How Inquiry Pedagogy Enables Teachers to Facilitate Growth Mindsets in Mathematics Classrooms

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Growth mindsets are vital for effective lifelong learning. Students with growth mindsets are more willing to learn new things, take risks, and embrace challenges. Students with fixed mindsets have limiting beliefs about their abilities, and will attribute success in learning to factors beyond their control. Inquiry in mathematics classrooms may have the potential to facilitate growth mindsets. This paper provides an analysis of inquiry mathematics in a primary classroom and reflects upon its potential to foster growth mindsets in classrooms.

What is the Problem?

The Australian Academy of Science (AAS) has expressed concerns that "Australia with be unable to produce the next generation of students with an understanding of fundamental mathematical concepts, problem-solving abilities and training in modern developments to meet projected needs and remain globally competitive" (2006, p. 9). The AAS is not alone, the research-based Australian National Numeracy Review Report (National Numeracy Review Panel, 2008), which came about in response to a need for improving numeracy and mathematics learning within Australia, recommended that:

> From the earliest years, greater emphasis be given to providing students with frequent exposure to higher-level mathematical problems rather than routine procedural tasks, in contexts of relevance to them, with increased opportunities for students to discuss alternative solutions and explain their thinking (2008, p. xii).

There is emerging evidence that innovative teaching approaches can significantly improve students' attitudes and engagement in learning (O'Brien, under review). Within mathematics classrooms, inquiry pedagogies are linked to observable improvements in students' levels of engagement, performance and interest in mathematics (e.g., Allmond & Huntly, 2013; Fielding-Wells & Makar, 2008). Building a classroom culture of thinking results in significant gains in improving student thinking and reasoning abilities (Ritchhart & Perkins, 2005); but doing so relies on the effective development of certain types of student dispositions–the propensity for open-mindedness, curiosity, attention to detail and evidence, imaginativeness, scepticism, and a high tolerance for ambiguity (Ritchhart, 2002; Ritchhart & Perkins, 2005).

Dweck's (2006) research on dispositions, or mindsets shows that students can hold beliefs about their personal qualities that reflect either a positive, flexible disposition towards learning and knowing (a growth mindset) or a limited, inflexible disposition towards learning and knowing (a fixed mindset). In this paper we present an analysis of a primary mathematics inquiry classroom to illustrate how the distinctive pedagogical practices of mathematical inquiry can foster growth mindsets in students.

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Literature and Theoretical Framework

Growth Mindsets

Beliefs play an important role in learning (Hofer & Pintrich, 2012). Dweck's (2006) recent research synthesises the complex but interrelated sets of beliefs about one's personal qualities and abilities as *mindsets*–noting the distinction between having a *fixed mindset* and having a *growth mindset.* This work can be illustrated by the diagram in Figure 1.

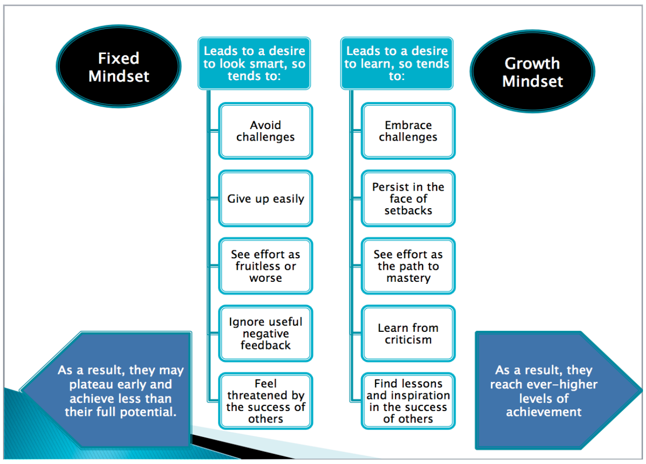

Figure 1. Fixed vs. growth mindsets (Press, 2014).

Having a fixed view of one's self means that you see personal qualities as stable and predetermined. In order to feel secure in a social context, students with fixed mindsets work hard to project a *positive* impression. They want to look smart, and they avoid challenges that can potentially reveal uncertainty or ignorance as they believe this to be unacceptable. They see any kind of feedback or guidance as a negative affirmation of their inabilities, and in turn, feel threatened by the success of others (*they know, I don't*).

