this paper was situated in a large Metropolitan school in South East Queensland. The class was an even mix of boys and girls of different backgrounds including some with EAL/D and Special Education needs. This inquiry took place in the second semester when norms around the classroom culture of inquiry had been established. The classroom teacher had participated in a longitudinal study investigating inquiry teaching in the classroom and was conducting her own research into classroom practice. She had been teaching with guided inquiry for a number of years and was becoming more comfortable with the teaching approach. The inquiry question asked students *How can we accurately predict the sum of the internal angles of any polygon?* Students already had language associated with naming polygons including being able to identify different types of triangles.

### *Data collection*

Part of a larger study, the first three lessons of the inquiry were filmed as the class explored learning in the Discover, Devise and Develop phases. The focus on explicit teaching was not an intention of the inquiry and the teacher in the video was not aware of this research focus at the time. The videos were viewed and analysed by both researchers independently, to firstly gain a general sense of when explicit teaching of a concept took place, similar to the process of open coding (Flick, 2009). These instances were compared and categorised so that an agreed understanding could be made between the researchers about the elements constituting explicit teaching in the inquiry context. The authors used the process of axial coding to further analyse the relations between categories and to interrogate the data further for patterns related to explicit teaching in guided inquiry.

Initial viewings emphasised the identification of key mathematical concepts to do with measurement of angle that were explored in this sequence of lessons (Table 1).

Table 1

*Key mathematical concepts to do with measuring angles*

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Student pre-understandings, difficulties and errors

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A polygon where all the sides are the same length, is a regular polygon

When comparing two similar polygons where one has been enlarged, the larger shape would have larger internal angles

The sum of the internal angles of different scalene triangles will differ because scalene triangles have sides of different lengths

Inaccurate measuring: The importance of double checking measurements and the issues of not closing the corners of a polygon when tracing a shape

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These identifiable moments within the lessons required further analysis to help characterise the associated teachable moments. Closer analysis would focus on how the teacher engineered a way forward for the learner in terms of explicit teaching.

## Results

The students were devising their plans for finding out how to accurately predict the sum of the internal angles for any polygon. It had become obvious that some students were moving to the next phase of the inquiry and had started collecting data to answer the question. Some students traced around pattern blocks as an easy way to generate shapes to measure. Other students used a ruler to draw polygons with a particular number of sides.

### *Regular and irregular polygons*

The teacher stops the class at a Checkpoint within the Devise phase for students to share their progress with others. One keen student, Nicholas, offers to share his plan and based on his measurements of two hexagons, states that he doesn't think there is a way to predict the sum of the internal angles of a polygon. Two of his hexagons have the exact same angles and a third has a totally different sum of the internal angles.

Nicholas: "My first hexagon which is the... perfectly... even one, was..."

The teacher sees Nicholas is struggling to think of the term to describe the hexagon with sides the same length and interjects:

"Do you know the word for that, that hexagon where all the sides are exactly the same? It's a regular hexagon. If it's regular, then all its sides and all its angles are the same. So, if that's regular, what do we call (Nicholas') hexagon that has still got six sides..."

This is a quick intervention by the teacher and before she finishes Nicholas responds with the word 'irregular' and continues to use these words to explain his plan. In this instance the teacher explicitly provided the students with the language of regular polygons, to support him to complete his statement. This counts as a Checkpoint in guided inquiry as all students are focused on the speaker and hear the language lesson in the context of the inquiry.

### *An enlarged shape has larger angles than its original shape*

Later in the lesson but part of the same Checkpoint, Annabel shares her groups' plan with the class. A key idea they share is that they hope to predict the angles of four different

shapes, then measure them to generate evidence about the accuracy of their predictions. The teacher asks the class to comment and Ramon shares his suggestion of focusing on one shape such as a pentagon, and to draw another larger pentagon to measure and compare the angles. Another student, Rick, builds on this idea and makes a conjecture that the sum of the internal angles of the smaller shape would be less because it is a smaller shape. The idea that an enlarged shape will have greater angles than the original similar shape is incorrect:

Teacher: “And you don’t know until you have tested it. You don’t know if you will come up with that at all.”

