Twenty-First Century STEM Citizens: Equipping students and educators with creativity and confidence to enable positive attitudes toward mathematics

by

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Glossary

STEM: Science. Technology, Engineering and Mathematics

MA: Mathematics Anxiety

ST: Stereotype Threat

ACARA: Australian Curriculum, Assessment and Reporting Authority

ABS: Australian Bureau of Statistics

OECD: Organisation for Economic Co-operation and Development

NAPLAN: National Assessment Program – Literacy and Numeracy

PISA: Programme for International Student Assessment

PCEK: Pedagogical Creative-Enhancement Knowledge

CPDK: Creative Pedagogical Domain Knowledge

CFTI: Creativity Fostering Teacher Index

GPA: Grade Point Average

CAT: Consensual Assessment Technique

W.E.I.R.D: Western, educated, industrialised, rich and democratic

Summary of the Thesis

As society transitions into Industry 4.0 (whereby industries integrate digital and physical objects) the role of educational systems is to shape students into 21st century STEM citizens (Morrar, Arman, & Mousa, 2017). In response to this emerging workforce, modern education systems develop 'soft skills' such as creativity alongside STEM capabilities.

Unfortunately, an unintended side effect of encouraging more students to study STEM subjects is the increased presence and psychological impact of Mathematics Anxiety (MA) experienced by students (Steen, 2012). Additionally, females experience higher levels of MA in comparison to males (Schmader, Johns, & Forbes, 2008). This creates a paradox: encouraging greater participation in STEM subjects can lead to negative mathematical attitudes in students, which may act as a barrier to studying STEM subjects, especially for female students. Given the developing workforce, the importance of STEM and creativity cannot be underrated and those left with negative mathematical attitudes are at a disadvantage (Nosek et al., 2009). This prompts the key question, 'How do we encourage positive mathematical attitudes and creative abilities in students, particularly females?' To answer this question, three key literature gaps were identified and addressed through three related studies.

Gap 1: There is limited research examining if there are sex differences (i.e. differences between males and females) in mathematical creativity in a student population. This gap was addressed through a 2-year longitudinal study of 1391 Australian students. Results suggest that female students are impacted by sex-based stereotypes in mathematics and have lower confidence in their mathematical creativity abilities in comparison to males.

Gap 2: There is limited research that examines how in-service teachers understand their role in perpetuating sex-based attitudes towards mathematics. This gap was addressed via qualitative interviews with 14 Australian teachers. The findings highlight that female teachers hold implicit negative sex-based stereotypes and regard mathematics as a male subject while male teachers do not endorse these sex-based stereotypes.

Gap 3: There is limited research investigating how creativity can mitigate negative experiences with mathematics in male and female teachers. In particular, there is limited research that explores how a creativity-based intervention affects teachers' attitudes regarding mathematics and Mathematics Anxiety levels. This gap was addressed through the implementation of a creativity-based longitudinal pilot study with 13 Australian teachers. The

results suggest that teachers' positive attitudes towards mathematics increased in response to the intervention and female teachers experienced a greater increase in positive attitudes than male teachers.

The final two chapters summarise the findings of the three studies and highlight the unique contributions that this thesis has made to the bodies of literature around mathematics, sex and creativity. Additionally, 5 journal publications, co-authored by the candidate, are included as appendices. These publications highlight novel contributions to the fields of mathematics, creativity and education. The overall outcome is a comprehensive assessment of the relationships between theories regarding mathematics, sex and creativity, with wide-ranging contributions to the academic and practical understanding of the three concepts and how society can address present issues with the under-representation of females in STEM-based education and occupations.

Declaration

This thesis presents work carried out by me and does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, are clearly acknowledged.

Rebecca Marrone

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Quotation

Somehow, it's ok for people to chuckle about not being good at math. Yet if I said, 'I never learned to read,' they'd say I was an illiterate dolt

Neil deGrasse Tyson

CHAPTER ONE

Introduction

1.1 Research Background and Motivation

The 1957 'Sputnik Shock' provided the catalyst that shifted Western education systems to a focus on Science, Technology, Engineering and Mathematics (STEM) subjects (Dickson, 2001). Americans were fearful and anxious about their perceived inability to rival the Soviets' apparently superior capabilities when Sputnik 1 (the world's first artificial satellite) was launched into space by the Soviet Union (Passow, 1957). The US responded, in part, to the launch of Sputnik 1 by enacting the National Defense Education Act (NDEA) in the following year (1958) (Jolly, 2009). The purpose of the NDEA was to increase the number of highly skilled mathematicians and scientists available to the US by encouraging more students to study 'STEM' subjects at higher education institutions (Jolly, 2009). Increasing the number of students studying STEM subjects was not without consequence, as one of the unintended side effects of the NDEA was the increased presence and psychological impact of Mathematics Anxiety (MA) experienced by students (Steen, 2012). A further issue associated with negative attitudes towards mathematics and MA is that they affect females more often than males (Schmader, Johns, & Forbes, 2008). This creates a paradox: encouraging greater participation in STEM subjects can lead to negative mathematical attitudes in students, which may, in turn, act as a barrier to studying STEM subjects, especially for female students.

As society has developed and is transitioning into Industry 4.0 (whereby industries are swiftly changing to integrate digital technologies and physical objects) the face of education has changed once more (Dalenogare, Benitez, Ayala, & Frank, 2018; Morrar, Arman, & Mousa, 2017). Modern education systems recognise the importance of developing 'soft skills'[1] such as creativity, critical analysis and problem-solving alongside STEM capabilities. Within the *Australian National STEM School Education Strategy, 2016–2026* these soft skills are considered crucial to facilitating STEM ability, as they ensure students are better prepared for STEM jobs that do not yet exist. In the context of mathematics, creativity becomes a key

[1] Soft skills are often a combination of social skills, people skills, communication skills, character or personality traits, attitudes and career attributes.

tool to address the negative impacts students are experiencing and may help alleviate negative attitudes towards the subject and MA.

Given the critical place of technology in the modern world, the importance of STEM and creativity cannot be underrated and those left with negative mathematical attitudes are at a disadvantage (Nosek et al., 2009). This prompts the key question, 'How do we encourage positive mathematical attitudes and creative abilities in students, particularly females?' It is proposed that adopting a creative approach to teaching mathematics may help answer this question.

1.2 The Role of Teacher Attitudes in Perpetuating Mathematics Anxiety

The subject of mathematics features in every school curriculum, and historically educators have focused on promoting mathematically competent students. Mathematics is a core skill at the basis of many subjects including science, physics, chemistry, biology, technology and engineering. Furthermore, mathematics provides a strong foundation for all STEM and therefore, will be used as the subject focus in this thesis. However, mathematics is often associated with being a negative and challenging subject and individuals throughout the world have been reported to experience Mathematics Anxiety (Lee, 2009).

Mathematics Anxiety (MA) can be defined as a state of worry triggered by undertaking mathematical tasks (Devine, Fawcett, Szűcs, & Dowker, 2012). MA evokes emotions such as apprehension, tension, frustration, fear and worry in the presence of a mathematical task (F. Hill et al., 2016; Punaro & Reeve, 2012). Several factors, including environmental elements, intellectual variables and personality factors, have been strongly correlated to MA (Baskan et al., 2012; Yüksel-Şahin, 2008); however, this thesis investigates how teacher attitudes towards mathematics can influence their students. The fact that learning is defined as a *process* highlights its sequential and hierarchical nature. If learning is identified as a step-by-step acquisition of knowledge and understanding constructed on experiences, it is logical that educators greatly impact student achievement. Expressly, teachers play a vital role in determining students' attitude towards a subject. In relation to mathematics, learning includes both knowledge of *concepts* (i.e., mathematical ideas such as fractions) and *procedures* (e.g., adding fractions). Students must comprehend mathematical concepts before they can apply mathematical procedures (Stump, Clark, Mitchell, & Roebuck, 2008). Thus, for students to experience successful mathematics development,

teacher practices should be properly addressed. With this in mind, it is proposed that a teacher's attitude towards mathematics can directly influence a student's own experiences with mathematics (Bandura, 1974). Both Bandura's (1989) 'social learning theory,' and Vygotsky's (1978) 'social development theory', highlight that social and cultural factors, such as interactions with adults, influence student learning and development. Both theories emphasise the influence of a teacher (Vygotsky's and Bandura's 'environmental' factor) on a student's own experiences with mathematics. This teacher-student interaction may influence the student developing either low or high confidence in their mathematical abilities (Bandura's 'personal' factor), which in turn might result in mathematics avoidance or selection of advanced mathematics courses and mathematics-related careers later in life (Bandura's 'behavioural' factor). In effect, if the teacher 'models' a positive mathematical attitude and behaviour, then the student is more likely to model a more favourable attitude and response and vice versa.

1.3 The Impact of Teachers' Mathematical Attitudes on Female Students

Bandura's theory of social learning and concept of 'modelling' posit that a student mimics their teacher's attitudes because of their identification with their teacher as a role model, if they are the same sex[2] as the teacher (Bussey & Bandura, 1984). The concept of modelling suggests that female teachers are more likely to pass on their personal attitudes towards mathematics to female students than male students (Bandura, 1974). Similarly, male teachers are more likely to pass on their personal attitudes towards mathematics to male students as opposed to female students (Bandura, 1974). This concept of modelling is important, not only in Australian classrooms but on a global scale, because elementary school teachers worldwide are primarily female (UNESCO, 2016). In Western countries such as the United Kingdom, USA, Australia and Europe, approximately 82% of elementary school teachers are female (Australian Bureau of Statistics, 2014; National Education Association, 2003; UNESCO, 2016). Recent research highlights that pre-service education students have the highest levels of Mathematics Anxiety in comparison to any other college major (Hayes, 2016). Therefore, if the majority of elementary school teachers are female (UNESCO, 2016) and mathematically anxious (Hayes & Bernato, 2016), it follows that their female students

[2] Sex is defined as a person's biological sex at the time they were born as either male or female.

are at a higher risk of also developing Mathematics Anxiety. However, despite research investigating how to minimse the effects of MA on pre-service teachers, (see Hourigan, Leavy & Carroll, 2016 for an example) there are very few studies that have examined in-service (working)[3], elementary school teachers. Considering that these same elementary school teachers have the potential to affect the behaviour of their students, particularly females, it is important to investigate this population. Moreover, female students are often impacted by negative sex-based stereotypes that impact their confidence and attitudes towards mathematics.

1.4 The Impact of Stereotype Threat on Female Attitudes Towards Mathematics

One widely reported factor that contributes to lower female representation in STEM is the concept of Stereotype Threat. Stereotype Threat (ST) refers to the phenomenon whereby people perform tasks at levels below their ability when a relevant negative stereotype is made salient in the performance situation (Steele & Aronson, 1995). Within the context of mathematics, ST is most often associated with the myth that males are innately better than females at mathematics (J. Shapiro & Williams, 2012). More specifically, if a female is made aware of this stereotype when in a situation involving mathematics, then she may experience anxiety surrounding her desire to disprove the stereotype. This anxiety may cause the female to underperform in mathematics (Beilock et al., 2010). Stereotypes and ST can perpetuate negative attitudes towards STEM subjects, consequently leading to higher levels of Mathematics Anxiety and mathematics avoidance, and also lower levels of STEM course-taking (Cheryan & Plaut, 2010; Hill, Corbett, & St Rose, 2010; Simpkins, Davis-Kean, & Eccles, 2006). The impact of ST on female students can be widespread; therefore, investigating techniques to alleviate both MA and ST are crucial. One promising yet under-researched field is investigating how a creativity-based approach influences female student experiences with stereotypes and MA.

[3] In-service primary school teachers are defined as school teachers presently teaching students aged between 5 and 13 years old (Hadley & Dorward, 2011; McAnallen, 2010).

1.5 The Role of Creativity in Mitigating Negative Attitudes towards Mathematics

Longitudinal research suggests that creativity is well suited to improving negative attitudes towards mathematics and alleviating Mathematics Anxiety, which in turn can increase student academic performance (Baas, De Dreu, & Nijstad, 2008; Mann, 2006; Ramirez, Shaw & Maloney, 2018). Nonetheless, as highlighted by studies carried out by Baas et al. (2008), and Byron & Khazanchi (2011), there are clear gaps in understanding the association between creativity and mathematics. Before exploring this research, creativity must be defined correctly. Plucker, Beghetto, and Dow (2004, p. 90) define creativity as the "interaction among *aptitude, process, and environment* by which an individual or group produces a *perceptible product* that is both *novel and useful* as defined within a *social context"*. For the context of this thesis, this definition can be further broken down and defined as Aptitude (the ability of both students and teachers); Process (the steps involved in the creative process); Environment (classroom, school, district, state, country); and Social context (the Australian education system and curriculum as outlined by the Australian Curriculum, Assessment and Report Authority (ACARA)).

When encouraging creativity in the classroom, two key elements are necessary. First, teaching *with* creativity, which is defined as teaching any subject matter creatively (Beghetto, 2013; Beghetto, 2017). The second element is teaching *for* creativity which involves cultivating creative thinking and educating students on how to be flexible and divergent thinkers (Beghetto, Kaufman, & Baer, 2014; Beghetto, 2017). When designing a creativity-based intervention, it is crucial to incorporate the methodological definition of teaching *with* creativity whilst simultaneously emphasising teaching *for* creativity (Beghetto, 2013; Beghetto, 2017). When devised to teach both *with* and *for* creativity, creativity-based interventions have been demonstrated to minimise anxieties, as research suggests that engaging in creative exercises frees working memory to focus on the task at hand (Napoli, Krech, & Holley, 2005; S. Shapiro, Brown, & Astin, 2011). Anxiety restricts an individual's working memory (Ashcraft & Kirk, 2001) and resultant ability to solve problems (Ashcraft & Krause, 2007), a key requirement in mathematics. When an individual increases their creativity levels, their anxiety levels are decreased (Byron & Khazanchi, 2010b). However, after an extensive literature search (see Chapter 2 for a full literature review), no research was found that measures *how* incorporating a creativity-based intervention into mathematics

learning impacts teachers' attitudes towards mathematics and MA whilst investigating sex differences. This lack of research represents a gap in the literature.

1.6 Stereotypes in Creativity

Although research suggests that creativity-based approaches can help alleviate issues such as MA, relatively unexplored in the literature is the potential relationship between ST and creativity. This is a significant omission, given that creativity, like mathematics, is a stereotyped field historically (Runco, Cramond, & Pagnani, 2010) and is an important component of most significant theories of intelligence (Kaufman, 2006). Most importantly, creativity is also considered a critical soft skill that will complement and aid mathematical practices in the emerging workforce (Deloitte, 2016; World Economic Forum, 2016). Unfortunately, it has been well documented that males have been provided opportunities and encouraged to pursue their creative potential more than females (Boorstin, 2012; Piirto, 1991). These past negative stereotypes may still impact modern females' ability to pursue creative endeavours and consequently limit their likelihood of success in the emerging STEM workforce (Runco et al., 2010). Considering the importance of students developing both mathematical and creative-based skills, research should investigate the impact of sex-based stereotypes in mathematics and creativity.

1.7 Why is this Research Important?

As society transitions into Industry 4.0, the economy and the state of education is changing. The Australian Bureau of Statistics (ABS) highlights that the number of people in jobs commonly held by workers with STEM qualifications has grown by 14 per cent between 2006 and 2011 in Australia. This compares with only 9 per cent growth for other jobs (Australian Bureau of Statistics, 2014). Furthermore, international research suggests that encouraging STEM capabilities across societies is essential in supporting innovation and productivity regardless of occupation and industry (PricewaterhouseCoopers, 2015). STEM literacy is becoming a core skill that Australian employers require and PricewaterhouseCoopers (2015) has estimated that changing 1 per cent of Australia's workforce into STEM-related roles would add $57.4 billion to Australia's GDP.[4] However,

[4] GDP = Gross domestic product

as noted earlier, modern society recognises the importance of developing 'soft' skills such as creativity alongside STEM capabilities. As such, the Australian *National STEM School Education Strategy, 2016–2026* initiative targets the development of skills such as problem-solving, critical analysis and creative thinking (Education Council, 2015).

Whilst encouraging both STEM and creativity skills is crucial to promoting student success, the literature also recognises the importance of making these fields equitable. The recent *Women in STEM Decadal Plan* also highlights the importance of encouraging female participation in STEM (Australian Academy of Science, 2019). As society transitions through the processes of mass change, impetus is needed, and researchers need to address and manage issues such as Mathematics Anxiety, ST and stereotypes in creativity to ensure future citizens are STEM-qualified. A key route to making strides in the present sex pattern of STEM participation is to begin in the classroom. A shift in the focus of education towards the career readiness skills associated with creativity enables students to view concepts from a different perspective, which leads to innovation and successful 21st century living.

1.8 Current Gaps in Knowledge

This thesis addresses three key gaps identified in the research and by investigating the relationship between mathematics and creativity-based interventions, sex, and teacher and student attitudes it takes a more holistic approach to previous research in the fields of creativity and mathematics education. Recent reports demonstrate the gaps in research on teacher and student mathematical attitudes and creativity (Australian Mathematical Sciences Institute, 2019). Specifically, there is a lack of research determining if there are sex differences in mathematical creativity in a student population. That is, do females and males have different experiences with creativity if it is presented mathematically? (Gap 1). Whilst research highlights that teachers' stereotypical sex beliefs in mathematics will negatively impact their students' beliefs (Gunderson, Ramirez, Levine, & Beilock, 2012) there is a lack of research that examines how in-service teachers understand their role in perpetuating these sex-based attitudes towards mathematics (Gap 2). Finally, some studies have observed how teachers (An, Tingting, & Capraro, 2011) and students (Beilock, Decaro, & Martin, 2007) are mathematically anxious, and some have attempted to counteract this anxiety (Adeyemi, Martinovic, Grant, Kajander, & Salinitri, 2015; Hembree, 1990); however, much of the research focuses on pre-service teachers or students. Additionally, there appears to be no

thorough research explicitly examining the impact of a creativity-based intervention on teacher attitudes to mathematics while observing how male and female teachers respond to the training (Gap 3).

To reiterate three gaps have been identified;

> Gap 1: Limited research determining if there are sex differences in mathematical creativity in students.
>
> Gap 2: Limited research that examines how in-service teachers understand their role in perpetuating sex-based attitudes towards mathematics.
>
> Gap 3: There is limited research that examines how creativity can mitigate negative experiences with mathematics in both male and female teachers. In particular, there is limited research that investigates how a creativity-based intervention affects teachers' attitudes regarding mathematics and Mathematics Anxiety levels.