In contrast a student with a growth mindset fundamentally believes that his or her personal qualities–intellectual ability, personality, character, preferences, and beliefs–are changeable and in a constant state of growth. As such, growth minded students are oriented to learning and feel less defensive in social settings. They embrace challenges and persist in the face of setbacks (a common occurrence in learning!). They value effort and see its contribution to mastery learning, easily learn from feedback or criticism, and are encouraged and inspired by the learning successes of others (*if they can do it, so can I*). In this way core beliefs about intellectual abilities and personal dispositions influence and shape the way students approach learning.

Inquiry Pedagogy

Cobb, Wood, and Yackel (1993) describe mathematical inquiry as an apprenticeship where ways of thinking are developed within classrooms. Students are supported to work with an ambiguous, ill-structured problem (Makar, 2012); ill-structured problems being those that are ambiguous or have a number of open constraints such that they require negotiation (Reitman, 1965).

In guided forms of inquiry, "The teacher provides the students with the problems or questions and the necessary materials. The students have to find the appropriate problem-solving strategies and methods." (Bruder & Prescott, 2013, p. 812). Throughout the process of solving an inquiry problem, students are scaffolded and challenged by the teacher to plan for, identify, and provide mathematical evidence. The need for negotiation, decision-making, reasoning, and collaboration is somewhat different from usual practices in school mathematics that centre on clarity, structure, and lack of ambiguity (Baber, 2011). Working with ambiguity and open-endedness requires flexibility and a willingness to *not know yet*; to see learning as an opportunity to build new knowledge and new ways of thinking, and to be prepared to take risks and work collaboratively on the creation and testing of ideas and solutions.

For those students who already have a growth mindset, inquiry potentially provides an engaging learning experience that offers a degree of openness, challenge, and autonomy. Provided there is appropriate scaffolding and support for skill development and the reinforcement of related dispositions (such as evidence-based reasoning, mastery learning, and resilience in the face of challenge), inquiry learning may further enhance and promote a growth mindset. It is an opportunity to learn to work confidently with the unknown, to learn how to learn from and with others; to take risks, explore ideas, to reflect on one's own learning process, and to question taken-for-granted assumptions and ideas. In this paper we identify pedagogical practices that, while inherent within inquiry pedagogies, can promote and scaffold a *growth mindset* within inquiry mathematics classrooms.

Methodology

This paper draws on classroom video data from the first year of a larger collaborative project between the authors that is investigating potential links between positive learner identity and mathematical inquiry (O'Brien, Makar, & Fielding-Wells, 2013; 2014). In the first stage of the project, the aim was for the researchers to learn to recognise characteristics of positive learning identity that occurred in mathematical inquiry lessons. Positive mindset is part of the first pillar of positive learning identity and among the first aspects of positive learning identity we are analysing in depth. This paper presents a case study from one of the classrooms in the project.

Study Context, Participants and Data Collection

For this paper, we focused on video data from a lesson in a Year 5 classroom in a suburban, middle class primary school in Queensland. The lesson took place 9 months into the first year of the project from a classroom with an experienced inquiry teacher and 27 students (aged 9-10 years old). The class was working on the inquiry question, "What is the best one litre container I can build with one face that is $125cm^2$?" This was the third inquiry unit the students had completed in the year so they had by this time developed a classroom environment that supported mathematical inquiry. We selected this lesson because it was one in which the class was at a point in their inquiry in which they were stuck and the teacher had taken the opportunity to stop the class and discuss the issues they were having. We recognised that *being stuck* was a productive context in which to observe characteristics of positive mindset (Dweck, 2006).

Data Analysis

The video data went through a process of analysis adapted from Powell, Francisco, and Maher (2003) who describe seven stages: intent viewing, describing the video data, identifying critical events, transcribing, coding, constructing a storyline, and composing narrative. A log was created from the video to provide time stamps, screen shots, and brief excerpts to provide a running summary of the lesson (*intent viewing; describing the video* *data*). Using the video log, the researchers re-watched segments to identify those that were potentially useful to characterise positive mindset (*identifying critical events*) and discussed the potential narratives within these critical events as explained by Powell and his colleagues, recognising how narrative and critical events "co-emerge" (p. 417). The critical events were transcribed and annotated (*transcribing; coding*) with characteristics of positive mindset (Figure 1). The researchers discussed the insights provided by the coded critical events and chose a small number of excerpts which would coherently and succinctly illustrate links between mathematical inquiry and the key characteristics of positive mindset (*constructing a storyline*). Finally, these insights were composed as the narrative written in the paper (*composing narrative*).

