

Premier’s Mathematical Association of NSW Mathematics Scholarship

Enhancing creativity in mathematics by improving student critical thinking and problem solving skills

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# Introduction

To prepare students who can successfully navigate the world as numerate citizens, schools need to develop learners who embrace mathematical problems with creativity and critical thinking skills. Being able to use knowledge, fluency and understanding to communicate strategies and justify conjectures is an integral part of the NSW Mathematics Syllabus K-10. However, the prevalence of procedural, rote learning is an ever increasing international issue in schools. Instructional pedagogy stifles mathematical freedom, creates fixed-mindsets and prevents students from developing a deep and flexible understanding of number.

Establishing an educational culture that values the development of creative and critical thinking will enable teachers to foster the essential learning dispositions needed to thrive as problem solvers. Students who possess the ability to persevere with difficult tasks, take risk with their learning and formulate questions, are able to perceive mathematics, not just a school subject, but a fundamental part of the world. They have the resilience and adaptability to learn from mistakes, collaborate with peers to develop deeper understanding and improve their own mathematical knowledge and skills.

Since 2000, there has been a steady decline in Australian PISA results which has sparked much debate in the media. It is clear that an educational paradigm shift has become a national priority, and this shift needs to steer teachers away from rote learning and memorisation and towards creativity and critical thinking. Jo Boaler asserts, ‘students who memorise Math are the lowest achieving in the world. The highest achieving students are the ones who think about the big ideas in mathematics’ (Boaler, 2008).

Ken Robinson (2006) poses the thought-provoking question, ‘Are we teaching the creativity out of our students?’ which I hope to investigate and discover how to reverse any damage imposed on our young mathematicians.

# Focus of Study

The focus of this 2019 MANSW scholarship tour was to investigate the key elements of mathematic lessons that develop a growth mindset and increase confidence to creatively embrace all problem solving tasks with excitement, perseverance and curiosity. The purpose of my research tour was to discover how educators enrich students’ conceptual understanding in mathematics, develop students’ ability to apply knowledge and skills to a multitude of problems, while heightening their creative and critical thinking skills.

The study tour incorporated school visits, museum tours, a mathematical festival and two conferences. The tour included school visits in Singapore, Cambodia, New York, Palo Alto and San Francisco. The tour afforded me the opportunity to engage in interesting and enlightening conversations with educational academics, school leaders, classroom teachers and primary aged students. During the seven school visits, I spent full days observing and participating in primary school maths lessons. Additionally, I interviewed students and teachers about their attitudes and experiences in mathematics, their ability to work creatively and the development of essential problem solving skills and dispositions.

Attending two major international conferences provided me with the opportunity to learn from educational leaders in pedagogical change and educational leadership. During the 2019 World EduLead conference in Singapore, the workshop days were spent engaging with educational change leader, Michael Fullan and Finnish educational leader, Pasi Sahlberg. Additionally, I participated in Jo Boaler’s Mathematical Mindset Workshop at Stanford University which addressed the key issues of creativity and curiosity in Mathematics.

# Significant Learning

Throughout my scholarship tour it became increasingly apparent that my learnings would be an affirming experience that would build upon the pedagogies and practices promoted by the leaders in my school system in Australia. My own beliefs and educational philosophies were strengthened through the tour, as I acquired new skills and knowledge of what constitutes optimal practices within a primary maths classroom.

I discovered many vital and common elements of mathematics education that leaders and teachers employed in order to enhance creativity in primary mathematics to ensure critical thinking and improved problem solving skills. These themes, which will be further explored in this report, include:

* the impact of standardised testing
* the importance of students having mathematical freedom through the use of deep thinking tasks that are ‘low floor, high ceiling’
* the importance of time when problem solving
* the vital role effective questioning plays in developing creative problem solvers
* developing positive learning dispositions, growth mindsets and attitudes.

## Standardised testing has a direct and dramatic impact on mathematic pedagogies

It was apparent from my discussions with school leaders and teachers that pressure from external, high-stakes, summative assessments directly impact how mathematics is taught and unfortunately the greater the pressure, the more these pedagogies moved away from creative and critical thinking. During the World EduLead congress speech, Pasi Sahlberg (2019) discussed standardised testing as a ‘global virus and disease’ as the impact it has on education can be extremely damaging. Jo Boaler introduced the idea of two different pedagogies existing that directly correlate to the pressure of data derived from standardised testing: mathematical freedom verses performance mathematics (Boaler, May 2019).