1.9 Aims and Objectives of the Thesis

Since the under-representation of females in Mathematics-based STEM programs is a key concern, this thesis explores the relationship between mathematics, creativity and sex differences (Australian Academy of Science, 2019; Roberts, 2014). Understanding the relationship between mathematics, creativity and sex will help answer the question: 'How do we encourage positive mathematical attitudes and creative abilities in students, particularly females?' In answering this overall question, and considering the three gaps in knowledge identified above, the thesis will incorporate three empirical studies, seeking to address several specific sub-questions, as follows:

1. What is the nature of sex differences in mathematical creativity? How do females and males experience creativity differently if it is presented mathematically? This problem will be addressed in Study One (Chapter Three).
2. How do teachers understand their role in perpetuating negative sex-based stereotypes in mathematics? This problem will be addressed in Study Two (Chapter Four).
3. What is the relationship between mathematics and creativity? How does a creativity-based intervention affect teachers' attitudes regarding mathematics? This problem will be addressed in Study Three (Chapter Five).

1.10 Research Methodology

Study One is designed as a repeated measures longitudinal quasi-experiment, seeking to address the research gaps described in Section 1.8 and tests six hypotheses. Study Two is exploratory and therefore uses an inductive approach and is designed around a qualitative research question. Study Three is designed as a pilot pre-test-post-test study; it is quasi-experimental and will test the theories produced from Studies One and Two. It will test four hypotheses.

Study One: Repeated Measures Longitudinal Quasi-Experiment with School Students

This study addresses the following questions: (1) What are the sex differences in the variable Mathematics Creativity (Metacognition)[5]? (2) What are the sex differences in Verbal Creativity (Metacognition)? (3) What are the sex differences in performance on a Mathematics Creativity task? (4) What are the sex differences in performance on a Verbal Creativity task? To answer these questions, six hypotheses were tested.

- **Hypothesis 1 (H1)**. Males will have higher self-rated Mathematics Creativity (Metacognition) than females, both pre- and post-task.
- **Hypothesis 2 (H2)**. There will be no sex differences on self-rated Verbal Creativity (Metacognition) both pre- and post-task.
- **Hypothesis 3 (H3).** Males' self-rated Verbal Creativity (Metacognition) and Mathematics Creativity (Metacognition) will be closely aligned both pre- and post-task.
- **Hypothesis 4 (H4).** Females' self-rated Verbal Creativity (Metacognition) and Mathematics Creativity (Metacognition) will not be closely aligned, in that Mathematics Creativity (Metacognition) will be lower than Verbal Creativity (Metacognition) Creativity (Metacognition) both pre- and post-task.
- **Hypothesis 5 (H5)**. Males will have higher creativity scores than females on the Mathematics Creativity task.
- **Hypothesis 6 (H6).** There will be no sex differences in creativity scores on the Verbal Creativity task.

[5] Metacognition is defined as an awareness and understanding of one's own thought processes.

(See Chapter Three for a full description of this study and its results.)

Study Two: Qualitative Interviews with Elementary School Teachers

This study investigates the research question: 'What attitudes do teachers hold regarding the relationship between mathematics and sex?' This study is designed to elicit attitudes from teachers through qualitative interviews. To answer this question, four structured interview questions were developed. These questions are:

- When you hear the word 'mathematics' what comes to mind?
- Can you describe any sex differences in mathematics? For example, is a particular sex better at mathematics?
- How do you think your sex influences your confidence teaching mathematics?
- To what extent do you agree with the statement 'boys are good at mathematics, girls are good at reading'. Why?

(See Chapter Four for a full description of this study and its results).

Study Three: Pilot Study with Elementary School Teachers

This study addresses the theories and results from Study One and Study Two and will answer the following questions: What is the relationship between mathematics and creativity? How does a creativity-based intervention affect teachers' attitudes regarding mathematics? How do males and females differ in their response to the creativity-based intervention? Four hypotheses were developed to answer these questions:

- **Hypothesis 1 (H1)**: Teacher attitudes towards teaching mathematics will increase in response to a creativity-based classroom intervention. Teachers will have more positive attitudes towards teaching mathematics in response to the creativity-based intervention.
- **Hypothesis 2 (H2):** In response to the creativity-based classroom intervention sex differences regarding attitudes towards mathematics will be reduced amongst teachers.
- **Hypothesis 3 (H3):** Teachers' Mathematics Anxiety will decrease in response to a creativity-based classroom intervention.

- **Hypothesis 4 (H4):** In response to the creativity-based classroom intervention sex differences regarding Mathematics Anxiety will be reduced amongst teachers.

  (See Chapter Five for a full description of this study and its results.)

1.11 Expected Contributions of the Thesis

The three studies conducted in this thesis will contribute to the field of knowledge regarding 'teaching mathematics creatively' and the impact of such pedagogy on teachers and students, particularly addressing the influence of sex. The first study will contribute knowledge regarding sex differences in mathematical creativity. While it is now acknowledged that students require both mathematical and creativity-based skills to be successful, there has been historic sex stereotyping of females in both these fields. This topic of sex stereotyping in mathematical creativity is crucial for the broader research community to understand because this research will establish that sex-stereotypes are not mathematics-specific (which has been the focus of previous research) but are also prevalent in mathematical creativity. This study further demonstrates that sex stereotypes do not impact the capability of females to be mathematically creative, rather such stereotyping negatively impacts their attitudes. These findings highlight that future research should focus on altering female attitudes regarding sex stereotypes and not focus on their abilities. This first study establishes the problem of stereotypes in mathematical creativity.

The second study will establish how teachers conceptualise and think about sex differences in mathematics. This study will build on the problem identified from the findings of Study One and will identify one cause of the sex-based stereotypes in mathematical creativity, teacher attitudes. These results will demonstrate how teacher attitudes develop as well as highlighting any inaccurate beliefs.

Study three will address the evidence provided by studies one and two and will focus on any misconceptions and inaccurate ideas that arise from these two studies. This study will demonstrate the benefits of utilising a creative-based approach to overcome sex-based stereotypes in mathematics. The incorporation of both teacher and students in all three studies provides greater insight into solving the issues of MA, attitudes towards mathematics and sex differences. This research has real-world implications for teachers, policy makers and students because if females learn to experience mathematics positively, then they may continue with STEM careers (Cheryan & Plaut, 2010), thus bridging the sex gap in STEM.

1.12 Structure of the Thesis

This research thesis comprises seven chapters. Chapter 2 examines the current empirical literature and research evidence related to the three key topics of mathematics, sex and creativity. These topics will be explored in the context of education.

Chapter 3 extends the knowledge gained in Chapter 2 by examining the role of sex-based stereotypes within the context of mathematical creativity. Information provided from more than a thousand students will be used to better understand the current barriers to mathematics and creativity as a result of sex-based stereotypes. The outcomes from Chapter 3 lay the foundation for Chapter 4.

Chapter 4 builds upon the findings from chapters 2 and 3. The role of Chapter 4 is to establish teacher attitudes towards mathematics, emphasising the role of sex-based stereotypes. The results of Chapters 3 and 4 were used to design and implement a creative solution to address the issues, and this is explored in Chapter 5.

Chapter 5 addresses the issues regarding negative attitudes towards mathematics highlighted in Chapter 3 and the implicit sex-based stereotypes teachers hold regarding mathematics that are exposed in Chapter 4. A creativity-based intervention was designed that increased positive teacher attitudes towards mathematics and mitigated the inaccurate sex-based beliefs about mathematics.

Chapter 6 summarises the findings from all three studies and highlights the unique contributions this thesis has made to the bodies of literature around mathematics, sex and creativity. Chapter 7 suggests future research that can be undertaken based on the findings of this thesis and acknowledges how this future work is already being undertaken. It will highlight the limitations of the work and will provide final conclusions. Finally, appendices K through O are 5 journal papers written during the thesis that further highlight contributions to the fields of mathematics and creativity education.

Importantly, although this thesis adopts the terminology of ‘sex differences,’ i.e., appearing to reference only the biology of being a male or a female, it must be noted that this cannot happen in isolation of a context that is inherently gendered. Within an environment where there is evidence of ST, differences in female confidence in mathematics may not be a function of ‘sex’ alone (i.e. biology), but partly the result of culture. Therefore, the use of the

terminology ‘sex differences’ in this thesis will not solely be defined as biological differences but will also encompass the role of the gendered culture when considering research.

CHAPTER 2: Literature Review

2.1 Introduction to the Literature Review

This chapter provides a review of current literature pertaining to three key areas – mathematics, sex and creativity – and the relationships and interconnections between all three. However, before exploring these three topics, it is important to lay the foundation as to why and how these three fields align. 'STEM-based education' is synonymous with 21st century classrooms and as society transitions into a new era, the fields of mathematics, creativity and sex shift with this change. At this point in education history these three topics are being brought to the forefront for policy makers, teachers and society as, in isolation, each is considered as being crucial to ensuring education aligns with the demands of the emerging modern workforce. When these three topics of mathematics, sex and creativity are combined and examined through the lens of STEM education, the issues associated with each can be explored. This review will highlight the unique issues associated with mathematics, creativity and sex as well as demonstrate the current gaps in the literature that must be addressed before all students can emerge from education as mathematically creative citizens.

2.1.1 What is STEM in Education?

The 'STEM' acronym groups the academic disciplines of Science, Technology, Engineering and Mathematics together. There are multiple ways of defining the STEM construct, however, a broad definition in the domain of education includes the fostering of inquiring minds, collaboration skills and logical reasoning (Tsupros, Kohler, & Hallinen, 2009). More specifically, for the purpose of this thesis, STEM will encompass the integration of Science, Technology, Engineering, and Mathematics by making the learning of these subjects more meaningful. In this context, students develop the skills to problem solve, collaborate and critically analyse new information by relating concepts and skills to everyday life. STEM involves encouraging children to apply their personal experiences and prior knowledge so that new understandings can be made. This independent thinking and the development of STEM literacy will equip students to compete in future economies (Tsupros et al., 2009).

2.1.2 Why is STEM Important?

Few would argue that the world is changing. As technology and automation advances, current vocations are disappearing, making way for new career pathways (Department of Education

Government of Western Australia, 2015). These ongoing global advances are impacting the way students learn, connect and communicate with others. Having a 'toolbox' of STEM skills and strategies is paramount to ensuring students not only adapt to the changing world but are equipped for success beyond the classroom. It follows that policy makers globally have an active interest in STEM education and the topic is frequently raised at the national level in the United States in science, education, workforce, national security and immigration policy debates (Gonzalez & Kuenzi, 2012). However, STEM-based debates are not unique to the US. A similar call to arms has been made around the world as nations realise that a shortage of highly skilled STEM workers poses a major threat to social, military and economic growth. It is widely considered that both STEM and non-STEM workers benefit from scientific thinking and STEM education is now considered to be a critical human competency for success (McComas, 2014). Before exploring the efforts currently underway to improve STEM involvement, it is important to place STEM in the context of global history.

2.1.3 Global Consequences of STEM for the Future

It is estimated that by 2030 approximately 4,500,000 new STEM-enabled vocations will be required in the UK, including scientists, engineers, IT professionals, economists, statisticians and teachers (Deloitte, 2016). In order to meet this requirement, governments must invest financially in STEM education. Deloitte's (2016) study identified a close link between investment in STEM education and the number of jobs at risk of automation. As an example, 69% of vocations in India are at high risk of automation with the Indian Government investing 3.8% of its GDP in STEM education as of 2016. In contrast, only 35% of vocations in the UK are at high risk of automation, with the UK government investing 5.7% of its GDP in education (Deloitte, 2016). To summarise, an increase in financial investment into education equates with a decrease in jobs that are at high risk for automation. As governments make strides towards mitigating the risk of job loss due to automation and preparing a workforce to meet the needs of the 21st century, it is paramount that STEM-education programs are effectual. Inadequate investment could have widespread consequences for our shifting economies.

Beilock and Maloney (2015) suggest that STEM-specific education programs should include lessons on Mathematics Anxiety (MA) to inform teachers, pre-service teachers and early education teachers (and, in turn, students and parents), of the risk of young children

developing MA from negative mindsets. Thus, by bringing MA to the forefront of the minds of STEM teachers, these teachers are well positioned to eradicate MA in their students (Beilock & Maloney, 2015). Many elements of conventional STEM thinking focus on increasing the acquisition of academic STEM knowledge. Consistent with this suggestion, Deloitte (2016) acknowledges that for our future workers to become more employable, education programs need to look beyond just teaching our children digital and STEM skills. As well as content knowledge, this report suggests that cognitive and social problem-solving skills and abilities are required, coupled with 'soft skills' such as creativity, collaboration and flexibility. Learning how to apply these skills in different contexts is an important part of the puzzle and as such, these abilities should be taught interchangeably. Whilst there is undoubtedly a benefit to acquiring these essential abilities, it is also noted in this report that mathematical knowledge is critical and will be utilised by 87% of the UK workforce (Deloitte, 2016). Addressing this need will involve supplanting negative attitudes towards mathematics and severing the link with MA.

Taking this argument further, as countries such as China ramp up their educational focus to engage in the modern 'Arms Race' (involving a pursuit for knowledge and technology), the unintended consequences of a heavy STEM focus is an increase in the risk and rate of MA. Of further concern is research suggesting that students identifying with MA are typically from racial minority groups, including Indigenous populations, and are often female (Australian Academy of Science, 2019). What follows is that fewer students from these groups are pursuing advanced study of STEM subjects or entering STEM fields. If the STEM pool of human resources is depleted, this is not only detrimental to the individual, but to society as a whole (K. Becker & Park, 2011). This issue underscores the need for further research to remediate Mathematics Anxiety and its deleterious effect on STEM pathways.

2.2 Mathematics Anxiety in Education

In the sections following, several strands of literature related to this overall topic are discussed, including evidence about the prevalence of MA and its relationship with mathematics achievement, factors (particularly teacher pedagogy) which may influence student attitudes towards mathematics and the impact of testing practices on student experiences with MA.

2.2.1 What is Mathematics Anxiety?

Mathematics Anxiety research can be traced back to the early 1950s when Mary Gough introduced the term '*mathemaphobia*' to describe the phobia-like feelings some individuals experience towards mathematics (Gough, 1954). Building on this definition, the term Mathematics Anxiety (MA) can be defined as feelings of worry elicited in the presence of mathematical tasks (Devine et al., 2012). MA evokes emotions such as apprehension, tension, frustration, fear and worry when individuals face mathematical problems or numbers (F. Hill et al., 2016; Punaro & Reeve, 2012). In the context of school environments, multiple factors are correlated with MA for students. These include environmental elements (negative experiences in class, teacher characteristics); intellectual variables (the degree of abstract or logical thinking of the individual); and personality variables (self-esteem, learning style, attitude and confidence) (Baskan et al., 2012; Yüksel-Şahin, 2008). All definitions of MA include the notion that, for some individuals, the thought of mathematics-related situations or interacting with numbers arouses an emotional response that is detrimental to their performance. Unfortunately, MA is experienced by students of all ages and is prevalent in countries throughout the world (Xie, Xin, Chen, & Zhang, 2018).

2.2.2 Mathematics Anxiety Across the Globe

MA is not a construct specific to the Western world (Xie, Xin, Chen, & Zhang, 2018). Researchers have estimated that 93% of Americans from kindergarten through to college, and 50% of British adults, experience varying degrees of MA (Chinn, 2009; Furner & Duffy, 2002). In addition, J. Wang and Lu's (2006) Chinese study highlighted that 69% of junior school students (aged approximately 5–12 years) experienced moderate to severe MA. Similarly, Lee (2009) concurred that high MA levels are found in Australia, Belgium, Canada, the Czech Republic, France, Ireland, Japan and Korea. Undoubtedly, MA impacts a significant proportion of the school-age population, including gifted students, as well as adults in post-secondary education (Chinn, 2009; Maloney, Risko, Ansari, & Fugelsang, 2010; Tsui & Mazzocco, 2006; Zakaria & Nordin, 2008; Zakaria, Zain, Ahmad, & Erlina, 2012). According to Jameson (2014) and Young, Wu, and Menon (2012), MA can manifest as early as junior elementary with young children experiencing feelings of trepidation when exposed to mathematical tasks. If left unaddressed, MA can have severe and long-lasting implications on student achievement in mathematics.

2.2.3 Mathematics Anxiety and Mathematics Achievement

The prevalence of MA and its impact on mathematics achievement has been acknowledged widely in literature (Beilock & Maloney, 2015; OECD, 2013). The concept of MA is best understood within a 'cause and effect' framework that considers an occurrence of MA as a predictor for diminished mathematical attainment. As an illustration, the relationship between MA and mathematical success was highlighted in the 2012 Programme for International Student Assessment (PISA) results. Sixty-three out of sixty-four education systems participating in PISA in 2012 reported that students with higher levels of MA displayed lower levels of mathematical success than their peers with lower levels of MA (OECD, 2013). After averaging this effect across participating countries, results indicate that a one-unit increase in the PISA MA index for a given student corresponds to a 29-point decrease in his or her mathematics score (with a small to medium effect size, Cohen's $d = 0.32$[6]) (Foley et al., 2017; OECD, 2013). Considering the implications of MA for mathematical achievement, it is crucial to understand how mathematics achievement indicators themselves (e.g., tests such as PISA) relate to MA.