At this point the teacher praises all the students for thinking about the problem systematically and sharing reasonable ideas. She highlights the importance of students listening to the ideas shared and not always agreeing with each other’s plans. She hopes that the students will explore this line of investigation to test the conjecture made.

### *Irregular polygons: Scalene triangles*

The following day and just before the class moves into the Develop phase of the inquiry, the teacher reviews the idea of measuring regular and irregular polygons that Nicholas proffered the previous day. This conversation takes place before students begin to put their devised plans into effect. Students then begin to collect evidence to answer the inquiry question and record measurements and calculations about the angles they are measuring in their scrapbooks. Building on the idea of measuring the internal angles of regular polygons to compare to the internal angles of irregular polygons, Nicholas turns his focus to triangles only. He discards the idea of testing scalene triangles as they are ‘always different’ yet is unable to explain how or if this property will change the sum of the internal angles of a scalene triangle and the teacher encourages him to test this. The students put their plans into action and soon after the teacher approaches Nicholas to check his progress. He quickly shares how the two scalene triangles he has measured both have a different result for the sum of the angles. The class had previously shared that they had heard of the sum of the internal angles in triangles always adding to 180 degrees and Nicholas has pursued the idea of using irregular polygons, such as scalene triangles, to test.

Teacher: “Can I just check with a protractor and test your theory?”

She asks him to identify one of the scalene triangles he has measured. As she measures the internal angles, Nicholas eagerly looks at what she is doing. The teacher talks about this process using a think-aloud strategy, to make explicit the process she is modelling. For instance, she adds a dot on the page at the end of the straight edge of the protractor and states out loud how this can help her measure the angle. The teacher points to the protractor and Nicholas moves closer to take over and read the measurement. The teacher keeps checking to read the measurement until the student recognises that the angle is 103 degrees. He had previously measured this as 105 degrees and the teacher recognises this as a minor discrepancy. She identifies a different angle as a ‘tiny, tiny little’ angle to measure next and highlights to the student that he has recorded a measurement of 145 degrees.

Teacher: “If you know this is a tiny little angle, what angle is it?”

Nicholas quickly explains his mistake in measuring the external angle and answers the teacher’s question.

Teacher: “So if it’s acute, can it be 145 degrees?”

She highlights the error and acknowledges how this has happened. She continues to measure the remaining angle in the scalene triangle with Nicholas to check his previous measurements. He recalculates the sum of the internal angles to discover a different total.

Nicholas: “Wow! 183 and 182!”

The teacher encourages him to try to create and measure another scalene triangle to test but he has become interested in checking his measurements on the previous triangle.

### *Variation due to inaccurate measuring*

Towards the end of the lesson, the teacher creates a Checkpoint to bring the class back together. She asks students to share what they have discovered and Nicholas comments that the sum of the internal angles in *some* scalene triangles are the same; after all, two that he measured ‘had’ 183 degrees and the other one of them ‘had’ 178 degrees. The teacher asks the class to comment while she records the measurements on the board for all students to see. Quite a few other students in the class had focused on measuring the internal angles of triangles and the teacher asks the class to consider their measurements. She refines the inquiry question to *How can we accurately predict the sum of the internal angles of a triangle?* to guide the Checkpoint discussion.

It is at this point that the teacher describes seeing 180 degrees in a number of books as she had travelled around the classroom and asks Africa, one of those students, to share their results. Africa explains that they had measured three triangles and the sum of the internal angles for all three triangles was 180 degrees. Other students confirm their efforts and the teacher records six measurements of 180 degrees on the board to reflect the calculations different students had made. She returns to the idea that there was also a total recorded of 183 degrees, 182 degrees and 178 degrees. Annabel makes a claim that most people got 180 degrees, yet this does not account for the other measurements. Students make possible suggestions such as adding up the measurements incorrectly, measuring different kinds of triangles (scalene and isosceles) and not measuring the angles correctly. The teacher pauses on this point, noting how the other measurements are close to 180 degrees and that these results may be only a couple of degrees away from 180 degrees.