The detrimental impact of standardised testing was evident when I visited different schools in America. The school board of The Bronx Charter School for Children, makes significant school-wide decisions based on the data derived from national tests; including the possible closure of a school. The pressure for outstanding results has driven teachers to implement procedural, teacher-directed pedagogy that relies on the memorisation of rules and step-by-step instruction for completing tasks or solving problems. I observed students in infant classes completing worksheets, using a single teacher-directed strategy, without the use of equipment; all the while working silently without peer collaboration.

Through discussions with the leaders at this school, we surmised that the direct consequence of testing pressure was the development of students with limited problem solving strategies, narrow views of their ability and an inability to apply their knowledge to different situations. The leadership team is investigating how to progressively enhance teacher skills and knowledge to teach in a more flexible way and how to communicate this need to the school board.

This scenario was juxtaposed with my observations at other private schools across America and Singapore. When there was limited or no importance placed on test data, learning experiences were enjoyable, creative and used maths facts in purposeful and meaningful ways. At The Imagination Lab School, Palo Alto, results from national tests were not used as evidence for major decisions. Alternatively, staff analysed the data to track student growth and identify school trends, rather than making detrimental judgements on student ability and the quality of teaching. This gave teachers the freedom to explore mathematical concepts rather than simply teaching maths facts.

Throughout Australia, NAPLAN assessments can also have the same impact and pressure on teachers and school leaders. Publicised results can alter how individual schools and entire school systems use the data and consequently how mathematics is taught. It is essential that schools use assessment data in purposeful and meaningful ways that impact on student learning, rather than promoting competition between schools and school systems. It is imperative that standardised assessments are used in conjunction with formative assessments to analyse a students’ cognitive development and growth.

## Students require mathematical freedom through the exploration of open, deep thinking tasks that are ‘low floor, high ceiling’

It was evident through classroom visits that students who had been encouraged to think independently about real-life mathematical problems from an early age developed into learners who could apply their skills, strategies and experiences to a range of complex, multi-step problems. To develop critical thinking, creativity and problem solving skills, tasks need to be contextual and purposeful for the students, as well as being transformational to real life. Tasks need to give students mathematical freedom and agency when making decisions as well as giving students time to think, experiment and make mistakes.

The term ‘low floor-high ceiling’ is used to describe mathematical problems that have a low entry point (so all students can work on the task) but they have a high ceiling so students can be extended to reach their potential. Introducing such problems encourages students to have the freedom, flexibility and confidence to creatively apply a multitude of strategies that most commonly results in a variety of answers for the same problem.

Year 2 students at the Hewitt School, New York, were developing their creativity and problem solving skills through a task exploring possible coin combinations equalling 25c (using American currency). This task was accessible for all students without teacher intervention and was also open enough for students to challenge themselves to think freely, deeply and more creatively about a concept. Students were able to explore multiple pathways, use different mathematical operations and concepts to generate a multitude of answers. Additionally, this task was memorable for students as it was transformational to life outside the classroom.

A recurring theme throughout the Mathematical Mindset workshop at Stanford University, was the importance of mathematical freedom, student autonomy and agency when making decisions. Creative and critical thinking is cultivated when students have the freedom to make decisions about their learning; the freedom to choose and use equipment, freedom to choose effective strategies to solve problems, freedom to work independently or collaboratively, freedom to explain and reason, freedom to have time to struggle, make mistakes and reflect on learning. Therefore, when prescriptive textbooks, repetitive worksheets or explicit explanations or instructing occurs, the imperative decision making processes is removed and the development of mathematical freedom ceases.

## Students need time to experiment and think about a problem

Learning experiences that incorporate think time and time to experiment and play with numbers allow students to expand or build on past ideas, evaluate and learn from their mistakes and discuss their thinking with peers. Having time to investigate ideas deepens understanding, promotes creativity and develops persistence and resilience.