Despite PISA examining only 15-year-old students, research by Krinzinger, Kaufmann, and Willmes (2009) on 149 German elementary students suggested that the prevalence of MA increases across school ages. A possible explanation for this rise could involve the pressure on students to improve scores as they transition into higher grades. Early theoretical perspectives emerging from the German study highlight a relationship between MA and impaired test performance. Similarly, Ashcraft and Krause in their (2007) study investigated the cognitive processes involved in the expression of MA. These researchers noted that the lower achievement of mathematically anxious students appears to be limited to mathematics commonly taught after elementary school (i.e., after Grade 5). High MA functions as a resource-demanding dual task which compromises the functioning of working memory for mathematical problem-solving (Ashcraft & Krause, 2007; Vukovic, Kieffer, Bailey, & Harari, 2013). One aspect of the vital relationship between working memory and mathematical competence involves the fact that larger arithmetic problems occur less frequently and are therefore stored at lower levels of strength in long-term memory. Hence,

[6] The effect size, Cohens *d*, is the mean for males minus the mean for females, divided by the pooled within- sex standard deviation.

when exposed to increasingly difficult operand problems, cognitive performance to retrieve information from long-term memory is inhibited by MA (Ashcraft & Krause, 2007). Related to this, Hunt, Clark-Carter & Sheffield (2014) propose that the relationship between MA and mathematics achievement is significantly related to the number of intrusive thoughts experienced by individuals during the problem-solving stage. These authors note that the degree to which intrusive thoughts impacted calculations during a task mediated the relationship between MA and the percent of errors on problems. This relationship between MA and problem errors was higher when solving more difficult problems that required greater working memory ability. These authors suggest that it is these intrusive thoughts that impact one's ability to utilise working memory ability and therefore, can lead to lower achievement. Similarly, Brown, Brown and Bibby (2008) found further evidence for a link between MA and mathematics achievement. These authors report that only seven percent of pupils in the United Kingdom undertake the subject mathematics all the way through their schooling career. These authors report that students cited anxiety about mathematics and a dislike of the subject as a reason for not continuing with mathematics.

Although the link between MA and mathematics achievement has received considerable attention in the literature, there is some debate about the relationship. Some research has shown small negative correlations between mathematics achievement and MA (average correlations of -.27. and -.34 in two meta-analyses) (Hembree, 1990; Ma, 1999). The results from Hembree's (1990) meta-analysis demonstrate that MA has a correlation of -.30 with high school grades, -.75 with enjoyment of mathematics, -.64 with motivation to study more mathematics or perform well in mathematics, and -.31 with the extent of high school mathematics courses taken. The overall correlation between MA and an individual's mathematics achievement, as measured by standardised tests, is -.31. Thus, highly mathematically anxious students receive poorer grades on tests, display low motivation to participate in (elective) mathematics courses, and in fact, do take fewer mathematics courses. These highly mathematically anxious students clearly learn less mathematics than their less anxious counterparts. These correlations demonstrate that as MA increases, mathematics achievement decreases. However, other research conducted by Lukowski et al. (2016) demonstrates that a negative correlation between MA and mathematics achievement is not universal across all testing situations, and therefore the mathematical performance of an individual suffering from high MA, may appear lower than actual cognitive ability and

mathematical mastery. Nevertheless, these authors note that the higher one's MA, the lower one's mathematics learning, mastery of the subject, and motivation to continue studying mathematics.

Disentangling the unclear relationship between MA and mathematics achievement is therefore difficult and may point to methodological flaws when collecting data about the two variables. One finding emerging from research suggests that students with high MA can achieve results in the normal range when mathematical problems are presented without time constraints (Beilock, 2008; Beilock, Decaro, et al., 2007). Therefore, the environment in which tests are presented may account for the lower performance associated with high MA. The reported negative correlations between MA and mathematics results may be inflated due to the effects of these types of methodological issues (Beilock, Decaro, et al., 2007; Beilock, Rydell, & McConnell, 2007).

A further methodological flaw in assessing MA is that often researchers group MA with test or trait/general anxiety and therefore may not be accurately measuring the unique construct of MA. Dreger and Aiken (1957) were among the first researchers to hypothesise that MA was conceptually distinct from general anxiety. Other researchers, including Dew and Galassi (1983), have demonstrated that "the two constructs do not seem to be interchangeable" (Dew & Galassi, 1983, p. 446), or that "it seems unlikely that Mathematics Anxiety is purely restricted to testing" (Hembree, 1990, p. 45). Likewise, Suárez-Pellicioni, Núñez-Peña, and Colomé (2016) have suggested that MA should be considered as a separate construct. Therefore, from a methodological perspective, it is important to ensure MA is treated as a unique variable.

Nonetheless, although research suggests that high levels of any type of anxiety are correlated with poor performance, the environment in which the test is experienced has received minimal attention. Hence, the apparent inherent relationship does pose an interpretive quandary: is lower mathematics achievement due to MA or to a lack of intervention to alleviate an individual's MA? Accordingly, further studies are warranted to establish how and why MA develops in school-age populations as well as providing effective interventions to alleviate situation-induced pressure (Brown et al., 2008). Moreover, MA is interwoven with situation-induced pressure often attributed to testing practices.

2.2.4 The Impact of High-Stakes Standardised Testing on Mathematics Anxiety

A student's mathematical ability is often assessed through testing and examinations. The pressure of such testing practices is increased when testing becomes high stakes and standardised (Lester, 2007). The term 'high stakes' refers to any assessment used by governments and policy makers to make decisions about students, educators and schools (Polesel, Rice, & Dulfer, 2014). High stakes testing has consequences for student success because this type of testing can determine punishments (sanctions, penalties and funding reductions), accolades (awards and public celebration), advancement (grade promotion or graduation for students), or compensation (salary increases or bonuses) for schools, teachers and students (Lester, 2007). A 'standardised test' is defined as an assessment that requires all test-takers to answer identical questions and in the same manner, to ensure that comparisons between the relative performances of individuals can be made (Roehl, 2015).

The Australian version of a high stakes standardised test is the National Assessment Program – Literacy and Numeracy (NAPLAN), undertaken by students in Grades 3, 5, 7 and 9. Used as a diagnostic tool, accountability strategies associated with NAPLAN are designed to improve academic results and contribute to more equitable educational outcomes. However, a recurring theme in the literature is the increasing impact of high stakes standardised tests on students' anxiety levels (von der Embse & Witmer, 2014). Students today are being shaped into future citizens with the skills and competencies to improve Australia's capacity for economic productivity, yet international research indicates high stakes standardised testing has had little or no effect on improving academic achievement (Rizvi & Lingard, 2009; Thompson & Harbaugh, 2013). In fact, often researchers report that tests such as NAPLAN can negatively impact students' MA levels as mathematically anxious individuals can make careless mistakes when performing mathematical computations because of the pressure experienced under stressful test-taking conditions (Beilock, 2008; von der Embse & Hasson, 2012; Segool, et al., 2013). In summary, an over-reliance on high stakes testing in our competitive world may reinforce MA by turning mathematics into a high-risk task.

In response to this growing body of literature, the Australian Government is taking measures to alleviate the pressures often associated with NAPLAN. This includes placing the test online, a change that could potentially lessen the adverse effects often encountered by students (NSW Government, 2019). Nevertheless, even in a different testing environment,

tests like NAPLAN could still have a tendency to increase MA levels. Moreover, MA and situation-induced pressure is interwoven with societal and educational contexts and is often country-specific, as explored in the following section.

2.2.5 Mathematics Anxiety and High-Stakes Standardised Testing: Societal and Educational Environments around the World

MA relates to both societal and educational environments and often differs by country. Lee's (2009) cross-cultural study of MA across 41 countries reported that students with high MA are found in Australia, Belgium, Canada, Czech Republic, France, Ireland, Japan and Korea. Although experiencing high levels of MA, students from these countries have average or above-average mathematical ability according to standardised testing results (OECD, 2012). A noteworthy fact is that these nations implement high stakes testing methods where there is more pressure on students to perform (Lee, 2009). Conversely, students from some Western European countries, including Liechtenstein, Sweden and Switzerland, have displayed high mathematical ability and low MA over the last two decades (OECD, 2000, 2012). Inquiries into the education systems of Liechtenstein, Sweden and Switzerland highlight that these nations place less value on school achievement in comparison to countries such as the United States, United Kingdom and Australia (OECD, 2012). Additionally, although students from Liechtenstein, Sweden and Switzerland are assessed, externally mandated testing is less frequently implemented and consequences for poor test performances are not enforced (OECD, 2012). Interestingly, Germany's education system embraces standardised tests and yet German students have high mathematics achievement and low MA (OECD, 2012). The German education system adopts standardised tests to measure students' abilities in Grade 3 (approximately 7–8 years old) and Grade 8 (approximately 13–14 years old) (Radtke, 2010). However, the German Government does not publicly broadcast academic results nor encourage sanctions for poor test results, which is in stark contrast to the educational practices of the United States, United Kingdom and Australia (Radtke, 2010). Closely associated with MA are self-efficacy and self-concept, so it is plausible that students from countries such as Germany, Liechtenstein, Switzerland and Sweden are less critical of their academic performance, which can positively influence motivation and confidence towards mathematics, and boost overall academic performance (Lee, 2009; Schmitt, Realo, Voracek, & Allik, 2008).

Clearly, under conditions experienced by students in some countries, standardised testing is beneficial. Test results are used to encourage poor-performing students by increasing funding and support rather than enforcing penalties (Neumann, Fischer, & Kauertz, 2010). Thus, research alludes to the notion that decreasing the effects of high stakes testing encourages students to perform at their best (Ashcraft & Krause, 2007; Lukowski et al., 2016; Neumann et al., 2010). Therefore, whilst it is difficult to generalise effects across countries, research suggests that it may not be the presence of standardised testing alone that induces MA, rather, the environment in which tests are administered that has consequences for students. Another environmental condition that exacerbates MA in students is teacher attitudes towards mathematics, as discussed below.

2.2.6 The Effect of Teacher Attitudes on Students Experiencing Mathematics Anxiety

It is well documented that a teacher's attitude can influence student success. Social cognitive theorists, including Bandura (1974) and Vygotsky (1978), suggest that children express their values and beliefs through the words and behaviours modelled by others. In terms of mathematics, a teacher's attitude encompasses a level of enthusiasm and resourcefulness to learn content knowledge, as well as a willingness to help students who are struggling. By extension, a teacher's personal feelings and attitude towards mathematics influence the messages they relate to their students. Or, as succinctly stated by Brady and Bowd (2005, p.44), "mathematics teachers tend to pass their anxiety on to their students". For example, recent research by Ramirez, Hooper, Kersting, Ferguson, and Yeager (2018) demonstrated that when teachers displayed a closed mentality indicative of MA, the student's ninth-grade GPA decreased. Furthermore, their findings suggest that students' mathematics performance is diminished by teachers who have higher levels of mathematics anxiety and who believe not all students have an ability for mathematics. This 'process-orientated' mindset is reflected in their teaching practices. As previously discussed, MA is correlated to self-concept and self-efficacy and can be transferred in teacher-student interactions (Gunderson et al., 2012). Although anxiety, self-concept, and self-efficacy, according to Pajares and Miller (1994), are distinct constructs, for the purposes of this review, they will be considered as indicators that reflect a teacher's individual attitude towards mathematics and will be discussed accordingly.

Since the early 1970s, teachers' attitudes towards mathematics have been recognised as significantly influencing children's learning practices and outcomes (Aiken, 1970). The literature concludes that there are clear links between negative reactivity and students externalising behavioural problems towards mathematics (Ramirez, Shaw, & Maloney, 2018). According to these authors, several empirical studies have directly explored this relationship see (Beilock, Gunderson, Ramirez, & Levine, 2010; Midgley, Feldlaufer, Eccles, & Calfee, 1989; Polly et al., 2015). The study conducted by Midgley et al. (1989) followed a sample of late elementary and middle school students. Results suggested a positive correlation between teachers' mathematical self-efficacy and student attitudes. Furthermore, these researchers found that teachers who had a higher mathematical teaching self-efficacy not only rated mathematics as less difficult but believed they were achieving more for their students. Consequently, their students predicted that they would perform better on mathematical tasks in the future.

Interestingly, studies in both the US and Canada have found that elementary school teachers tend to have high levels of MA (Brady & Bowd, 2005; Bursal & Paznokas, 2006; Hembree, 1990). As a novice[7] teacher, it is crucial to consider how best to support students to learn mathematical and numerical concepts, however, research has repeatedly demonstrated that pre-service teachers report higher levels of MA compared to other undergraduates (Bursal & Paznokas, 2006; Gresham, 2007; Harper & Daane, 1998; Hembree, 1990; Kelly & Tomhave, 1985). In fact, Hayes (2016) highlights that, of all college majors, pre-service education students have the highest levels of MA. This is of particular concern because novice teachers are often placed in disadvantaged schools which require considerable professional and emotional investment to achieve good student outcomes (Morrison, 2012). This clearly has the potential to influence how students experience MA. For all educators, pedagogical techniques are also contributors to teacher attitudes towards mathematics.

2.2.7 Mathematics Anxiety and Teacher Pedagogy

Researchers have highlighted pedagogical factors that may affect levels of MA; these include instructional techniques and the way educators organise the mathematical content for students to learn (Fennema, Peterson, Carpenter, & Lubinski, 1990; Pajares & Miller, 1994). The

[7] Novice is defined as having less than two years teaching experience.

method by which lessons are planned, content is explored, and skills and processes are presented and developed, motivates students and personifies the teacher's views of learning (Reys et al., 2012). It is well established that students learn best when they are engaged and motivated to learn (Deci & Ryan, 2010; Niemiec & Ryan, 2009). Pedagogy that limits students by external control can foster disengagement and resentment, limit self-determination and prevent students from taking control of their learning, which in turn increases the propensity for MA (Niemiec & Ryan, 2009). However, often the reality is that mathematically anxious educators are characterised by an over-reliance on traditional instructional techniques, including direct lecturing or whole-class instruction and assigning identical work for all students rather than differentiating the curriculum to accommodate a variety of learning styles (Gurganus, 2017). The author reports that mathematically anxious teachers overuse repetitive drills, flashcards and worksheets as opposed to open-ended tasks that foster problem-solving skills. Additionally, Gurganus (2017) notes that mathematically anxious teachers often display a lack of flexibility by teaching to the textbook problem by problem; they also restrict student autonomy by insisting on only one correct way to complete a problem and concentrate heavily on basic skills rather than concepts. More alarmingly, Furner and Berman (2005) and Tobias (1998) note that assigning mathematical problems as a punishment for bad behaviour fosters a negative attitude towards mathematics, rather than encouraging a positive disposition. Gresham (2007) bemoaned that these 'traditional' ways of teaching can be the direct cause of MA in students.

Clearly, 'drill' type pedagogy is required to develop mathematical speed and accuracy so that skills become progressively automatic. Equally clearly, children need to develop an understanding of mathematical concepts by relating knowledge to experiences both within and outside of the school environment (Reys et al., 2012). More importantly, teachers must creatively guide students to think, question, solve problems and discuss their understanding to develop a more complex comprehension of mathematics (Wood, 1988). The skills learnt throughout this process will minimise the risk of MA and support students to problem-solve during test-taking situations. This presents a paradox: children require some traditional teaching to learn mathematics, however, if this is the only teaching that is fostered, then children become disengaged. For those who bring MA into the classroom, it is crucial that their own fears and lack of confidence are challenged and controlled (Martinez, 1987).

2.2.8 The Proactive Educator – The Role of Teachers in Mitigating Mathematics Anxiety

Research conducted by Whyte and Anthony (2012) indicates that implementing effective mathematical learning practices is challenging, however, some practical implications drawn from their research can help mediate the complex role for teachers in understanding the antecedents of MA. Pedagogical strategies used by teachers to reduce MA (particularly with younger students) include using a hands-on approach to understanding mathematics which involves concrete, pictorial manipulatives[8] to act out, draw or model the concept before moving to the symbolic, abstract representation (Blazer, 2011). Another pedagogical strategy involves the use of technology, including computer-based assignments, which reduces MA by enabling students to receive instant feedback and to work at their own pace (Blazer, 2011). The internet allows students to access cooperative learning platforms where they can discuss mathematical problem-solving with peers in a stress-free environment (Hellum-Alexander, 2010; Sun & Pyzdrowski, 2009).

A commonality found amongst programs reporting a reduction in MA is that such programs involve allowing children to construct their own knowledge (Reys et al., 2012). This student-centred, 'functional' approach to learning encourages children to problem-solve and equips them to meet their needs as future citizens (Reys et al., 2012). Other efforts to minimise MA include cultivating a learning environment that encourages students to take risks and explore ideas in collaboration with peers and having time for reflection so that teachers are informed of any misunderstandings (Haylock, 2007). Furthermore, Bursal and Paznokas (2006) and Gresham (2007) highlight that the most successful programs are those featuring teachers who use instructional pedagogy[9] to change the way students perceive and apply mathematics to the real world. Overriding any pedagogical practices in the classroom, however, is a teacher's attitude and teaching quality.

[8]A manipulative is an object which is designed so that a learner can perceive some mathematical concept by manipulating it (e.g. blocks to teach counting).

[9] Instructional pedagogy refers to practices that encourage student learning such a problem-based learning.

2.2.9 Teacher Quality in Mathematics

With the advent of national standards in education in many Western countries, teachers are being encouraged to integrate a range of teaching and learning practices that support students' learning. A meta-anaylsis conducted by Gonzalez and Kenzi (2012) highlights that research conducted over the past 20 years consistently demonstrates that when teachers have a specialist mathematics qualification student comprehension is increased. However, the researchers demonstrate that many teachers lack this credential (Gonzalez & Kuenzi, 2012). Research emphasises that nearly all high school teachers have at least a bachelor's degree, however, mathematics teachers are less likely than teachers of other subject areas to have majored in the subject they teach (J. Hill, 2011). As a further example, in the 2007–08 school year around 17% of all high school educators in the United States did not major in the subject they taught, compared to 28% of mathematics teachers who did not major in mathematics (J. Hill, 2011). According to Reys et al. (2012), a thorough understanding of how mathematics is best taught and learnt should be a high priority for educators. Furthermore, these authors advocate that teachers continue to seek mathematical knowledge and experience by undertaking ongoing professional development. Without specialised training, it is possible some educators may lack the confidence to teach mathematics, particularly elementary school teachers who are general-subject trained (Reys et al., 2012). In order to overcome their MA, educators should consult curriculum guidelines, however the lack of policy regarding MA within the Australian Curriculum is apparent.