Results

This learning episode has been selected from a sequence of lessons in which the teacher had implemented a unit of inquiry in her mathematics classroom. In our analysis, we identify the opportunities in the lesson that reinforced the need for a *growth mindset* in learning, in particular with reference to the need to:

- embrace challenges
- persist in the face of setbacks
- see effort as the path to mastery
- learn from criticism
- find lessons and inspiration in the success/learning of others.

Embrace Challenges, Persist in the Face of Setbacks, See Effort as the Path to Mastery

Facing ambiguity and doubt can be a challenging experience, and one that students might initially be inclined to shy away from. However in inquiry pedagogy, the challenge that ambiguity presents is actively embraced and reinforced as highly valuable in order to deepen mathematical understanding and decision-making. In this particular episode, the students faced the challenge of devising a one litre container and realised they were yet to learn specific mathematical concepts that might help them when one group's container required finding the volume of a cylinder.

In the excerpt below, one of the students had researched the formula for calculating the volume of a cylinder; however Ms Thomson, the teacher, wanted the students to develop conceptual understanding of volume rather than move to a formula so quickly. The teacher reassured them that while that may be a challenge, they have much they already know that they can draw on to respond to that challenge, and in doing so, reinforced that challenge is an expected feature of learning.

Noah:	Actually I have an answer for Isabelle and whoever said you can't measure a circle. We in my group we found it easy to make this circle. What we did is we umm we got the diameter and then we halved the diameter which is the radius … We put the scratchy bit (referring to the point of a compass) at the end and we twirled it all the way around and then we cut this scratch and it made this thing here. And, to measure a circle you actually need to halve the diameter which is from this side to this side
Student:	Radius times the pi?
Noah:	Radius times radius times pi.
Ms Thomson:	OK, now that is a formula that you will learn later on for measuring the area of a circle … If you don't know any formulas, how do you measure the area of the base of that cylinder? … How could you do it? Think of all your years

	of schooling and what you've done in the past how could you measure it? What could you do? Benjamin?
Benjamin:	I'm confused.
Ms Thomson	... [to the class] Think outside the box, [if you] don't use the mathematical formulas. …
Student:	Circles aren't square centimetres….
Students:	(several students in unison) You can— (long pause)
Ms Thomson:	At least you are thinking. How can you use square centimetres to measure, or how could you measure area of the base when it's a circle? What would you do, Alkina?
Alkina:	I don't know how to measure [a circle].
Ms Thomson:	[to the class] No idea? Oh, come on, think, think … If I gave it to a five year old and said 'How many square centimetres do you think are on the bottom of this?' What would they do? ...
Arnav:	They'd get blocks like this so you could put it on the bottom and then trace it around and whatever is left you could estimate how much of the block is, how many blocks are left that it hasn't covered and then you'd probably get a close answer.
Ms Thomson:	You would! You'd get a pretty close answer. Do you understand what he's talking about? What else could you do?

You can see in this exchange that the teacher did not give the students an answer, or a way forward, but rather continued to probe and question until the students suggested a solution. The students therefore experience that they can find the answers within themselves if they persist: that challenge is an opportunity to think about something more deeply rather than a stopping point, which links closely to Dweck's (2006) third point: effort as the pathway to mastery.

Learn from Criticism

As this same episode continued, the teacher asked students to explore various options for responding to the task, and where necessary she acknowledged how difficult it was, but affirmed that such difficulty is to be expected. By doing so, she modelled to the entire class that their approach or preliminary solutions may be incorrect or not working, but that is to be expected; and that feedback and critique on that approach is a valuable part of the learning experience, on the path to mastery. As the teacher continued to question each group and specific students about where they were up to and how they were approaching the problem, she provided feedback and facilitated critique from herself and other students on their progress thus far:

Chloe:	… if you keep that one the same then make that the height we need it be to equal a litre, um, then we need to keep this one the same as well.
Ms Thomson:	Why?
Chloe:	Because if you change that [side], it would kind of be like the sides would curve instead of being straight and that's not really what we want, so [pause]. You could kind of, I think you could do that. [pause] Well, it's going to be open because the base like, the other side of it needs to be open.
Ms Thomson:	OK. Isla?
Isla:	Well, if we make it higher, then the base will have to change and that might not equal a litre.
Ms Thomson:	Why? Sorry what did you say?