At My City School, San Francisco, there are only 12 students from Grade 5-8 who have been diagnosed with learning disabilities and were unsuccessful in mainstream schools. The school aims to cater for each students’ learning needs as well as rebuilding their self-confidence and self-belief. When given a problem to solve, the students were not told how to solve it, what strategies would help, what equipment to use or what past experiences would assist in solving the task. Most importantly, they were given time to explore possible answers independently. Students were given the opportunity to read, comprehend and decipher a problem; they had the opportunity to experiment, to struggle and make mistakes. The teachers did not assist students, instead they allowed them time and with this time, every student was able to create a solution for the task. Whether this solution was correct or not, they were praised and given feedback for their thinking process and engagement.

## Developing the ability to play and experiment with numbers flexibly

Developing a deep understanding of number and being able to use number skills flexibly in any given problem or situation is referred to by Boaler as ‘number sense’. Deep number sense is essential for creatively manipulating numbers in order to solve maths problems in and out of the classroom. Teachers need to balance developing fluency, conceptual understanding and problem solving skills during lessons or units of work. During her workshop, Boaler discussed that without this balance in mathematics lessons, students become rote learners who memorise rules, have low number sense and an inability to flexibly use numbers.

Within a single Year 5 lesson at The Australian International School, Singapore, the teacher addressed the three aspects of mathematics discussed above. The teacher commenced the lesson with a fractions number talk to deepen conceptual understanding, followed by a multiplication game to practise fluency, which led into a problem solving task that incorporated both concepts. The numeracy leader, Mr Luc McKay discussed the shared belief that even though fluency of maths was important, it did not equate to speed, 100% accurately or closed problem solving. Boaler discussed her own inability to learn the times tables in primary school, which many people believe is vital for success in mathematics, however, she could solve multiplication sums by flexibly using known facts and her understanding of numbers.

When students are able to use numbers flexibly it demonstrates a deep conceptual understanding rather than a procedural learning of numbers that only requires recall of facts and rules. In one school, part of the daily routine was the completion of worksheets to increase fluency. However, during fluency time, I observed every students solving every addition question the same way, and when probed about alternate strategies they were unable to apply any. The students lacked the conceptual understanding of addition, or deep number sense to effectively use a variety of efficient strategies.

This experience was juxtaposed with another Year 1 class in a different school, where students completed addition tasks posed as real-life problems. Students flexibly experimented with numbers by employing a variety of effective strategies and they experimented with how to record their thinking (some took photos of equipment, some drew pictures and others used numerical form).

## Effective questioning plays a vital role in a maths classroom; it can transform a fun, frivolous game into a deep, rich learning experience

Effective questioning can have a monumental impact on the effectiveness of a mathematics lesson or task. It can transform a game into a deep thinking experience. Through my work with Ron Richhardt and the team at Project Zero, our school has been developing a Culture of Thinking through the use of questioning to promote and develop different styles of thinking. In mathematics, questioning can enrich a child’s understanding of a concept by making connections to real life situations, past experiences and other mathematical ideas. A teacher can facilitate creativity by asking open questions that steer a student’s thinking in different directions. However, to further enhance the effectiveness of questions in order to promote deep and creative thinking, both teachers and students must have opportunities to ask questions throughout a lesson.

I witnessed the positive impact peer questioning has on a child’s thinking process during a Year 4 lesson at Keys School, Palo Alto. During a fractions lesson a student volunteered their answer, yet made errors. The teacher refrained from correcting these errors and instead directed the class to ask probing and clarifying questions. Through this student-led discussion, everyone in the class was able to evaluate their own thinking, heighten their reasoning abilities and value different perspectives.

During my classroom visit to a Year 1 class at The Australian International School, Singapore, I witnessed the teacher transform a fun fluency game into a rich thinking task. In pairs students were playing a card game to increase fluency of knowing two more or less than a number. During this game, the teacher roamed the classroom asking probing questions which compelled the students to slow down, consider their strategies and develop the ability to justify their thinking. Without these questions, the students would have enjoyed the game but would not have thought critically about the embedded mathematical concept. This, in turn, results in a deeper understanding of the concept and the ability to apply it in different situations in the future.

## Developing a growth mindset and positive attitudes

The majority of lessons I observed had very similar elements that led to highly effective, engaging and challenging learning experiences. The students I observed were excited, creative, interested and curious mathematicians. They possessed confidence when solving problems and high levels of self-belief in their ability to choose and use effective strategies. These students were not all high performing students academically, but had been educated in a way that developed beneficial learning dispositions; allowing them to succeed in problem solving tasks. I observed students collaborating, persevering, making generalisations, applying past experience and using resources flexibly.