2.2.10 Mathematics Anxiety and the Australian Curriculum

A common thread in studies of MA is to target both teachers and students when attempting to alleviate MA (Betz, 1978; Ramirez, Gunderson, Levine, & Beilock, 2013; Vance & Watson, 1994). However, by focusing on the nature of mathematics knowledge for teaching purposes (Hart & Swars, 2009) or on a teacher's preparation to teach (Adeyemi et al., 2015), past research does not consider how the mathematical aims and the rationale of the Australian Curriculum are hindered by MA more specifically. At a national level, policy only directs attention to monitoring student achievement and progress levels, lifting student achievement through definition of the Australian Curriculum Standards, and developing teachers' pedagogical content knowledge without explicitly addressing MA (Australian Curriculum Assessment and Reporting Authority (ACARA), 2016). One of the aims stated in *The Australian Mathematics Curriculum* is for students to "recognise connections

between the areas of mathematics and other disciplines and appreciate mathematics as an accessible and enjoyable discipline to study" (Australian Curriculum Assessment and Reporting Authority (ACARA), 2014, p.1). Students who experience MA cannot achieve this goal due to the lack of policy attention to MA, and thus the opportunity to recognise and enjoy mathematics in everyday life and in other subjects they are studying can be compromised (Beilock & Maloney, 2015; Blazer, 2011). Even more salient than this gap between policy and reality is that any relationship that may exist between teacher's anxiety and the aims of the Australian Curriculum to bolster interest and enjoyment in mathematics may be present from the start of a child's schooling

2.2.11 Exposure of Young Children to Mathematics Anxiety

Whilst a considerable body of research has documented associations between MA and mathematical outcomes, to date there is limited research or policy direction regarding the social and affective outcomes of assisting children to learn mathematics in elementary school. This gap exists despite some evidence that even students who have a high working memory can experience MA from as early as first or second grade (Gunderson, Park, Maloney, Beilock, & Levine, 2018; Vukovic et al., 2013). One of the first studies to examine the anxiety-attitude link in early elementary school highlighted that early identification and treatment of MA is vital because within the first two years of schooling, mathematical attitudes and achievement are already linked and feed off each other (Gunderson et al., 2018). Additionally, the same authors' study of females teaching to first and second grade highlights how MA can impact young children (Gunderson et al., 2018). More importantly, Maloney et al. (2010) demonstrated that a deficit in the basic mathematical ability of counting[10] can have a detrimental effect throughout schooling and even impact employment opportunities. Specifically, these authors predicted that deficits appearing in higher-level mathematics may be the result of a lower level numerical processing deficiency. It follows that if a mathematically anxious individual's working memory is challenged in the basic component of single-digit arithmetic, other deficits in numerical tasks such as subtraction and multiplication will also emerge. In addition, Beilock and Maloney (2015) suggest that this deficit in basic numeracy can have widespread repercussions for everyday life. Mundane

[10] Counting is defined as the process of learning how to move from one digit to the next (i.e., 1,2,3 etc.).

tasks such as deciding if you have received the right amount of change at the supermarket or calculating a tip when dining out can cause anxiety. Impaired numerical ability can also lead to incorrect drug calculations by nurses and poor financial planning. These findings highlight the importance of early intervention in MA as well as how MA is prevalent at an earlier age than is often hypothesised.

‘Other research about MA in young students was conducted by Wu, Amin, Barth, Malcarne, and Menon (2012). These authors investigated MA using a Scale for Early Mathematics Anxiety (SEMA) to rate children in Grades 2 and 3. Their results indicated that SEMA scores were strongly linked with mathematical reasoning scores (assessing complex verbal problem-solving tasks). These authors also reported this MA/mathematics achievement link was unrelated to trait anxiety. This was the first study that highlighted that the specific effects of MA could be detected in the earliest stages of formal schooling. Although mathematical reasoning is a variant of a mathematical task, both variables yield a similar pattern of results based on the foundational skill of counting. Students who have not mastered this skill of counting will experience challenges with more complex mathematics (Beilock & Maloney, 2015). In addition, research by Punaro and Reeve (2012) postulated that high MA in nine-year-old children is related to mathematics worry ratings and self-rated problem-solving judgments. Analysis of these results revealed that a high MA subgroup showed poorer mathematics performance than low-worry (low MA) subgroups. This suggests that if these children had difficulties with the foundational skills of mathematics in the early school years, then their worry level would increase as the mathematical tasks increase in complexity. The argument is that complex mathematics evolves from the basic building blocks of numbers, and consequently, a causal cycle can develop. This research underscores the need for future studies to focus on MA because in the subsequent analysis of literacy worry subgroups and literacy achievement, the authors found no similar relationship (Punaro & Reeve, 2012).

In summary, the small number of authors who have studied younger children (under 12 years old) have explicitly addressed how counting can influence MA, emotional self-efficacy in managing the effects of MA and how working memory is impaired by MA. Relatively few studies have explored the use of interventions to alleviate MA, a notable example being the study conducted by Beilock and Maloney (2015). These authors suggest the use of focused breathing exercises to minimise the physiological stimulation that arises

from MA. Further interventions based on psychological research suggest that expressive writing can help mathematically anxious individuals to reappraise a potentially negative situation (e.g., a mathematics test). Beilock and Maloney (2015) note that the use of psychological interventions, such as a simple writing exercise, will not undo years of damage caused by MA. The apparent gaps in the literature provide a clear indication that studies of children who are most vulnerable to early exposure to MA are required. Additionally, further theoretical and methodological refinement is needed to account for the associations between sex differences and MA. Previous research exploring these associations is presented in the next section.

2.3 The Effect of Sex Differences and Stereotypes on Mathematical Education

In the sections following, several strands of literature related to this overall topic are discussed, including evidence about the prevalence of sex differences and stereotypes in both MA and mathematics achievement. As previously mentioned, whilst this thesis uses the language of 'sex differences' thus implying the biology of being a male or a female, it must be noted that this cannot happen in isolation of a society that is gendered. Within an environment where there is evidence of sex stereotypes, differences in female confidence in mathematics may not be a function of 'sex' alone (i.e. biology) but also the result of societal culture. For consistency, this review will adopt the terminology 'sex differences' however, this will encompass both biology and gendered culture.

2.3.1 Sex Differences and Mathematics Anxiety

Despite most children beginning school with an informal mathematics competence, it is evident that MA can develop in the classroom; this is not only a function of a negative attitude towards mathematics but also sex. Considerable consistency and specificity have been revealed in the connections between mathematical functioning and sex. Among research on the constructs of sex, MA and mathematics achievement, studies by Baloglu and Koçak (2006), Chinn (2009), Else-Quest, Hyde, and Linn (2010) and Krinzinger et al. (2009) highlight significantly greater levels of MA in females than in males. The review explores various possible explanations for sex differences in mathematics. It then summarises how a

student's sex can influence not only their achievement in mathematics but also their experiences with MA.

2.3.2 Biological and Cognitive Reasons for Sex Differences in Mathematics

Several researchers propose that sex differences in mathematics are due to biological or cognitive differences between males and females. For example, Z. Wang et al. (2014) suggest that 40% of mathematics ability is genetically based or, as proposed by Halpern et al. (2007), sex differences in mathematics are influenced by a multitude of factors including biological differences in brain development. Halpern et al. (2007) also note that individuals are born with an innate ability to learn mathematics, and how that skill is developed can be impacted by hormones organised in the brain during the prenatal stages of birth. Wang et all. (2014) notes that MA can be co-morbid with other anxiety disorders which often have a biological basis. Their research suggests that correlations between MA and general anxiety were moderate. Other researchers, including Ashcraft, Krause and Hopko (2007) and Hembree (1990) also found a moderate relationship between MA and general anxiety. Therefore, literature that proposes biological reasoning for sex differences in mathematics often groups MA with general or trait anxiety. As previously mentioned, research demonstrates that MA and general or trait anxiety are separate constructs and should be considered individually (Dreger and Aiken, 1957; Dew & Galassi, 1983; Suárez-Pellicioni, Núñez-Peña, and Colomé 2016). This highlights methodological issues with literature that proposes biological reasons for sex differences in mathematics. A more robust field of literature highlights the role of socialisation and culture in perpetuating sex differences in mathematics.

2.3.3 The Impact of Socialisation and Culture on Perpetuating Sex Differences in Mathematics

Sex differences in mathematics are often the result of negative mathematical attitudes held by females (Stoet & Geary, 2018). Many models emphasise the potential influence of competency beliefs (including poor mathematics self-efficacy and self-concept) and MA (Ahmed, Minnaert, Kuyper, & van der Werf, 2012; Bander & Betz, 1981; Frenzel, Pekrun, & Goetz, 2007; Götz, Cronjäger, Frenzel, Lüdtke, & Hall, 2010; Griggs, Rimm-Kaufman, Merritt, & Patton, 2013; F. Hill et al., 2016; Hoffman, 2010; Jain & Dowson, 2009). However, these more personal attributes are in turn related to environmental factors such as

school, peers, family and neighbourhood and can influence an individual's innate potential for mathematics proficiency (Halpern et al., 2007).

In a longitudinal study involving 7040 students from third to eighth grade, Ganley and Lubienski (2016) reported that MA and mathematical performance develop from the socialisation factors of both confidence and interest. The authors reported that sex differences in mathematical confidence are much larger than differences in the mathematical interest or achievement of elementary school children, however, the three concepts are mutually intertwined. The small gap in the achievement of third-grade students suggests that females' self-reported lack of confidence in their mathematical ability may be unwarranted at that age. By eighth grade, sex differences in confidence had declined to approximately the same magnitude as the gap in performance and interest. These authors suggest that the strongest predictor for 'later' confidence (and 'later' mathematical performance), is 'prior' confidence. Ganley and Lubienski (2016) also note that current performance and interest predict students' 'later' interest, particularly for girls. Their research highlights that intervention measures (especially for girls) should begin early and be ongoing to have a positive and lasting effect on confidence, attitude, interest, achievement and career decisions.

Meta-analytic studies also suggest that males, more than females, are encouraged to participate in mathematics and that the cumulative effects of this differential socialisation may be most evident in difficult mathematical material (Hyde, Fennema, & Lamon, 1990). Similarly, although Hyde, et al., (2008) reported that sex differences in mathematics achievement were generally trivial – males scoring higher than females but with a negligible effect size (d = –0.05) – the researchers also noted differences existed for more advanced course work undertaken in high school years (small effect size; d = +0.29, males scoring higher). This difference may account for the diminished number of females pursuing mathematics at higher levels. By contrast, other researchers (e.g., Birgin, Baloğlu, Çatlıoğlu, & Gürbüz, 2010; Chinn, 2009) highlighted that average sex differences were statistically not significant, and that any differences tend to decline over time. Additionally, Abiam and Odok (2006), in their study of Nigerian high schools, found no significant relationship between sex and achievement in number, algebraic processes and statistics. MA research has increasingly recognised the role of parents in the socialisation of their children, specifically through parents exposing children to negative attitudes towards mathematics and therefore, MA (Gunderson et al., 2012).

2.3.4 The Role of Parents in Perpetuating Sex-Role Socialisation in Mathematics

The family context is highly relevant to social development in young children, as described in theories such as Bandura's social learning theory (1974) or Piaget's theory of cognitive development (1936). Despite this, empirical data on MA-by-parenting interactions is not widely reported. Research from Maloney et al. (2010), cited in Beilock and Maloney (2015), reported that, across the school year, children of higher mathematically anxious parents experienced an increase in disposition towards MA and also learnt less mathematics. This was particularly noted when mathematically anxious parents helped their children with homework. During these parent-child interactions, negative attitudes and emotions (e.g., dislike of mathematics, frustration and confusion about the mathematics content) is unintentionally transferred to the child. Similarly, Berkowitz et al., (2015) highlighted that children of highly mathematically anxious parents learn less mathematics than students who do not have high mathematically anxious parents during first grade. Schaeffer, Rozek, Berkowitz, Levine, & Beilock (2018) tested a similar pathway between high parental MA and child mathematics achievement and also found that children who have highly mathematically anxious parents have lower mathematics achievement from first through to third grade. However, these authors also note that this relationship between parent MA and child mathematics achievement is ameliorated if the family is provided with a first-grade mathematics app. The app served to increase parents' positive attitudes towards mathematics by altering parents' expectations for their children's potential success in the subject. The authors therefore demonstrate the importance of parental attitudes on children outcomes in mathematics.

A study conducted by Whyte and Anthony (2012) suggests parental MA can have a demoralising effect on children, who in turn may invest less effort in learning mathematics. When parents give a low status to mathematics or convey their disappointment and despair, they are providing an excuse for their child to stop trying when they are mathematically challenged. Moreover, children who start school with difficulties with the basic concepts of mathematics may be predisposed to adopt negative stereotypes and social cues from their parents. Responses from parents such as 'Don't worry, mathematics was always hard for me at school too' or 'Never mind, you don't need to worry about mathematics because you're a girl', may plant a seed that grows into a strong belief that they lack the ability to do well in

mathematics. Hence, difficulties with mathematics, together with exposure to negative social cues, may engender MA (Beilock & Maloney, 2015; Whyte & Anthony, 2012).

2.3.5 The Role of Sex Theories in Explaining Sex Differences in Mathematics

In 1993 Baker and Jones proposed a 'sex stratification' theory which explains how sex differences in mathematics are embedded in socio-cultural factors. This research theorises that male students connect mathematics to careers and future outcomes. In contrast, in patriarchal cultures, females are not afforded the same opportunities and may face structural impediments (e.g., access to formal education) as well as social barriers (e.g., culturally embedded stereotypes that mathematics is a male-dominated field). Furthermore, if the societal roles that females fulfil do not include mathematics, then they are less likely to perceive the link to future opportunities and career outcomes. In turn, females are less likely to achieve in domains (including mathematical fields) that are culturally depicted as less likely to be beneficial (Beilock & Maloney, 2015). Several studies have investigated and supported the sex stratification theory including Eccles (1994), Jacobs et al. (2005) and Meece, Parsons, Kaczala, & Goff (1982), as highlighted in the meta-analysis conducted by Else-Quest et al. (2010). In their meta-analysis, these authors used an 'expectancy-value' model to explain the associations between sex, mathematics, achievement, attitudes and affect. According to this model, an individual will not engage in an activity unless they foresee a measure of value or success from that activity. The perceived merit of the task (such as undertaking mathematics) is embedded in the society and culture which they inhabit. For instance, if a person has the long-term goal of training as an early childhood teacher, they will apply a 'cost-benefit' analysis and deem that advanced mathematics is not required. Likewise, they would understand that mathematics is needed for some careers, such as engineering. To expand on this notion, the researchers suggest that if the value a female places on mathematics is low, or if they notice fewer females undertaking mathematics at school, and/or they do not have a positive role model, they are less likely to continue with mathematics.

To reiterate, these sex differences in MA may be engendered when females believe that they have less aptitude for mathematics than males which is supported by Bandura's social learning theory (Bandura & Walters, 1977). Underpinning this theory are the concepts of modelling, reinforcement and self-efficacy. If females do not believe in their innate ability

to achieve mathematical goals, or if parents, teachers, and peers do not expose them to more complex mathematics, negative attitudes and self-beliefs, together with anxiety towards mathematics, can prevail. Research also points directly to the crucial significance of role models in female lives (Bandura, 1977). However, while many models of differential socialisation and mathematics achievement are amenable to implicit stereotyping, Marsh and Yeung (1998) conclude that there was little influence of such myths on student self-concepts towards mathematics when they examined students in eighth through tenth grade. Cvencek, Kapur, and Meltzoff (2015) argue that socialisation occurs earlier and suggest that as early as second-grade boys hold stronger explicit and implicit mathematics self-beliefs than girls. Other, more recent, data suggests that there are large differences in self-confidence between boys and girls (Schmuck, 2017).

A recent meta-analysis by the authors Niepel, Stadler and Grieff (2019) concludes that stereotypes figure strongly in many theories of mathematical achievement. The authors' analysis of 120,270 students from 23 countries is consistent with the social structural theory. With a focus on the psychological factors responsible for sex differences in attitudes and attainment in mathematics, results suggest that sex similarities in mathematics will be evident when there is greater sex equity in society. However, a direct contradiction to the findings from Niepel et al. (2019) is research by Stoet, Bailey, Moore & Geary (2016). Stoet et al., (2016) investigated 761,655 15-year-old students across 68 nations and their findings dispute the gender stratification model. These authors demonstrate that countries that are more economically developed and more gender equal have a lower overall level of mathematics anxiety, and yet a larger national sex difference in mathematics anxiety relative to less developed countries. Therefore, research must look beyond current sex theories and in order to best alleviate issues with the sex gap in mathematics, a targeted approach focused on the educator or role model level is recommended.

In discussing levels of societal stereotyping and MA, three influential sets of studies on how mathematics sex stereotypes can impair females' mathematics learning and performance were conducted by Appel, Kronberger, and Aronson (2011), Spencer, Steele, and Quinn (1999) and Beilock et al. (2010). Evidence suggests that connections between females' test preparation and ability to evaluate the notes of others are impaired by MA (Appel et al., 2011). Written tests or activities carried out within a competitive environment are often the cause of students' MA (Spencer, Steele, & Quinn, 1999). When the test is

difficult, any problems working out the answer, pose the stereotype as a possible explanation for an individual's performance. Students are at risk of feeling embarrassed and judged by the negative stereotype that females are less able at mathematics than males (Spencer et al., 1999). The direct contribution of social factors, including 'stereotype-based' mathematical myths (e.g., boys are better at mathematics than girls) was investigated by Beilock et al. (2010) in their study of female teachers. Female teachers' MA and negative female student mathematics achievement significantly related to negative self-efficacy beliefs which overlaid females with increased levels of MA. Since elementary school teachers are predominantly female, and sex has been demonstrated to be a highly influential factor for children in elementary school, it is very probable that girls, rather than boys, will perceive their teacher's negative emotions towards mathematics. This, in turn, can negatively impact female mathematics achievement (Beilock et al., 2010). Even when controlling for female students' mathematics achievement at the beginning of the year, female students who held stereotypical beliefs (boys are good at maths, girls are good at reding) had diminished mathematics results by the end of the school year if their teacher was female and also highly mathematically anxious, (Beilock et al., 2010). Notably, this relationship was mediated by the female students' internalisation of 'traditional'[11] sex stereotypes, suggesting that sex differences are an environmental antecedent in MA. Furthermore, by year-end, those females who endorsed traditional mathematics-sex stereotypes showed a deficit in performance on a standardised mathematics test relative to peers who did not adopt these stereotyped beliefs (Beilock et al., 2010). These findings reaffirm that the problems associated with MA exist at some level independent of age or biological effects.