Teacher: “These are really close. 178 is really close and 183. So, if you’ve made an error of 1 or 2 degrees then that will make a slight variation. So, can you ‘answer the question’ and can you prove using evidence? When you know something – think you’ve come up with an answer that’s correct – you need to prove this to us. Show the class how you answered it.”

The Checkpoint highlights how inaccurate measuring could cause variation in the data students collect and this becomes the focus for the remainder of the lesson. The class considers how to overcome this issue and it becomes clear that every measurement will need to be checked by another student to confirm it is accurate.

The students continue to measure to gather evidence and the teacher uses this time to travel around the classroom to gain feedback about how what each group is doing. After a short while the teacher pauses the class again. She has noticed that when some students have measured the internal angles of polygons using pattern shapes they have traced in their books, the corners are not precise and are difficult to measure. Tracing shapes had resulted in some polygons with rounded corners.

Teacher: “When you are tracing shapes (models on the board) this is what is happening on the corner. And if you measure from there the angle is completely different to if you measure on the corner. Where the 2 lines cross is where to measure the angle from so this might be the difference in

measuring angles but if you are trying to be accurate then this could be significant. If you're out by one degree by every angle in an octagon, then what will you be out by? 8 degrees! So be careful."

The students continue to measure and check the angles they have measured, in pairs.

## Discussion

Illustrations from two lessons have been presented, spanning the Discover, Devise and Develop phases of the inquiry *How can we accurately predict the sum of the internal angles of any polygon?* Four key mathematical ideas were identified and are listed in Table 1. Often inquiry questions include ambiguity in the pathways students can take to solve a problem and we use the term 'presented' here in the discussion to highlight that these concepts arose within the inquiry although the teaching intent, as guided by the Curriculum, was on using a protractor to measure angles. The nature of the inquiry question does lend itself to exploring Geometry understandings outlined by the Curriculum and this illustrates the richness of the task. The interactions are used to highlight how the teacher makes mathematical teaching and learning explicit through guided inquiry.

In the first instance, there is a need for teaching the definitions of regular and irregular polygons, presented by a student's need to communicate his ideas using this vocabulary. There is an opportunity for the teacher to "jump in" to assist students with developing their understandings of these concepts at a point in time when the students need to know this. The vocabulary and related mathematical understandings can assist in moving the inquiry forward. Comparing the internal angles of regular and irregular polygons that are similar then becomes the next investigation focus for many of the students. When one student presents the idea that an enlarged shape has larger angles than its original shape, the teacher acknowledges this as a worthwhile endeavour to pursue. In this instance, the teacher has not intervened to correct the student. She sees value in spending time exploring this idea as a way to deepen connections between mathematical concepts of transforming shapes through enlargement. One student (Nicholas) decides to focus on irregular polygons (scalene triangles) and when he finds that the sum of the internal angles of two different scalene triangles is not the same, the teacher joins him in his investigation into knowing. This is a second example of the teacher placing explicit emphasis on the need to follow a line of investigation: do enlarged shapes have greater angles than smaller, similar shapes and do all scalene triangles have internal angles that sum to 180 degrees. Placing value on the students' solutions makes it explicit to the class that challenging these ideas will contribute to a collective understanding, as a community of learners, about shapes and measuring angles. Finally, the fourth illustration presents the teacher using Checkpoints that focus on the students' efforts and the issue of variation in angles measured due to inaccurate measuring. The teacher connects measurement errors made, directly to the concept of evidence which needs to be reliable. Although she doesn't use the term reliable the emphasis she places on accuracy of measurements makes explicit the importance of reducing variation. This provides further purpose for students to continue to use a protractor to measure angles.

Knowing when to 'jump in', when to pursue students' incomplete ideas or partial understandings, and when to make connections between mathematical concepts seems to be skills this teacher uses to make mathematical learning explicit through guided inquiry. Rather than an emphasis on explicit teaching, the explicitness in guided inquiry focuses on explicit learning. Explicit teaching and guided inquiry are very different pedagogies when taken at face value, yet the importance of the teacher making learning explicit exists in both. It will be useful to explore how teachers engineer the explicitness of learning mathematics

in other guided inquiries to inform classroom teachers generally about how experienced inquiry teachers make learning explicit.

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