Isla:	If they make like them higher to 8cm, they've got to change the size of their base so it fits.
Alkina:	No, 'cause that's going to be the base so if you just make it higher it won't change the base. We're just making these higher. It won't change the base.
Isla:	OK.
Zhang:	You just have to change these sides.
Ms Thomson:	What did you say Zhang?
Zhang:	I reckon that'd work, I think if you just make it like 3 cm higher, all the other sides, um, then that would be 8 [cm] and then it would work.
	[The group of girls are talking quietly about what they need to do.]
Ms Thomson:	So do you guys know where you are going with that?
Chloe:	Now we do because we didn't, we thought we knew before Josh's group did their's because they were doing the same thing that we are doing. But then we realised it wasn't going to work, so yeah.
Ms Thomson:	… Have you got anything to add to that, Alkina?
Alkina:	No
Ms Thomson:	Harrison. Harrison, your turn to share what you've found so far.

In this episode, the students illustrate their willingness to rely on one another to challenge and develop each other's thinking. The critique from peers became a resource for learning rather than an indication that they were performing poorly. This suggests that the students in this class were building positive mindsets through their collaborative wrestling and critique of each other's thinking.

Find Lessons and Inspiration in the Success or Learning of Others

In this last extract from the final stages of the episode, the teacher asked students who had worked out a satisfactory solution to explain what they found and how, providing evidence for their claims. In doing so, she purposefully brought in the experiences of other students into the lesson as a shared experience of learning–an opportunity for students to learn from (and appreciate) the success of others as an inspiration for their own learning process and experience:

Ms Thomson:	So when you said your container, you don't know how high it is and you didn't know how high to make it … But do you understand why you have to make it that high?
Alexander:	Because that equals a litre.
Ms Thomson:	Why? …
Alexander:	125 x 8 = 1000
Ms Thomson:	1000 what?
Alexander:	Cubic centimetres.
Ms Thomson:	Harrison?
Harrison:	What we could do is we could make it 8cm high with a base of 125 square centimetres and that will be 1 litre . …
Ms Thomson:	Why? [pause] Benjamin?
Benjamin:	Because 125 centimetres x 8 = 1000
Alexander:	1000 cubic centimetres and that's what we need to make it equal a litre.
Students:	Why? (several students, anticipating the teacher's next question)
Ms Thomson:	… You made the container and then what did you do?

Zhang:	And then we—
Max:	Tested it.
Zhang:	Then we tested it.
Ms Thomson:	How? …
Max:	Well we had a cup equalled 500 ml or approximately it said apparently according to someone and we put some sand in it to fill the 500ml mark and poured that in twice.
Ms Thomson:	Anybody going to add, anyone going to say something? They tested it; does anyone want to say anything? … No one? …
Lucy:	Well we did the same way of testing except we did it like 5 times, to make sure it was perfect.

Hearing about the solution pathways that other students in the class had developed was an important learning opportunity for all students. They were exposed to a variety of approaches to the problem and a set of strategies for finding a solution that they might not have considered themselves. By making these explicit, the teacher actively encouraged all students to consider adopting these strategies in the next stage of the learning task. She also reinforced the value of learning from what others had done–whether ineffectively or successfully–as a valid part of the learning experience. The teacher was quite deliberate about paraphrasing the puzzling out that has occurred with some groups (e.g., the opening sentence in this extract). In doing so, she invited *all* of the other students to participate in the unpacking and development of the possible solution pathways. Even students who had reached an impasse could reconnect with, and contribute to the dialogic exploration of the solution. Lastly, exploring the various approaches taken by different groups explicitly valued both the successes *and* failures (however temporary) of the class. While the inquiry offered the teacher an opportunity to scaffold learning and direct thinking and reasoning, her role was primarily to bring all learning experiences into view and to highlight and value each for their contribution to the learning of the class as a whole.

Discussion

Engaging effectively in learning and in life requires flexibility, determination, resilience, and a host of high-level intellectual capabilities (Dweck, 2006). While mathematics classrooms can provide comprehensive opportunities to develop mathematical knowledge and concepts, a more deliberate pedagogical approach is required if we are to foster the kinds of *dispositions* that accompany significant gains in student thinking and reasoning (Ritchhart & Perkins, 2006), and mathematical capabilities (NNRP, 2008).