2.3.6 Sex Differences in Younger School-Age Children

Literature supports the importance of positive experiences with mathematics in early education as vital to providing the foundation, motivation and willingness to successfully study mathematics at higher levels of education (Expert Group on Future Skills Needs (EGSFN), 2007; Hourigan & O'Donoghue, 2013; National Council for Curriculum Assessment (NCCA), 2006). Researchers also report that the quality of teaching mathematics is crucial to improving student proficiency (Expert Group on Future Skills Needs (EGSFN),

[11] Traditional is defined here as boys are better at mathematics than girls.

2007). Nonetheless, whilst an extensive body of literature addresses sex differences, MA and mathematical performance, the links between these constructs for younger students (typically ages 5–13) are unclear as relatively few studies address this population (F. Hill et al., 2016). Of those studies that have investigated elementary school-age students (Gierl & Bisanz, 1995; Punaro & Reeve, 2012; Vukovic et al., 2013) very few report sex-related MA differences. Some studies have found modest associations between early reactivity to MA, with elementary school-age girls reporting higher levels of MA than boys (e.g., Griggs et al., 2013; Ramirez et al., 2013; Yüksel-Şahin, 2008). Fryer and Levitt (2010) observed the mathematics achievement of over 20,000 school students. Their results highlight that female and male students do not differ on mathematics achievement scores upon entry into school but by Grade 6 females have lower maths test grades than males, with a small effect size (d = 0.24). Similar results were obtained by Penner and Paret (2008), however, these researchers found sex differences in mathematics performance in children as early as kindergarten. Typically, these sex discrepancies were greater in the upper tail of the distribution set, with the highest test results typically coming only from male students (Penner & Paret, 2008; Robinson & Lubienski, 2011). Additionally, Satake and Amato (1995) demonstrated that fifth and sixth-grade girls reported higher levels of 'mathematics test anxiety' than their male peers.

When examining variations across age in sex differences, meta-analytical results by Lindberg, Hyde, Petersen, and Linn (2010) reported no overall sex differences in mathematics proficiency. Their data suggests a small effect size (d = 0.23) for students in secondary school and a medium effect size (d = 0.40) for high-performing individuals. Given that the social and academic context of mathematical proficiency increases in secondary school and among college-age students, studies tend to focus on these sample groups. There is further evidence of this sex differences and mathematics proficiency in older, secondary school-age children with meta-analytic studies indicating a male advantage in mathematics for this age group (Hedges & Nowell, 1995; Hyde et al., 1990). Research conducted by Hyde et al. (1990) and Hedges and Nowell (1995) provides further insight into how MA fits into the complex interplay of factors that drive mathematical development. Nevertheless, studies that examine sex differences in mathematics achievement vary across country suggesting a limitation of research in this area (Else-Quest et al., 2010).

Some researchers, such as Devine et al. (2012), claim that the sex gap is disappearing. These researchers found no sex differences in arithmetic performance, despite girls reporting higher MA than boys. This may actually indicate that females have greater potential for mathematics than males (Hyde et al., 2008; Hyde & Mertz, 2009; Lindberg et al., 2010). Generally, the research on younger age groups lacks consistency, with research suggesting that MA develops later (Hyde et al., 1990). Therefore, caution should be used when interpreting sex differences in children and adolescents (Beilock et al., 2010). Nonetheless, sex differences in mathematics, particularly MA in elementary school-age children is an under-explored area and therefore a more systematic investigation of sex-specific pathways to positive mathematical outcomes is warranted.

2.3.7 Limitations of Sex Differences and Stereotyping Research

The research reviewed thus far in this, and the previous section has generally examined how pathways to MA differ for males and females. Whilst research has established males have greater confidence and self-identification with mathematics, more positive mathematics self-perceptions and stronger ratings of the value of mathematics, the possible impact of methodological issues on these findings cannot be discounted (Griggs et al., 2013; Ramirez et al., 2013; Yüksel-Şahin, 2008). Methodological variables such as participants being explicitly told that a test had shown sex differences in the past might exacerbate females' experience of MA (Spencer et al., 1999). This characterisation could evoke MA and reinforce the stereotype about females' mathematic ability (Spencer et al., 1999).

Additionally, data collected on sex differences typically utilises self-report measures which are likely to be biased by personal-competence beliefs, and it is also more probable that females will report their anxieties (Beilock et al., 2010). However, even if the sex differences are due to subjective reporting bias, the subjective perception of higher MA may not be extraneous. Indeed, research indicates that females experiencing higher subjective levels of MA are less likely to pursue careers requiring quantitative skills (Cheryan & Plaut, 2010; C. Hill, Corbett, & Rose, 2010; Simpkins, Davis-Kean, & Eccles, 2006). Hence, although subjective biases may partly underpin females' higher MA, these interpretations can have significant enduring effects on behaviour, including a tendency for females to avoid continuing with mathematics or pursuing mathematically based careers (Beilock et al., 2010).

Furthermore, there are limitations with the language used to describe differences between males and females. Terminology such as 'sex' and 'gender' are used to explain these differences, however, they are not identical constructs as sex refers to biological differences and gender is a construct embedded in society and culture. Often previous research does not distinguish between the two characterisations, thus highlighting a limitation. However, when conducting this review, 'sex differences' were defined as encompassing, both the interaction between biology and culture, thus overcoming the weakness in previous research.

In summary, although the body of research depicts at times contradictory and complex findings, taken together most research indicates a small sex difference in MA and mathematics test performance that favours males. This has the potential to increase as children develop and, because of this risk, it is important to explore further factors related to the development of this gap.

2.3.8 The Theory of Stereotype Threat in the Context of Mathematics Education

In grappling with contradictory data, the phenomenon 'Stereotype Threat' can be used to explain sex discrepancies and negative experiences with mathematics. Stereotype Threat (ST) can be defined as a concern or worry that an individual's performance or actions will be perceived through the lens of a negative stereotype (J. Shapiro & Neuberg, 2007). ST produces anxiety that influences and undermines performance in negatively stereotyped domains (Beilock et al., 2010; Beilock, Rydell, et al., 2007; Schmader et al., 2008). In the context of mathematics, the term Stereotype Threat refers to the wrongful perpetuation of the myth that males are innately better than females at mathematics (J. Shapiro & Williams, 2012).

A model proposed by Good, Aronson, and Harder (2008) suggests that four cognitive and socio-cognitive abilities must be present in order for ST to impact female mathematical outcomes. Specifically, females must: (a) have an awareness of sex stereotypes; (b) comprehend the personal and societal implications of these stereotypes; (c) have an adequately formed sex identity; and (d) have a well-developed understanding of academic ability. The researchers predicted that these conditions are typically met at around 11–12 years of age, however, many of these factors are likely to emerge at a younger age and become more stable throughout a child's development. The researchers propose that evaluative mathematical tests are perceived by females to mean poor performance indicates

low ability. This perception, combined with an individual's sex being made salient (i.e., by mentioning sex differences or by undertaking the test in a mixed-sex environment), increases the probability of the negative stereotype about females and mathematics being observed. Aspects of this increased risk are associated with working memory. More challenging tests contain problems that require greater processing in working memory, which is compromised when under additional strain from ST. In these circumstances, the fear of confirming the stereotype is made more plausible (Good et al., 2008). Whilst considerable research has posited a unidirectional view that the phenomenon of ST has direct linear effects for females on mathematical functioning, most research to date has focused on college-age women (Good et al., 2008). Indeed, Good and Aronson (2008) suggest that there is little understanding of how ST manifests in childhood and adolescence. Understanding at what age children are susceptible to ST can help identify the opportune time to administer interventions to alleviate its effects. The literature regarding ST will be further explored in Chapter 3 (Study One) as it is crucial to that investigation.

2.3.9 The Impact of Sex Differences in Mathematics on Engagement with STEM

Mathematics is an important filter in terms of preparation for STEM careers, and data highlights an under-representation of women in advanced mathematics courses at school and university and STEM careers (Australian Academy of Science, 2019). Parallel to the substantial body of evidence that explicit and implicit stereotypes about mathematics are related to mathematical achievement, Schmader et al. (2008) proposed that sex discrepancy in STEM more broadly can be attributed to the impact of Stereotype Threat (ST). ST can perpetuate negative attitudes towards STEM subjects, leading to high levels of MA, mathematics avoidance and lower levels of STEM course-taking (Cheryan & Plaut, 2010; Hill, Corbett, & St Rose, 2010; Simpkins et al., 2006). As an illustration, in Australian secondary schools, males are twice as likely to study advanced mathematics and five times more likely to study physics than female students (Justman & Méndez, 2016). This can have a ripple effect across society and the economy. As a further example, in Scotland, a significant portion of females graduate in STEM subjects but fail to move into a STEM career. One reason for this, as highlighted by Burnell (2012) is that ST biases in the workforce impede females' ability to gain employment following graduation. In monetary terms, this represents a £170 million per annum loss to Scotland's national income (Burnell, 2012).

Building on the work of past researchers, Nosek and Smyth (2011) examined implicit negative attitudes and mathematics stereotypes as predictors of STEM engagement. Their study investigated over 5,000 participants (average age = 27 years, 65 % female) and emphasise that implicit attitudes and stereotypes may operate "under the surface" (p. 1147). These authors demonstrate that although women may not endorse explicit stereotypes (e.g., mathematics-is-male), this does not exclude their self-ascribed ability, self-efficacy, anxiety and behaviour from being impacted by the stereotype. They propose that because the stereotype is "learned and encoded in memory" (p. 1147), there is the added risk that the implicit cognitions will shape female motivation and involvement in STEM. Furthermore, the authors acknowledge that whilst explicit stereotyping has become progressively discouraged, implicit stereotyping in moulding conscious decisions about mathematics and STEM engagement may be increasing (Nosek & Smyth, 2011). Their investigation suggests new avenues for theoretical and empirical studies in ameliorating sex differences in STEM participation.

2.3.10 Current Initiatives to Bolster Female Participation in STEM

Worldwide, females account for only 30 percent of people in STEM fields (UNESCO, 2015). Promoting and improving sex equality by empowering women is the fifth priority identified in the United Nations (UN) 'Sustainable Development Goals' (United Nations, 2019). The UN's vision to fight poverty recognises women are disadvantaged because of their unequal access to paid work and lower wages. Australian policy makers are also attempting to address this inequity with initiatives such as the Australian Academy of Science 2019 '*Women in STEM Decadal Plan'*. This collaboration between the Australian Academy of Science and the Australian Academy of Technology and Engineering offers guidance and opportunities for government, education, industry and the wider community to "attract, retain and progress girls and women in STEM" (Australian Academy of Science, 2019, p. 5). These organisations envisage that a "cohesive and collective'" approach will diminish the sex disparity across all STEM fields (p. 4).

In further attempts to elevate the number of females working in STEM roles, the Australian Government has launched a series of initiatives including scholarships, mentoring programs and internships. For example, the Digital Transformation Agency's Women in IT Executive Mentoring Program (WITEM) aims to attract and retain women in digital roles

across the Australian Public Service. Other STEM sex equity programs include the 'Women in STEM and Entrepreneurship' (WISE) grants scheme which provides opportunities to boost the participation of females in STEM education and careers and in senior entrepreneurial roles (Department of Industry Innovation and Science, 2019). Although increasing motivation for women to participate in these schemes is important, many elements of these initiatives focus on inspiring females who already enjoy STEM subjects. It is unlikely that females who have already developed a strong sense of MA will be attracted to such programs. In addition to these sex equity initiatives, the Australian Government would be well suited to endorse similar programs that serve to encourage mathematically anxious females to become inspired to pursue STEM course-taking and careers.

Moreover, as the Australian Government progresses with its initiative to maximise students' capabilities for success in the modern era, it has noted the importance of teacher training concerning student STEM outcomes. Reports such as '*Optimising STEM Industry-School Partnership: Inspiring Australia's Next Generation'* and *'Australia 2030: Prosperity Through Innovation – A Plan for Australia to Thrive in the Global Innovation Race'* identify the need to provide teachers with access to high-quality professional learning (Education Council, 2018). Recommendations made by the Australian Education Minister include provision for elementary school teaching graduates to have a specialisation by 2019, with a focus on STEM disciplines. Alternative efforts to reduce the STEM sex disparity could include collaboration between educators, industry experts and professionals, whilst building professional learning communities (Education Council, 2018).

The Australian Government has recently pursued the improvement of the quality of initial teacher education through the 'Action Now: Classroom Ready Teachers' initiative (Department For Education, 2014). This mandates that beginning[12] teachers must comply with a set of Professional Teaching Standards and be assessed as being 'classroom-ready' by a national assessment framework before gaining provisional registration to teach in Australian schools. This legislation may serve to inoculate children against negative attitudes towards mathematics developing in the first place.

[12] Beginning teachers are defined as teachers who report having five or fewer years of teaching experience.

Additionally, the Australian Government has followed the OECD recommendations to optimise learning by informing teacher practice and implementing educational reforms (OECD Publishing, 2010). Evidence-based research has shown that traditional educational approaches are no longer suitable, and that students can benefit from a mix of teacher-directed instruction and inquiry-based learning (Reys et al., 2012). It is envisaged that such teaching practices will foster 21st century skills, including creative thinking and problem-solving. Group work is also advocated, where children brainstorm ideas with peers and learn from each other. These activities may enable mathematically anxious children to control their anxiety better and reappraise the demands of a mathematics task as a challenge rather than a threat (Beilock & Maloney, 2015). Threaded through the Australian Curriculum, the 'General Capabilities' strand mandates that educators incorporate competencies such as Literacy, Numeracy, Information and Communication Technology, Critical and Creative Thinking and Personal and Social Capability across the Curriculum (Australian Curriculum Assessment and Reporting Authority (ACARA), 2014). Regarding mathematics participation, research indicates that both the framing and delivering of mathematics content can have a marked effect on children's MA (Whyte & Anthony, 2012). As such, the use of suitable children's literature (including digital books and YouTube videos) can motivate children and bring mathematics to life by explaining concepts visually (Whyte & Anthony, 2012). This then helps in shaping students to develop positive attitudes towards STEM. At a state level, the New South Wales (NSW) Government recognises the need to prepare for the future and has committed to adding one million jobs in NSW by 2036 (Jobs for NSW, 2016). Strategies to meet this target include supporting the integration of digital skills in schools and attracting people to NSW by removing the barriers of age and childbirth to help females enter back into paid work. Although many of these strategies and initiatives may be highly effective, there is always more that can be done. Leveraging the research on MA and incorporating rich discourse about the role of negative attitudes and stereotyping in creating a barrier for entry into STEM domains will enhance any programs or policy directed at creating a stronger, more equitable STEM workforce.

2.4 The Role of Creativity-Based Approaches in Mathematics Education

2.4.1 Mitigating the Effect of Negative Mathematical Attitudes through Creativity-Based Interventions

Literature in the previous sections has exposed the detrimental impact that MA and ST can have on teacher and student experiences with mathematics. Worldwide, many efforts are in place to improve the teaching and learning of mathematics. Although currently there are no proven interventions to prevent the onset of MA, findings from a wide body of research on the impact of non-genetic (e.g., environmental) factors are promising (Ramirez, Shaw, et al., 2018). One promising yet under-researched field involves implementing a creativity-based approach to teaching and learning mathematics. However, mathematical creativity cannot occur in isolation and needs a context in which student creative potential is developed. To this end, the notion of implementing a creativity-based intervention to foster mathematical creativity as proposed by Kaufman, Glăveanu, and Baer in (2017) suggests that a differentiation be made between teaching *about* creativity, teaching *for* creativity and teaching *with* creativity. At the professional level, the authors suggest that teaching *about* creativity involves acquiring knowledge about creativity in the same way knowledge is obtained by educators for any other subject matter. Teaching *for* creativity focuses on fostering students' creative thinking and actions. A combination of creativity-domain knowledge, together with a specialised Pedagogical Creative-Enhancement Knowledge (PCeK), is needed. PCeK involves understanding how to amplify students' creative beliefs, attitudes and abilities across all subject areas. Educators 'must know' their students to overcome any potential barriers and constraints and hence apply creativity to the individual.

Teaching *with* creativity is the ability to teach any subject matter creatively. This element requires the combination of creativity-domain knowledge and creative pedagogical knowledge, termed Creative Pedagogical Domain Knowledge (CPDK). This specialised knowledge varies across subjects, topics, students and contexts. They are thus inferring that teaching Grade 8 students creatively in mathematics will not transpose to creatively teaching Grade 3 students a History lesson (Kaufman et al., 2017). Whilst the association between teaching *with* and *for* creativity makes conceptual sense, linking them together can mask exactly what is involved in teaching creatively – how creativity develops and its influence on teachers and students. In terms of using creativity to mitigate MA, further clarification is

needed beyond a general understanding of behaviours such as openness, flexibility and risk-taking. Rather than equipping teachers with a set of ready-made techniques and strategies to 'teach well', much work is needed to pinpoint precisely what teaching creatively involves and the outcomes of doing so (Kaufman et al., 2017).

2.4.2 Definitions of Creative Teaching

In order to successfully implement a creativity-based intervention in any classroom teachers must first understand the conceptual definition of creativity. Creativity is often explained as one's ability to imagine novel solutions to situations (Runco & Jaeger, 2012). One standard definition of creativity is the "interaction among aptitude, process and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" (Plucker et al., 2004, p. 90). D.H. Cropley and Kaufman (2012) and D.H. Cropley and Cropley (2011) further define this perceptible product to include four factors that are particularly relevant to a classroom and education context: Novelty, Effectiveness, Elegance and Genesis.

'Novelty' refers to a new or original idea or concept. 'Effectiveness' is defined as the ability of the product or solution to achieve its desired result. 'Elegance' refers to how well completed and executed a product is and is described as "bridging the gap between form and function" (Oman, Tumer, Wood, & Seepersad, 2013, p. 65). Finally, 'Genesis' is manifested as solutions or products that change underlying paradigms[13]. Independent of the domain, each of these four factors are considered important. In the context of education, the hierarchy is as follows: Effectiveness, Novelty, Elegance and finally, Genesis. A creative idea or outcome does not have to display all four criteria but must display both novelty and effectiveness. As such, creativity is not "an all-or-nothing quality", and there are both *levels* and *kinds* of creativity (D.H. Cropley & Kaufman, 2012, p. 122). The definition of creativity was expanded by Russian psychologist Krutetskii, in the specific context of mathematics, as being characterised by factors including problem formation (problem finding), invention, independence, and originality (Haylock, 1987; Krutetskii, Wirszup, & Kilpatrick, 1976).