It was apparent that all students I spoke to had developed a growth mindset and perceived themselves as successful mathematicians. Boaler (2019) discusses that the greatest time for brain development is when we struggle and make mistakes, as this is when connections are made and brain synapses fire. When a student is resilient and able to take risks when exploring a problem, they accept that mistakes are inevitable and these can be a learning experience. However, when students believe the damaging misconception that ‘people are born with a maths brain’ or some people are just ‘maths people’ they can limit their learning potential based on societal comments. Teachers and parents have the powerful ability to dispel these misconceptions by educating students about the brain and modelling a positive and growth mindset.

Boaler (2008) has conducted extensive research into the issues of maths anxiety and gender stereotypes that are both destructive and harmful for a child’s cognitive, emotional and social development. Both damaging pressures are extremely prevalent in the mathematics classroom and can hinder the development of growth mindsets and further improvements in mathematical learning. Teachers and parents play a critical role in eliminating these pressures by what they say, how they act and react towards mathematics. Students who are able to overcome or avoid these pressures have a greater prospect in developing into innovative and successful mathematicians.

# Conclusion

Through my study tour, I surmise that in order to enhance creativity, problem solving skills and critical thinking, a major influence is the role of the mathematics teacher and student. As well as following the advice included in my study findings, I strongly recommend that schools and school systems consider what they perceive these roles to be, question if they align with shared beliefs about effective teaching and how these stereotyped roles impact on the type of mathematicians being developed.

I believe that when a student’s role is transformed into one of a questioner, investigator and risk-taker, they develop the curiosity, motivation and desire to think deeply about maths concepts and solve meaningful problems. The teacher also needs to transform themselves into these roles while maintaining the confidence and content knowledge to know how to facilitate discussions that provoke creative and critical thinking. In order to create stimulating and engaging learning experiences for students, a teacher requires the skills and subject specific knowledge to create rich problems that connect content strands, mathematical ideas and transfer to real life situations.

A paradigm shift is needed from all educational stakeholders. A shift that no longer perceives teachers as the fount of all knowledge. Mathematics can stimulate deep thinking and creativity about not only mathematical concepts and ideas but also the world in which we live. It is a subject where students and teachers can work together to investigate problems, flexibly play and experiment with numbers while maintaining a high level of conceptual understanding.

I strongly recommend every school year, that teachers work with their students to develop a classroom environment and learning culture that promotes growth mindsets, positive attitudes towards mathematics and confidence in one’s ability to excel at mathematical problem solving. A classroom where risk taking, perseverance, questioning and resilience are valued and celebrated is also vital to ensure students embrace mathematics. This positive and safe classroom environment impacts not only on a child’s self-belief and confidence, but also on their ability to have mathematical freedom to make mistakes, experiment and evaluate their own thinking without judgement.

Primarily, a teacher must acknowledge and cater for each child’s individual learning trajectory, their past experiences in mathematics and the individual attitudes and feelings concerning maths. Without a supportive classroom environment, a student will fail to fully develop the essential learning dispositions needed to grow into an inspired problem solver who can think critically and creatively about the numbers in their world.

The findings of my study tour have been extensively communicated through social media, blog posts and presentations at network meetings. Regular blog posts prior to, during and after my study tour capture my experiences, learnings and classroom applications (refer to my [blog site](https://creativemathsdotblog.wordpress.com)). Additionally, teachers internationally have been following and interacting with my Facebook page which contains specific examples of problem solving tasks that enhance creativity and critical thinking (refer to my [Facebook page](https://www.facebook.com/enhancingcreativitythroughmaths/) @enhancingcreativitythroughmaths). My scholarship work has also been shared during network meetings, leadership conferences and individual school meetings within my Australian school system.

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5. The Keys School, Palo Alto
6. My City School, San Francisco
7. The New School, San Francisco
8. Jo Boaler and Cathy Williams; ‘Mathematical Mindset’ workshop, Stanford University
9. All speakers at the 2019 World EduLead Conference, Singapore

# References

Boaler, J. 2008. *What’s Maths Got to Do With It?* Penguin Books. London

Robinson, K. 2006. *TED Talk: Do Schools Kill Creativity?* February 2006 <<https://www.ted.com/talks/ken_robinson_says_schools_kill_creativity?language=en>>