In this analysis we identified specific pedagogical practices that foster and reinforce a *growth mindset* amongst students. In general, mathematical inquiry pedagogies elicit (and require) the kinds of open-mindedness and willing flexibility that is the hallmark of the growth mindset. However a key feature of inquiry is the time, encouragement, and scaffolding of students' exploration of solutions in a shared, collegial way. Where there is an open-ended solutions pathway, there is the possibility of running into dead-ends, of becoming lost, and of encountering difficulties and disagreements. Such setbacks, and the effort we must exert to navigate them, are all part of engaging positively in a field that we eventually master. The teachers' role in inquiry is to monitor the momentum of the inquiry carefully, to look for opportunities to redirect, to gently guide and to offer hints, clues or support (both intellectual and psychological) to students, and to generally inject needed momentum along the way. By doing so, the teacher reinforces a range of dispositions and personal qualities that are characteristic of growth mindsets. This paper has outlined how the pedagogy of inquiry within mathematics classrooms can enable the teacher to model and scaffold–and the students to experience first-hand–what it means to embrace challenges, persist, mobilise effort in the pursuit of mastery, learn from criticism, and find lessons in the learning and successes of others. In doing so, the features of a growth mindset are integrated into the students' experiences of mathematical thinking and reasoning.

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References

Allmond, S. & Huntly, K. (2013). Achievements and challenges encountered by classroom teachers involved in a research project: A reflection. In V. Steinle, L. Ball, & C. Bardini (Eds.), *Mathematics education: Yesterday, today and tomorrow* (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australasia). Melbourne: MERGA.

Australian Academy of Science [AAS]. (2006). *Mathematics and statistics: Critical skills for Australia's future*. Retrieved from *http://www.review.ms.unimelb.edu.au*

Baber, R.L. (2011). *The language of mathematics: Utilizing math in practice.* New York; Wiley.

Bruder, R., & Prescott, A. (2013). Research evidence on the benefits of IBL. *ZDM – The International Journal on Mathematics Education, 45*(6), 811-822.

Cobb, P., Wood, T., & Yackel, E. (1993). Discourse, mathematical thinking and classroom practice. In E. A. Forman, N. Minick, & C. A. Stone (Eds.), *Contexts for learning: Sociocultural dynamics in children's development*. New York: Oxford University Press.

Dweck, C. (2006). *Mindsets: The new psychology of success.* New York: Random House

Hofer, B., & Pintrich, P. (2002). (Eds). *Personal epistemology: The psychology of beliefs about knowledge and knowing.* New York: Routledge.

Fielding-Wells, J., & Makar, K. (2008). *Student (dis)engagement with mathematics*. Paper presented at the Australian Association of Research in Education (AARE), Brisbane, Australia. Retrieved from http://www.aare.edu.au/08pap/mak08723.pdf

Makar, K. (2012). The pedagogy of mathematical inquiry, In R. Gillies (Ed.), *Pedagogy: New developments in the learning sciences* (pp. 371-397). Hauppauge, NY: Nova Science.

National Numeracy Review Panel (NNRP). (2008). *National numeracy review report*. Canberra: Author.

O'Brien, M. (under review). Developing pedagogical expertise to support the development of *positive* learning resources in Primary School students. *Educational Action Research.*

O'Brien, M., Makar, K., & Fielding-Wells, J. (2014). *Characterising positive learner identity within mathematics inquiry classrooms.* Paper presented at the 2014 AARE/NZRE conference, Brisbane.

O'Brien, O., Makar, K., & Fielding-Wells, J. (2013). Investigating connections between mathematics pedagogies and student efficacy and engagement. In V. Steinle, L. Ball, & C. Bardini (Eds.), *Mathematics education: Yesterday, today and tomorrow* (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australasia). Melbourne: MERGA.

Powell, A. B., Francisco, J. M., & Maher, C. A. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *The Journal of Mathematical Behavior*, *22*(4), 405-435.

Press, L. J. (2014, October 29). The mindset of growth and success [Web log post]. Retrieved from https://visionhelp.wordpress.com/2014/10/29/the-mindset-of-growth-and-success

Reitman, W. R. (1965). *Cognition and thought: An information processing approach*. New York: Wiley.

Ritchhart, R. (2002). *Intellectual character: What it is, why it matters, and how to get it*. San Francisco: Jossey-Bass.

Ritchhart, R., & Perkins, D. N. (2005). Learning to think: The challenges of teaching for thinking. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 775-802). New York: Cambridge University Press.