[13]An example of a product high in genesis is Thomas Savery's steam pump invented in 1698 which not only altered the way water was pumped but also led to locomotives, textile manufacturing and electrical power generation. see D.H Cropley, 2019 for a detailed description.

Lithner (2008) built on this approach by summarising creative mathematics based on the following reasoning:

1. Novelty – a new (to the reasoner) reasoning sequence is created, or a forgotten one is recreated.
2. Plausibility – there are arguments supporting the strategy choice and/or strategy implementation motivating why the conclusions are true or plausible.
3. Mathematical foundation – the arguments are anchored in intrinsic mathematical properties of the components involved in the reasoning (Haavold & Birkeland, 2017, p. 185).

To summarise, the definitions of creativity presented above share similarities and there are several qualities that are common to the definition of creativity (such as novelty and effectiveness). However, the concepts relate to the notion of the creative product and exclude other elements, such as the classroom environment and personality, which are crucial to understanding creativity in a classroom holistically. Therefore, a broader understanding of creativity involves examining other creativity theories that suggest how a creativity-based intervention in mathematics can be fostered. A standard theory used by educators that provides a prescriptive approach to creativity in the classroom is Rhodes' 4P's Model of Creativity.

2.4.3 Theoretical Models of Creativity: The 4P Model of Creativity

For many years, education systems around the world have attempted to implement creative approaches to teaching and learning. Typically, educators will draw on the theoretical understanding of Rhodes' 4P's model. The 4P's require an interaction between the *person*, *product*, *process* and *press* (Rhodes, 1961). Throughout the 20th century, in the context of education, each of the four aspects of the model have been popular at different times. Outside the domain of academia, the 4P's model is applied in different sub-disciplines of psychology, human resources, management and entrepreneurial studies, highlighting its diversity and functionality (Hennessey & Amabile, 2010). Despite this approach being useful in aiding our understanding of individual aspects of creativity (such as personality), it is important to recognise that the 4P's do not happen in a vacuum or isolation; that is, creativity cannot occur without interaction between all 4 of the 'Ps'. As described by Rhodes, "each strand has unique identity academically… only in unity do the four strands operate functionally"

(Rhodes, 1961, p. 307). This model provides researchers with a solid basis for investigations into creativity in education, as all four strands are important to ensuring a creativity-based intervention can be designed effectively.

Product in Creativity-Based Interventions

The 'Product' addresses the tangible artefact of the creative endeavour. The Product can be defined as any product, process, system, or service that is both novel and useful (Sternberg & Lubart, 1999). Researchers, including MacKinnon (1978), conclude that the "analysis of creative products is the bedrock of all studies of creativity" (p. 187). The Product is often viewed as an objective approach to creativity, as it deals with tangible objects available for measurement (Kozbelt, Beghetto, & Runco, 2010).

In education, a Product can vary greatly and could include outputs such as the solution to a maths problem, a geometric piece of art, or the development of a new tool to study statistics. The creativity of a Product is often the most obvious aspect of creativity to measure in terms of the 4P's, as it relies on a tangible product that can be physically observed and rated. Scales for measuring the creativity of a product are pivotal in aiding this process. The Creative Solution Diagnostic Scale (CSDS) is an instrument that teachers can use to assess their students' creativity whether in an essay or a mathematics proof (D.H. Cropley, Kaufman, & Cropley, 2011). This instrument highlights different qualities of creativity and is very useful for providing formative feedback to students about the outputs they produce.

Process in Creativity-Based Interventions

'Process' identifies the style of thinking that results in an innovative product (Rhodes, 1961). Guilford (1957) first described two main thinking styles associated with creativity: divergent and convergent thinking. While divergent thinking is solely associated with creativity, it is essential to recognise that convergent thinking also plays a critical role, particularly when creativity is considered in the context of problem-solving, education and all STEM disciplines (D.H. Cropley, 2015). In simple terms, divergent thinking is defined as generating multiple solutions to a problem. In contrast, convergent thinking involves working towards one single solution to a problem. An example of a teacher encouraging her students to act divergently and be creative in mathematics may be to prompt her students with the statement 'how many ways can you arrive at the answer 8?' This question allows for endless solutions to be generated and can foster creative thinking in students. A teacher could gauge the

creativeness of her students by examining the student's responses and deciding that 4 + 4 is not very creative, however, 8 + 12 divided by 1000 x 0 + 8 may be highly creative. By providing students with an open-ended task that allows divergent thinking, creativity can be enhanced. Alternatively, whilst convergent thinking is synonymous with 'traditional' teaching methods, it is also important in a classroom. In order to teach mathematical concepts such as addition, convergent teaching methods are often utilised. For example, one cannot teach a student the concept of addition whilst allowing the student to brainstorm (i.e., engage in divergent thinking about) what symbol should be used as an addition sign; a student must simply learn the plus sign symbol. It is crucial to note that before a student can act divergently, they must have the theoretical knowledge taught through convergent thinking methods. In a classroom context, knowing when to utilise either a divergent or convergent teaching style is important in fostering mathematical creativity (A. Cropley & D.H. Cropley, 2009).

The notion of knowing when, where, why and how to adopt a divergent or convergent approach in a classroom was described by the pioneering work of Guilford (1957) and by Balka (1974). The research conducted by these authors paved the way for other researchers to apply the concepts of originality, fluency and flexibility (i.e., divergent thinking) to creative mathematics (Haylock, 1987; Jensen, 1973; Kim, Cho, & Ahn, 2004). The authors suggest these elements are demonstrated through divergent thinking and are displayed in both problem-posing (i.e., when students find unique and novel ways to approach a problem) and problem-solving applications (i.e., when they think analytically to evaluate and solve a complex problem). As the mathematical problem-posing or problem-solving process unfolds, creativity can be recognised in four distinct stages: preparation, incubation, illumination, and verification (Hardy, 1946; Poincaré, 1913; Wallas, 1926). More recently, researchers (e.g., Hansen, Lumpkin, & Hills, 2011; Lubart, 2009; Sriraman, 2009) have emphasised these stages by suggesting that the mathematically creative Process can either unfold in order or meander back and forth between the stages before discovering a solution.

The 'preparation' stage involves gathering materials to solve the problem (including activating background knowledge) and establishing the groundwork for the next stage of rest or 'incubation' to occur (Wallas, 1926; Sriraman, 2009). In the incubation stage, one may walk away from the problem momentarily to enable the brain to continue formulating a solution at a subconscious level (Sriraman, 2009). This is particularly pertinent for

mathematically anxious students who often need additional time to arrive at an answer to a problem. Illumination is the stage many associate with creativity. It often occurs unexpectedly and is the 'ah-ha!' moment (Poincaré, 1913; Sriraman, 2009). The final 'verification' stage is when the solution or strategy is tested by the individual to discern if it is appropriate (Wallas, 1926; Sriraman, 2009). At this stage, it is very beneficial to foster mathematically creative writing as it allows students to share ideas and receive feedback to validate the verification process. Wallas (1926) proposes that the four stages of creative thinking processes can be taught by educators to support children who are struggling with mathematical concepts. It is vital that both convergent and divergent thinking can be used interchangeably depending on the context in which they are used (A. Cropley & D.H. Cropley, 2009). Process manifests itself as activities, or procedures, such as brainstorming, however, these are simply tools to help people recognise and engage in divergent and convergent thinking. In problem-solving tasks it is also possible to think of Process in terms of the stages that help teachers understand what cognitive processes need to take place, and when (A. Cropley & D.H. Cropley, 2009).

Press in Creativity-Based Interventions

'Press' examines the role of environmental and social factors on creativity and is defined loosely as the level of 'pressure' applied or perceived in an environment. Press can be used to address both: (a) how the 'climate'[14] can either facilitate or inhibit creativity; and (b) how the 'environment'[15] reacts to the production of creativity (D.H. Cropley, 2015). The positive or negative influence does not shape the creative outcome directly, but rather these influences mediate or moderate the outcome by affecting variables related to the creative process or person. Press, therefore, highlights elements such as leadership support for creativity (e.g., rewarding creativity, encouraging risk-taking), and how the physical environment may foster creativity (e.g., through the provision of appropriate resources and adequate lighting in the classrooms) (D.H. Cropley, 2015). Press also highlights how society tolerates radical deviations from norms (e.g., 'are creative teachers or lessons ridiculed or hailed?'). In their

[14] The climate refers to the conditions of the environment – is the environment favourable or not for creativity?

[15] The environment is defined as both the social environment (influence of various aspects of society) and the institutional environment (e.g., day-to-day workplace or classroom).

research, Pagnani and Runco (2011), as cited in Gruszka and Tang (2017, p 61-62), depict how press underpins the rules and standards that govern education departments at a state and federal level. More specifically, the authors identify six levels of socialisation acting as Press factors:

a) Physical surroundings
b) Family upbringing
c) Schooling experiences
d) Workplace environments
e) Cultural traditions
f) The historical milieu in which we happen to have been born.

The Press phase receives considerable attention in the literature and understanding the mechanisms by which Press can be used to mitigate the effects of MA in the classroom is crucial. A practical example of initiating the element of Press in the classroom may involve reading children's literature, such as *Mathematics Curse* by Jon Scieszka, to the class. This may prompt mathematically anxious individuals to identify with the main character and encourage discussion around their discomfort towards mathematics (Whyte & Anthony, 2012).

Person in Creativity-Based Interventions

'Person' relates to the psychological factors or personality of an individual. Research has demonstrated that personal elements (e.g., optimism, openness, self-confidence), motivation (both intrinsic and extrinsic), and feelings (e.g. excitement, hope, fear) are distinct dimensions of the Person and that each can be applied to creativity (D.H. Cropley & Cropley, 2012). However, scholars maintain that there is no one 'distinct' creative personality profile, and researchers, teachers, parents and students themselves must consider how each variable interacts with a multitude of other factors (D.H. Cropley, 2015). Hence, the Person variable is multifaceted and defining the construct within a MA-mathematics achievement setting is complex. Kaufman and Beghetto (2009) acknowledged the difficulty and proposed an extension of the 4P's model to include the concept of a 4C model of creativity, described below.

2.4.4 The 4C Model of Creativity

Consider the notion of a Grade 1 student and Albert Einstein, both falling under 'Person' in the 4P model. For obvious reasons, the two are very different people. The 4C model of creativity was theorised to account for such differences and proposes a 'mini-c, little-c, pro-c, and big-C' approach. This model is also essential in the context of education as the 4C's model provides an explanation and description of the developmental trajectory of creativity in children. This allows teachers to gauge what level of creativity can be expected from a 5-year-old as well as an 18-year-old, thus allowing creativity exercises to be scaffolded accordingly.

Mini-c

The first level, mini-c or personal creativity, represents the personal (Runco, 1996; Vygotsky, 2004) and developmental (Cohen, 1989) aspects of creativity. Mini-c is concerned with subjective self-discoveries that are important to the person involved, even if other people do not recognise the activity as being creative. An example is a Grade 8 student discussing why the Fibonacci sequence is found in both leaves and shells. This student may use their imagination to pose questions about this discovery, however, it is not creative to the Grade 9 student who has posed the same questions twelve months ago. Likewise, as that same Grade 8 student progresses in their mathematical abilities, the original, imaginative questions regarding the Fibonacci sequence will no longer be creative.

Furthermore, the mini-c element is not restricted to children as the educator who designs a new method to teach algebra exhibits mini-c creativity. In terms of MA, teachers who foster creativity in their classroom would benefit from the notion of mini-c creativity because it enables them to implement new ways of reducing MA in their students. Cho, Chung, Choi, Seo, and Baek (2013) demonstrated in their research (which they described as teachers encouraging mini-c creativity) by inviting students to draw on their own experiences to help understand and interpret new concepts. The use of open-ended questions prompted students to examine ideas from multiple perspectives to gain deeper comprehension (Cho et al., 2013). As students feel comfortable and safe sharing their mini-c ideas in a supportive classroom environment, the teacher can then extend the students' mini-c ideas into little-c contributions.

Little-c

Little-c is also termed ‘everyday creativity’ and refers to something that is recognised as being creative by other people. Examples of little-c creativity include designing a new way to teach statistics and then writing lesson plans to share with other teachers. Typically, little-c creations are enjoyed by others and not just appreciated by the individual involved, as is the case with mini-c. In the classroom context, a teacher can expand on students’ mini-c ideas by creating opportunities for students to elaborate on their ideas and share them with peers. Group work provides a platform for individuals to shape and mould their individual ideas towards an outcome that encompasses the group’s collective knowledge. Beghetto (2013) explains that an exploration of ideas and prior knowledge before a concept is elaborated by the teacher has been shown to encourage creative outputs and shape mini-c ideas into little-c contributions. For example, for students who are challenged in basic numerical concepts, allowing students to work in groups and engage in number-talk (e.g., using words like ‘decrease’ and ‘reduction’) while they are using concrete manipulatives can help bolster foundational number competencies and combat some anxiety towards mathematics. The teacher will also gain an understanding of the student’s creative capabilities and therefore, can prepare tasks appropriately whilst encouraging creativity to develop.

Pro-c

Pro-c or ‘professional creativity’ involves the deliberate practice of becoming an expert in any field or discipline. Practice and repetition of a particular topic is the key to developing pro-c. Ericsson (1996) asserts that it takes 10 years to become an expert in anything, including creativity. Pro-c is deemed the peak that can be achieved within one's lifetime. An example is a scientist who has dedicated an entire career to researching genome projects or a chef who has mastered a cuisine. Additionally, pro-c could manifest as a mathematics teacher who has spent their lifetime developing new methods to help students engage with geometry.

Big-C

Big C- or ‘legendary creativity’ is the culmination of genius work, in that this work will be appreciated and remembered for centuries. Big-C is similar to the genesis notion in both D.H. Cropley and Kaufman (2012) and D.H. Cropley and Cropley (2011) definitions which incorporate the shifting of paradigms. Examples include the invention of the steam pump by Thomas Savery in 1698 (D.H Cropley, 2019). This invention was the precursor to the first

Industrial Revolution and significantly altered manufacturing industries. Very few people will experience legendary creativity.

4P's and 4C's in Relation to Teaching and the Classroom

Each level of the 4C's model can help teachers understand how to approach creativity in the classroom. Most students will not reach the pro-c or big-C levels of creativity, however, the levels can help shape students' goals and aspirations. Specifically, whether by presenting information on famous theories in a mathematics class or allowing engineers and physicists to visit and share their work, students will help tailor teacher expectations to the right level. When implementing these models in inquiry-based learning, there is scope for students to develop skills needed for the 21st century, including problem-solving and critical thinking skills. At a practical level, students could work collaboratively to solve the proofs of life-changing innovations such as Galileo's use of the telescope and how he concluded that the world was round. The difference in framing the material as 'X is what you need to learn' and 'This is how you learn X' will lead to improvements in learning, particularly when students are scaffolded to learn creatively (Beilock & Maloney, 2015). The 4C's support teachers' understanding of age-appropriate levels of creativity that they can model for their students (Bandura's social cognitive theory) thus supporting their students to exhibit similar behaviours (Bandura, 1997; Beghetto & Kaufman, 2016; Jeffrey & Craft, 2004).

In summary, research supports that both the 4P's and 4C's models of creativity are comprehensive in providing a conceptual framework for supporting student learning and development. Both models are based on a holistic approach to learning that aligns with the rationale and Achievement Standards of the Australian Curriculum. The 4P's are a prescriptive framework that allows teachers to move beyond abstract definitions of creativity and develop creativity in their classrooms and their students. However, the context of education is varied and a descriptive framework (the 4C's) is required that explains both the levels and kinds of creativity that teachers can expect from school children of varying ages. In the context of mathematics, it must be acknowledged that a creative approach involves an interaction between all 4P's and 4C's, with a realistic expectation of outputs. Another critical aspect of designing a creativity-based intervention is cultivating the right 'Press' conditions as the classroom environment can have a significant influence on teacher and student experiences with mathematics.

2.4.5 The Role of Press in Cultivating a Creative Classroom

Taking the sentiment of Press further and placing it in the specific context of a classroom, the question researchers, education departments, teachers and parents often ask is *'How can teachers embed creativity in their classrooms whilst meeting the requirements of the Australian National Curriculum?*' In response to this question, creativity research highlights several factors, including teacher attitudes, student attitudes and current mathematics curricula, that can help create a classroom where creativity can flourish (Soh, 2000). Research demonstrates that the learning environment can impact student engagement, and, to learn deeply, students must be active participants (Strong, Silver, & Robinson, 1995). Teachers who are primed with the 'right' attitudes towards fostering creativity across the Australian Curriculum are well prepared in supporting students to attain these requirements (i.e., the knowledge and skills expected in subjects at each year level) (Patston, D.H. Cropley, Marrone, & Kaufman, 2017; Patston, D.H. Cropley, Marrone & Kaufman, 2018) (discussed in detail in the journal publications highlighted in Appendix K and Appendix L). However, if misconceptions regarding creativity are present, it may be difficult for students to attain these requirements.

It may be that it is not curricula that stifles creativity; in fact, all four Proficiency Strands of the Australian Mathematics Curriculum **(**Understanding, Fluency, Problem-solving and Reasoning) have links to the definition of creativity. These Proficiency Strands are an integral part of mathematics across the three Content Strands of Number and Algebra; Measurement and Geometry; and Statistics and Probability (Australian Curriculum Assessment and Reporting Authority (ACARA), 2014). Therefore, it may be the interpretation of the teacher in implementing the Strands that can create a barrier to creativity. To facilitate the implementation of creativity, educators must be guided by research and practice. Such research includes A. Cropley's (1997) book chapter, '*Fostering Creativity in the Classroom: General Principles'* which outlines the general principles of creativity and provides specific examples and methods for how teachers can establish a creative classroom environment that fosters creativity. The Creativity Fostering Teacher Index (CFTI) assesses nine relevant factors that are thought to encourage creativity in the classroom. These were derived from properties outlined in the *Fostering Creativity in the Classroom: General Principles* research. Specifically, the CFTI includes the following nine key factors and has a reliability of 0.82 (Soh, 2000, p. 132-134):

1. Independence: *I encourage students to show me what they have learned on their own.*
2. Integration: *In my class, students have opportunities to share ideas and views*.
3. Motivation: *Learning the basic knowledge/skills well is emphasized in my class*.
4. Judgement: *When my students have some ideas, I get them to explore further before I take a stand*.
5. Flexibility: *In my class, I probe students' idea to encourage thinking*.
6. Evaluation: *I expect my students to check their own work instead of waiting for me to correct them*.
7. Question: *I follow up on my students' suggestions so that they know I take them seriously*.
8. Opportunities: *I encourage my students to try out what they have learned from me in different situations.*
9. Frustration: *My students who are frustrated can come to me for emotional support*.

Soh (2000) elaborates on Cropley's 1997 framework and emphasises the importance of correctly fostering the right environment for creativity to flourish. The implementation of these creativity facilitating factors can create the right classroom environment, which can lead to a subsequent increase in students' engagement, motivation and academic performance. However, previous literature does not examine how fostering creativity in a classroom can help teachers and students experience mathematics. Identifying and addressing this gap is a key contribution of this thesis.

2.4.6 Teaching Mathematics Creatively

Mathematical creativity is defined as (a) the process that results in unusual (novel) and/or insightful solution(s) to a given problem or analogous problems, and/or (b) the formulation of new questions and/or possibilities that allow an old problem to be regarded from a new angle requiring imagination (Sriraman, 2005, p. 24). Mathematical creativity is most often assessed by using a multiple-solution task, in which students can provide several solutions to a mathematical problem (Leikin, 2009; Schoevers, Kroesbergen, & Kattou, 2018). The emergence of concrete definitions of 'mathematical creativity' by Krutetskii et al. (1976), Haylock (1987), and later Lithner (2008) prompted a review of educational literature between

1999 and 2009 by Leikin and Pitta-Pantazi (2013). These researchers studied seven leading research journals in Mathematics Education and seven leading journals in Gifted Education before concluding that very few publications combined both mathematics and creativity research. In the last decade, more attention towards combining the two fields has become a focus of research. However, to date, only a small number of empirical studies on teaching mathematics creatively have been conducted (Leikin, Berman, & Koichu, 2009; Leikin & Pitta-Pantazi, 2013).

Given that achievement in learning mathematics at school correlates with work and social achievements, it is vital to understand how the processes of applying creativity may facilitate children learning mathematics (Leikin & Pitta-Pantazi, 2013). Preliminary work on establishing a relationship between teaching mathematics creatively and increased mathematical achievement was carried out by Japan's National Institute for Educational research between 1971 and 1976. The results from this six-year study suggested that the use of open-ended problems (i.e., problems that allow multiple correct answers) promotes higher-order thinking and enables students to experience early stages of mathematical creativity (from the translation by J. Becker and Shimada, 1997). In response, Japan adopted an "open-ended" teaching approach as a method for improving mathematics teaching and learning in Japanese schools. (Mann, 2006, p. 241). While this research is important as an illustration of the benefits of fostering higher order thinking and creativity, it occurred before the implementation of high stakes standardised testing regimes which have altered the teaching of mathematics. It, therefore, has limited bearing on present-day practices.

2.4.7 Current Research on Teaching Mathematics Creatively

Despite a lack of empirical research regarding the impact of teaching mathematics creatively, some recent studies explore these topics. Sak and Maker (2006) studied the relationships between age, grade, mathematical knowledge and creative mathematical thinking in first- to fifth-grade students. The authors reported that there was an increase in mathematical knowledge when children's creative mathematical thinking increased (Sak & Maker, 2006). Similarly, Mann (2006) explored the associations between teaching mathematics creatively and mathematical achievement in seventh-grade students. He suggested that mathematical achievement was the strongest predictor of mathematical creativity (Mann, 2006 as cited in Tabach and Friedlander, 2013).

Additionally, a flexibility-based[16] intervention was undertaken by An et al. (2011) in their study of 64 pre-service teachers, with the integration of music into a 90-minute mathematics lesson. This study focused specifically on how encouraging flexibility impacts MA, and the authors concluded that flexibility is a vital component in alleviating MA. The researchers hypothesised that the flexibility-based intervention would promote positive attitudes and confidence in mathematics. Pre- and post-flexibility intervention questionnaires were provided to evaluate the change in pre-service teachers' attitudes and beliefs toward mathematics. The results demonstrated that the mathematics lesson integrated with flexibility had a positive effect on pre-service teachers' attitudes and beliefs toward mathematics teaching and learning.

A more systematic investigation of creativity-specific pathways to positive outcomes in mathematics was conducted by Tok (2015). His study of sixth graders focused on how teaching mathematics creatively impacts student attitudes towards mathematics, MA and mathematics achievement. The study was designed as a quasi-experiment that used pre- and post-intervention tests and a control group. The data were collected by administering the Math Achievement Test, Mathematical Attitudes Scale and the Math Anxiety Scale. Students in the experimental group received 'mathematically creative' teaching, which involved divergent thinking tasks whilst being taught subject matter. Alternatively, the control group was taught using 'traditional' pedagogy which involved direct lecturing. The results of the study demonstrated that employing a strategy of 'teaching mathematics creatively' in sixth-grade mathematics can be effective in increasing mathematics achievement, improving attitudes towards mathematics and decreasing MA. In addition, effect sizes in this study were substantial as teaching mathematics creatively had a large effect size for students' mathematics achievement (d = 1.97, $\eta 2$= .57), a moderate effect size for attitudes towards mathematics (d = 0.50, $\eta 2$= .08) and a large effect size for MA (d =1.37, $\eta 2$= .32).

Other researchers emphasise how a creative approach to teaching mathematics can alleviate MA in students (Köhler, 1997). In a study of pedagogical approaches to mathematics, Köhler (1997) followed two groups of children who were presented with a set of questions. The first group was given a traditional teaching approach and were directed to

[16] Flexibility is a key aspect of divergent thinking and involves generating a variety of different ideas.

use calculations to solve the problems. 'Traditional' is defined in this context as restrictive, closed, rote teaching techniques. These traditional problems were constructed such that only a closed, single answer existed. The second group was given an 'open-ended' approach and were told that there was more than one 'right' answer. The results showed that the 'open-ended' group posed and solved more questions than the 'closed' group. This open group also calculated problems with more accuracy and produced more error-free results. In support of these findings, Mann (2006) explains that mathematical creativity is stifled if students are limited to traditional 'rule-based' applications that only allow for one answer.

In conclusion, the literature suggests that students experience less MA when teachers make changes to the way they teach mathematics, with a shift away from the more 'traditional' approach (Bursal & Paznokas, 2006; Gresham, 2007). Therefore, despite only a few studies investigating the relationship between creativity and mathematics, the tentative findings to date do suggest that creativity may alleviate issues associated with mathematics, such as MA, and increase mathematical achievement.

2.4.8 Gaps in Current Creativity Research

In the past, literature has typically aligned teaching *with* creativity in the context of teaching *for* creativity (Beghetto, 2013; Gregerson, Snyder, & Kaufman, 2012; Jeffrey & Craft, 2004). A possible explanation for this is that researchers who centre on teaching *for* creativity typically focus on how teachers who approach teaching with a flexible mindset and an open mind establish a safe learning environment. This environment, in turn, fosters student creativity as students seek out risk-taking opportunities, complexity, accept uncertainty and learn from (rather than avoid) mistakes. Underpinning this notion of how creative teachers support student creativity is the social modelling theory proposed by Bandura (Bandura, 1997; Beghetto, 2016). Any future studies in the under-researched area of teaching *about* creativity would need to measure changes to students' knowledge and beliefs about creativity through using traditional measurement methods such as formal and informal assessment grades. Kaufman et al., (2017) note that the ability for studies to apply creativity across all academic year levels (including higher education settings) would open avenues to discern how best to apply creativity to specific subject areas such as mathematics. This would help tailor effective solutions to individual contexts rather than have a 'one size fits all' approach to implementing creativity (Kaufman et al., 2017). These authors acknowledge that further

work is needed to develop, apply and assess PCeK before applying it in a specific context such as mathematics. These authors recommend future research on teaching *for* creativity aim to develop "more sensitive and multifaceted" methods for measuring this construct, such as concurrently assessing the convergence of teacher, student and environmental elements on domain-specific creativity enhancement (Kaufman et al., 2017, p. 560).

2.5 Summary of the Literature Review

This review has highlighted that MA can prevent students from demonstrating their mathematical competencies and repeated experiences of MA can contribute to lost opportunities as students avoid STEM subjects and careers. Literature highlights the importance of future research to understand the association between mathematics, creativity and sex differences in order to inform educator-focused prevention and early intervention efforts. This review demonstrates that examining more complex pathways could include interactive creativity-based interventions targeted towards altering the relationship between negative mathematics attitudes and sex stereotypes. Refining actions to illuminate the disparate relationships between sex differences and mathematics will lead to a better understanding of how to overcome this negative relationship, thus encouraging equality in the STEM workforce.

Additionally, although literature highlights that there are apparent disadvantages for females accessing STEM opportunities, it is nevertheless the case that facilitating equitable outcomes for females involves altering the presentation of mathematics. Thus, understanding the processes involved with Stereotype Threat is an important future research goal as changes stimulated by creativity in educational settings may lead to increased self-efficacy and decreased MA.

Finally, sex differences in mathematics experiences and achievements emerge in numerous studies, suggesting the likelihood of sex-specific connections with mathematical attainment. However, there are clear gaps in the existing literature on elementary students and surprisingly, there has been little research addressing the role of female educators in elementary schools and links to MA. Developing mathematical creativity at school should start with the training of teachers. It could be argued that only creative teachers can provide a learning environment conducive to developing children's creativity. Striking the right balance between the development of expertise and practical solutions warrants further investigation.

Chapter 3: The Role of Stereotype Threat in Impacting Females' Abilities to be Mathematically Creative in the 21st Century (Study 1)

The content of this chapter has been used as a basis for a journal publication. It is currently under review as a 'short report' submitted to the Journal of Developmental Science, where I am the first and lead author.[17] This chapter is a more in-depth approach to this topic and was solely written by me.

The research described in this chapter, designated Study 1, addresses Gap 1, as identified in the Introduction (Chapter 1). This longitudinal study explores mathematical and verbal creativity in children across Grades 6 to 12 at a large Australian school.

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3.1 Abstract

The transition into the Fourth Industrial Revolution (Industry 4.0) is highlighting the need for education to target both STEM and creativity competencies thus ensuring students have the necessary aptitude for employment in the 21st century. However, not every student is afforded an equal opportunity to succeed in this emerging workforce. Historically, females have encountered sex-based stereotypes in STEM, particularly in mathematics, as well as the field of creativity. These negative stereotypes have impeded females' ability to access opportunities to develop their skills. Taken together, these elements are the catalyst for two key questions: *Are female students experiencing negative stereotypes in mathematical creativity? Could these stereotypes be impacting their likelihood of transitioning into the STEM workforce?* This study explores mathematical and verbal creativity in children across Grades 6 to 12 at a large Australian school. The results suggest that female students are impacted by sex-based stereotypes and have lower confidence in their mathematical creativity abilities in comparison to males. The results also demonstrate that females outperform males on a mathematics-based creativity task. Conversely, there are no sex differences in verbal creativity, suggesting that females are experiencing negative sex stereotypes specific to mathematical creativity.

This chapter explores possible reasons for these sex differences, suggesting that they are driven by a combination of personal, societal and environmental elements. The study underscores the relationship between STEM and creativity in high school students and demonstrates how the development of these skills may be impeded for females.

3.2 Introduction

Few would argue that society is changing. As technology and automation advance, current vocations are disappearing, making way for new career pathways (Department of Education Government of Western Australia, 2015). Known as the Fourth Industrial Revolution, or Industry 4.0, industries are swiftly changing to apply the intelligent networking of machines with digital technologies (Dalenogare, Benitez, Ayala, & Frank, 2018; Morrar, Arman, & Mousa, 2017). In a modern, industrialised society that is characterised by rapid technological change, it is imperative to have a workforce trained in the academic STEM disciplines whilst also competent in soft skills such as creativity, collaboration and problem-solving (Deloitte, 2016). Unfortunately, common and persistent social stereotypes exist that prevent females from demonstrating their true proficiencies in modern tasks that require both STEM and creativity. Additionally, although Australia shares similar demographics with the USA and UK (i.e. it is a W.E.I.R.D[18] country) the majority of prior research on teaching practices are derived from American or English samples and do not consider the unique context of Australian school children. It is therefore important to investigate this student population.

Stereotype Threat and Mathematics

Worldwide, females account for only 30 percent of people in STEM fields (UNESCO, 2015) despite a growing body of literature suggesting that there are no biological differences in the mathematical capabilities of females and males (Kersey, Csumitta, & Cantlon, 2019). Why then are so few women entering STEM careers? One explanation lies in the large body of literature that examines the damaging impacts of negative stereotypes and Stereotype Threat.

Stereotype Threat (ST) refers to the phenomenon whereby people perform worse than their ability dictates on a task when a relevant negative stereotype is made salient in the performance situation (Steele & Aronson, 1995). Within the context of mathematics, ST is most often associated with the myth that males are innately better than females at mathematics (J. Shapiro & Williams, 2012). More specifically, if a female is made aware of this stereotype when in a situation involving mathematics, then she may experience anxiety surrounding her desire to disprove the stereotype. This anxiety may, paradoxically, lead to

[18] W.E.I.R.D is defined as Western, educated, industrialised, rich and democratic.

underperformance (e.g., Beilock et al., 2010). Stereotypes and ST can perpetuate negative attitudes towards STEM subjects, consequently leading to higher levels of Mathematics Anxiety and mathematics avoidance, and also lower levels of STEM course-taking (Cheryan & Plaut, 2010; Hill, Corbett, & St Rose, 2010; Simpkins et al., 2006). Seminal research by Spencer, Steele, and Quinn (1999) demonstrated that females perform worse on mathematics tasks when sex stereotypes are salient relative to when they are not. Two decades later, modern research highlights that this trend persists (Beilock et al., 2007; Kiefer & Sekaquaptewa, 2007; et). Indeed, an action as simple as identifying one's sex before engaging in a mathematics task can be enough to induce ST in females and create a downward spiral phenomenon (Danaher & Crandall, 2008).

These sex-based stereotypes also have the capacity to negatively affect females' views of mathematics (Nosek et al., 2009). In a sample of 5,139 adults (mean age of 27), Nosek and Smyth (2011) found that stronger implicit 'mathematics equals male' stereotypes predicted greater negativity toward mathematics, less participation, weaker self-ascribed ability, and worse mathematics achievement for females. For males, those relationships were weakly in the opposite direction (Nosek & Smyth, 2011). The negative effect of ST in mathematics is not limited to adult females. Boys and girls as young as six years of age demonstrate evidence of endorsing explicit and implicit 'mathematics equals male' stereotypes (Cvencek et al., 2015) and confirmation of this stereotype is associated with lowered mathematics performance in girls (Beilock et al., 2010). Similar results from the 2012 PISA study suggest that even when girls are aware that they are outperforming boys on mathematics tasks, girls continue to rate their ability as lower than boys (OECD, 2012). When asked to rate their aptitude at school, 15-year-old girls tend to under-report their abilities, despite possessing good grades (OECD, 2012). Ehrlinger and Dunning (2003) further support a ST claim and report that although females performed as well as males on science tasks, females thought less of their general scientific reasoning ability and underestimated their performance. Consequently, females were less likely to enter a science competition. The authors also found that males were more likely to over-report their abilities in a given subject than females (Ehrlinger & Dunning, 2003). This phenomenon is commonly referred to as 'the confidence gap' or 'imposter syndrome' (Ehrlinger & Dunning, 2003).

Stereotypes in Creativity

The preceding literature highlights the role of ST in explaining sex disparities in mathematical achievements, attitudes towards mathematics and STEM subjects in general. Relatively unexplored in the literature, however, is the potential relationship between ST and creativity. This is a significant omission, given that creativity, like mathematics, is a historically stereotyped field (Runco, Cramond, & Pagnani, 2010), is an important component of most major theories of intelligence (Kaufman, 2006) and, most importantly, is considered a key soft skill that will complement and aid STEM practices in the emerging workforce (Deloitte, 2016; World Economic Forum, 2016). Indeed, in a world where digital transformation associated with STEM continues to develop, the role of creativity becomes central. Unfortunately, it has been well documented that, historically, males have been afforded more opportunities and encouraged to pursue their creative potential more than females (Boorstin, 2012; Piirto, 1991). Research suggests that these archaic stereotypes may still negatively influence females' abilities to pursue creative endeavours and consequently limit their likelihood of success in the modern STEM workforce (Runco et al., 2010). Baer and Kaufman's (2008) review of sex differences in creativity reported numerous explanations as to why sex differences in creativity may be evident. These authors credited the role of nurture over nature and propose that society has a responsibility for perpetuating such stereotypes, thus implying a potential ST phenomenon in creativity. Therefore, an investigation into the impact of these sex stereotypes in both creativity and mathematics is warranted.

The Present Study

The ability to find creative solutions to STEM-based problems is crucial to an individual's future employability and is of paramount importance to a developed society (Deloitte, 2016). It is now more important than ever to understand the role of sex in both mathematics and creativity. Therefore, this chapter addresses the following questions: *Are female students experiencing negative stereotypes in mathematical creativity? Could these stereotypes be impacting their likelihood of transitioning into the STEM workforce?* In order to answer these questions, participants completed a Mathematics Creativity test as well as a Verbal Creativity test (to serve as a control). Mathematical creativity is widely operationalised in terms of divergent processes (and therefore measured using the criteria of fluency, flexibility, originality and elaboration). Importantly, before attempting the tasks, students were asked to

predict how well they expected to perform. These pre-task questionnaires will be referred to as Metacognition[19].

Four general hypotheses are proposed in this study. First, it is hypothesised that males will self-report higher Mathematics Creativity (Metacognition) than females (Hypothesis 1), but no sex differences on self-rated Verbal Creativity (Metacognition) will be present (Hypothesis 2). It is also hypothesised that there will be no sex differences in Creativity scores on the Mathematics Creativity task (Hypothesis 3) or the Verbal Creativity task (Hypothesis 4).

3.3 Methodology

Participants

A total of 1,391 students from an Australian school in the state of Victoria participated in this study. Two hundred and sixty-six students chose not to identify their sex and therefore, were excluded. In total, the final sample included 625 male and 500 female students ranging from 8 to 18 years old (M=13.7 years old). In 2016, a total of 51 students identified as being in Grade 6, 128 students in Grade 8, 230 students in Grade 9, and 232 students in Grade 10.

Students were presented with a set of creativity tasks once a term for an entire school year in 2016. The school year runs from January to December with four terms. Therefore, participants completed the task four times over one school year. Not all 1,391 students participated at each or every time point, and, as such, the number of participants included is noted for each analysis.

Measures

Students completed a series of online questionnaires via Survey Monkey as part of a larger creativity-based study. To measure students' self-assessed Verbal Creativity (Metacognition) and performance on a Creative Verbal task, measures were taken from the Creative Production Verbal Creativity Instrument (Amabile, 1982; Kaufman, Baer, Cropley, Reiter-Palmon, & Sinnett, 2013). To measure students' self-perceived Mathematics Creativity (Metacognition) and performance on a Mathematics Creativity task, measures were taken

[19] Metacognition is defined as an awareness and understanding of one's own thought processes.

from the Creative Production Mathematics Task Instrument (Tidåsen et al., 2015). The participating school selected all scales.

Verbal Creativity (Metacognition): The Verbal Creativity (Metacognition) task is a self-report assessment on perceived ability to perform creatively on a verbal task. This task was adapted from Amabile (1982) and Kaufman et al. (2013). Scoring was based on a Likert scale ranging from 1 to 5, where 1=strongly disagree, 2=disagree, 3=neither agree/nor disagree, 4=agree and 5=strongly agree. There were four pre-task questions. Please see Appendix A for the full measure. An overall Verbal Creativity (Metacognition) pre-task score was constructed by calculating the mean of the four pre-task questions. The average reliability alpha of all four time points was .833.

Verbal Creativity task: The Verbal Creativity task is a performance task in which students are prompted to creatively design a title when presented with a photo. Students were given two minutes to design a title. Students were prompted with the statement 'What is the most creative title you can think of for the following photo?' and then they were shown a photo. Each time the students engaged in the task, they were presented with a different photo. Please see Appendix B for the full measure.

In this study, three independent judges (high school teachers) rated the level of creativity of the students' responses using the Consensual Assessment Technique (CAT) (Amabile, 1982; Kaufman, Plucker, & Baer, 2008), a technique in which judges with expertise in a relevant domain assign a rating of the creativity of products. Past research has shown very high inter-rater agreement (Kaufman & Baer, 2012) and evidence of validity (Amabile, 1996) and high school teachers have consistently been shown to be an appropriate choice for rating student creativity (Baer, Kaufman, & Riggs, 2009; Kaufman et al., 2013). Judges scored student creativity on a scale of 1 to 6, where 1=not at all creative and 6=most creative. Inter-rater reliability was calculated for each time period and the reliability of the judges' scores ranged from .726 to .744. The mean inter-rater reliability for these measures (based on all raters over all time periods) was .734. In addition to the Verbal Creativity measure, the school provided each student's English grade point average (GPA) score. This is a measure, ranging from 1 to 10, of each student's GPA at the end of 2016 (November) for the specific subject of English. Individual teachers assign GPAs at the school to individual students for the subject in question. They are not scaled. Please see Appendix C for the instructions given to the judges.

Mathematics Creativity (Metacognition): The Mathematics Creativity (Metacognition) task is a self-assessment on perceived ability to perform creatively on a mathematics task. This task was adapted from Insulander, Ehrlin, and Sandberg (2015), in which a similar Mathematics Creativity task was implemented to measure students' entrepreneurial Creative Mathematics learning. Scoring was based on a Likert scale ranging from 1 to 5, where 1=strongly disagree, 2=disagree, 3=neither agree/nor disagree, 4=agree and 5=strongly agree. There were four pre-task questions. An overall Mathematics Creativity (Metacognition) pre-task score was constructed by calculating the mean of the four pre-task questions. Please see Appendix D for the full measure. The average reliability alpha of all four time points was .741.

Mathematics Creativity Task: The Mathematics Creativity task is a performance task in which students are prompted to design equations for a designated number. Students were given three minutes to design equations. The purpose was not necessarily to get the correct answer, but rather to be creative. The statement students were prompted with was: *What is the **most creative way** you can use what you know in Mathematics to write some Mathematics questions or equations where the answer is 8 (for example, '4 x 2', or '10 – 2' are **not** very creative answers)?* Each time the students engaged with the task, the number they were told to arrive at was different. Please see Appendix E for the full measure.

The same three independent judges who assessed the Verbal Creativity of the students' responses also rated the students' Mathematics Creativity task in the same manner, using a scale of 1 to 6, where 1=*not at all creative* and 6=*most creative*. Inter-rater reliability was calculated for each time period and the reliability of the judges' scores ranged from .726 to .781. The mean inter-rater reliability for these measures (based on all raters over all time periods) was .754. In addition to the Mathematics Creativity task, the school provided each student's mathematics GPA score. This is a measure, ranging from 1 to 10, of each student's GPA at the end of 2016 (November) in the subject of mathematics. Individual teachers assign GPAs at the school to individual students for the subject in question. They are not scaled. See Appendix C for the instructions given to the judges.

3.4 Results

All data were analysed using SPSS version 25.0. Significance was set at $p<.05$. Participants with missing data were excluded. Both graphical and numerical assessments of skewness and kurtosis indicated that the data were normally distributed, and therefore suitable for parametric analysis. To test hypotheses regarding sex differences across individual testing periods, One-Way ANCOVAs were conducted for each testing period pre-task on the Mathematics Creativity (Metacognition) task (H1) and Verbal Creativity (Metacognition) (H2) and with the judges' scores on the Mathematics Creativity task (H3) and on the Verbal Creativity task (H4). The covariates for H1 and H3 were mathematics GPA and grade level and the covariates for H2 and H4 were English GPA and grade level.

Means and standard deviations of self-rated Verbal Creativity (Metacognition) and Mathematics Creativity (Metacognition) and judges' assessments are presented in Table 1 for the Verbal Creativity task and Table 2 for the Mathematics Creativity task.

Table 1

Descriptive statistics for Verbal Creativity (Metacognition) and judges' assessments of creativity by sex

Sex	Time	Creativity Scale	N	*M*	*SD*
Females	2	Metacognition (Pre-task)	100	3.5	.72
	2	Judges' Assessment	101	3.1	.96
Males	2	Metacognition (Pre-task)	122	3.5	.77
	2	Judges' Assessment	124	3.1	1.1
Females	3	Metacognition (Pre-task)	221	3.5	.66
	3	Judges' Assessment	211	2.7	.91
Males	3	Metacognition (Pre-task)	248	3.7	.69
	3	Judges' Assessment	240	2.6	.89
Females	4	Metacognition (Pre-task)	192	3.3	.68
	4	Judges' Assessment	193	2.9	1.0
Males	4	Metacognition (Pre-task)	253	3.5	.76
	4	Judges' Assessment	252	2.9	.98
Females	5	Metacognition (Pre-task)	124	3.4	.72

	5	Judges' Assessment	122	2.6	.96
Males	5	Metacognition (Pre-task)	186	3.4	.77
	5	Judges' Assessment	185	2.5	.99

Note. N = sample size; *M* = mean; *SD* = standard deviation.

Note that the time begins at 2 and not 1 as 'Time 1' was designated for the collection of baseline data unrelated to this study.

Figure 1 highlights mean sex differences on the Mathematics Creativity (Metacognition) pre-task, Verbal Creativity (Metacognition) pre-task, Mathematics Creativity task and Verbal Creativity task at time point 3.

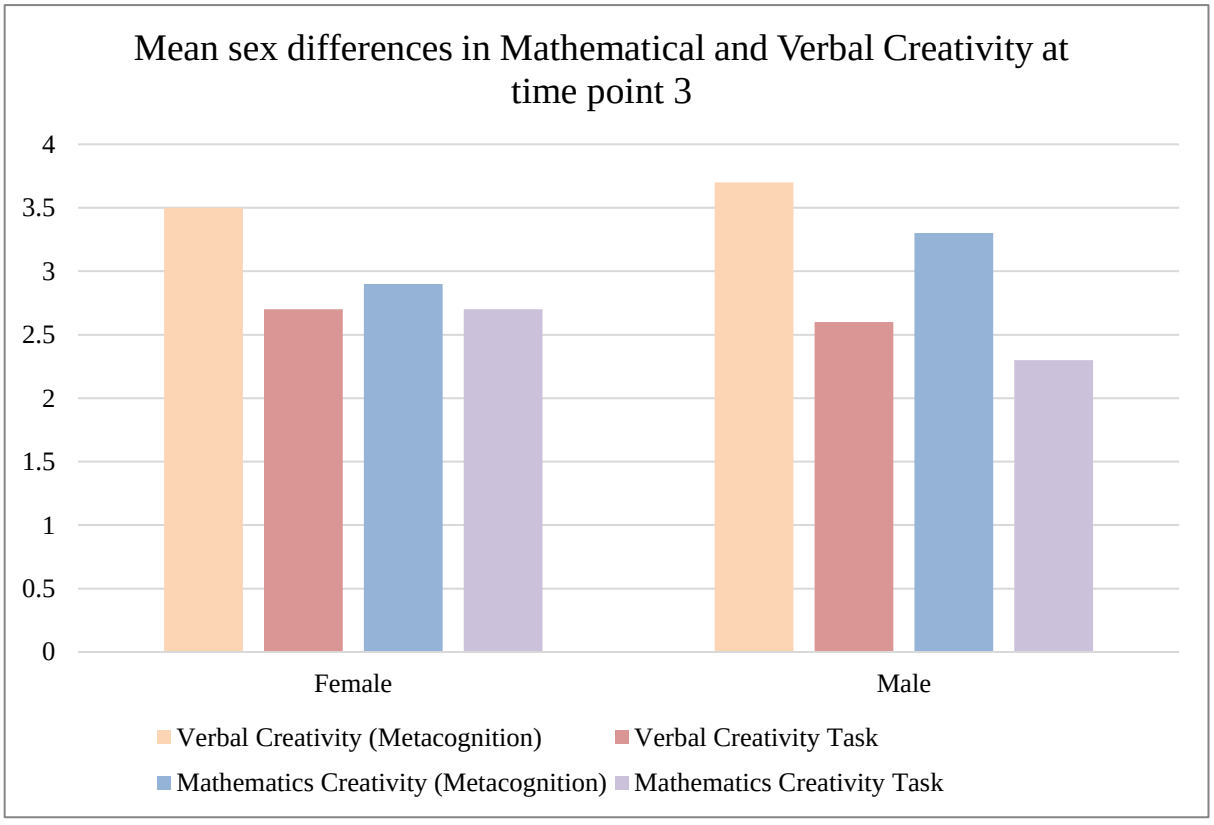


Figure 1 Mean values for males and females for both verbal and mathematical creativity tasks at time point 3

Table 2

Descriptive statistics for Mathematics Creativity (Metacognition) and judges' assessments of creativity by sex

Sex	Time	Creativity Scale	N	*M*	*SD*
Females	2	Metacognition (Pre-task)	102	2.9	.82
	2	Judges' Assessment	97	2.7	1.0
Males	2	Metacognition (Pre-task)	123	3.3	.86
	2	Judges' Assessment	119	2.3	1.0
Females	3	Metacognition (Pre-task)	220	3.0	.77
	3	Judges' Assessment	212	2.2	.78
Males	3	Metacognition (Pre-task)	247	3.4	.85
	3	Judges' Assessment	234	2.0	.73
Females	4	Metacognition (Pre-task)	191	3.0	.76
	4	Judges' Assessment	181	2.1	.76
Males	4	Metacognition (Pre-task)	251	3.3	.87
	4	Judges' Assessment	239	2.0	.71
Females	5	Metacognition (Pre-task)	124	3.0	.86
	5	Judges' Assessment	110	1.9	.74
Males	5	Metacognition (Pre-task)	187	3.3	.82
	5	Judges' Assessment	170	1.8	.69

Note. *N* = sample size; *M* = mean; *SD* = standard deviation.

One-Way Analysis of Covariance (ANCOVA)

Mathematics Creativity One-Way ANCOVA for Time Period 2

Firstly, the hypothesis that males would report feeling significantly more confident in their ability to generate creative solutions to mathematics problems than females were tested. The results of a One-Way ANCOVA examining the effect of sex on Mathematics Creativity (Metacognition) after controlling for mathematics GPA and grade level yielded a statistically significant difference in Mathematics Creativity (Metacognition) scores between males and females, $F(1, 193) = 15.836$, $p < .001$, partial $\eta^2 = .076$. Post hoc analysis performed with a Bonferroni adjustment indicated that Mathematics Creativity (Metacognition) scores were

greater in males (M = 3.28, SE = 0.08) than females (M = 2.8, SE = 0.09), a mean difference of 0.470, 95% CI [0.237, 0.703], $p < .001$ (see also Table 3).

Next, males' and females' solutions to the Mathematics Creativity task were compared to examine whether males' solutions were rated as more creative than those of their female peers Importantly, an ANCOVA examining the effect of sex on Judges' Assessment of Mathematics Creativity, after controlling for mathematics GPA and grade level, yielded no difference in Judges' Assessment of Mathematics Creativity between males and females, $F(1, 183) = 3.0189$, $p = .084$, partial $\eta^2 = .016$. In other words, even though males expected to have higher Mathematics Creativity ratings than females, they did not.

Verbal Creativity One-Way ANCOVA for Time Period 2

Next, the effect of sex on Verbal Creativity (Metacognition) was examined. After controlling for English GPA and grade level, a One-Way ANCOVA yielded no significant difference in Verbal Creativity (Metacognition) between males and females, $F(1, 192) = .065$, $p = .798$, partial $\eta^2 = .000$; males (M = 3.3, SE = 0.08); females (M = 3.4, SE = 0.08), a mean difference of 0.070, 95% CI [.296, .155], $p = .541$ (see also Table 4).

A One-Way ANCOVA was conducted to determine the effect of sex on Judges' Assessment of Verbal Creativity, after controlling for English GPA and grade level. This analysis yielded no significant difference between males and females in Judges Assessment of Verbal Creativity, $F(1, 192) = .445$, $p = .505$, partial $\eta^2 = .002$.

A One-Way ANCOVA was conducted for each time period for Mathematics Creativity (Metacognition) and Judges' Assessment of Mathematics Creativity (See Table 3 for statistics). A One-Way ANCOVA was conducted for each time period for Verbal Creativity (Metacognition) and Judges' Assessment of Verbal Creativity (See Table 4 for statistics).

Table 3

Mathematics Creativity ANCOVA for remaining time periods

Time Period	Mathematics Task	*F (x, y), p* (two-tailed) η^2
3	Metacognition (Pre-task)	Pre: $F(1, 408) = 32.066$, $p < .001$, partial $\eta^2 = .073$.**
3	Judges' Assessment	$F(1, 389) = 2.487$, $p = .116$, partial $\eta^2 = .006$.
4	Metacognition (Pre-task)	$F(1, 389) = 18.384$, $p < .001$, partial $\eta^2 = .045$.**
4	Judges' Assessment	$F(1, 369) = .083$, $p = .773$, partial $\eta^2 = .000$.
5	Metacognition (Pre-task)	Pre: $F(1, 254) = 8.499$, $p = .004$, partial $\eta^2 = .032$.*
5	Judges' Assessment	$F(1, 229) = 1.833$, $p = .177$, partial $\eta^2 = .008$

*p<.05. ** p <.01

A One-Way ANCOVA was conducted for each time period for Verbal Creativity (Metacognition) and Judges' Assessment of Verbal Creativity (See Table 4 for statistics).

Table 4

Verbal Creativity ANCOVA for remaining time periods

Time Period	Verbal Task	*F (x, y), p* (two-tailed) η^2
3	Metacognition (Pre-task)	$F(1, 412) = 10.505$, $p = .001$, partial $\eta^2 = .025$.*
3	Judges' Assessment	$F(1, 389) = .138$, $p = .710$, partial $\eta^2 = .000$.
4	Metacognition (Pre-task)	$F(1, 393) = 8.739$, $p = .003$, partial $\eta^2 = .022$.*
4	Judges' Assessment	$F(1, 394) = .014$, $p = .906$, partial $\eta^2 = .000$.
5	Metacognition (Pre-task)	Pre: $F(1, 254) = 2.753$, $p = .098$, partial $\eta^2 = .011$.
5	Judges' Assessment	$F(1, 251) = .285$, $p = .594$, partial $\eta^2 = .001$.

*p<.05. ** p <.01

3.5 Discussion

Despite several studies examining various aspects of sex-based stereotypes in mathematics or negative stereotypes in creativity, considerable uncertainty remains about the effect of sex-based stereotypes in mathematical creativity. With the advent of the Fourth Industrial Revolution and transformation of industries, it is now more important than ever to understand the impact of school education on STEM-based creativity and ensure equality for all students regardless of sex.

In this study, potential sex-based effects across creativity tasks amongst students ages eight through eighteen were investigated. The overarching research questions that were asked were: *Are female students experiencing negative stereotypes in mathematical creativity and could these stereotypes be impacting their likelihood of transitioning into the STEM workforce?* Both verbal and mathematical creativity were assessed through self-rated Metacognition Creativity tasks relative to actual performance on Verbal and Mathematics Creativity tasks.

Hypothesis 1 was supported as males did report higher self-efficacy regarding their perceived Mathematical Creativity (Metacognition) in comparison to females. Interestingly, even though females scored just as high as males on the Mathematics Creativity task (when scored by the judges), they nonetheless had lower self-efficacy (Mathematics Creativity (Metacognition)) than their male counterparts, which was predicted by Hypothesis 3. Hypothesis 2 and Hypothesis 4 were also supported, as there were no sex differences in either the Verbal Creativity Metacognition task (Hypothesis 2) or the Verbal Creativity task (Hypothesis 4). This lack of sex discrepancy on either Verbal task provides evidence that the sex discrepancy observed on the Mathematics tasks cannot be attributed to females only having lower expectations for themselves overall. The stark disconnect between females expected and actual performance in the Mathematics Creativity task strongly suggests the presence of negative internalised stereotypes about females' mathematical abilities.

Thus, sex-based differences did not impact females' performance on the Mathematics Creativity task, but it did impact their confidence or self-efficacy regarding their ability to be creative in mathematics. This 'confidence gap' and lack of self-efficacy may suggest that females endorse sex stereotypes about mathematics, which is in line with current ST theories (Cvencek et al., 2015; Nosek & Smyth, 2011). Indeed, Ehrlinger and Dunning (2003)

suggest that male school students are more likely to over-report their general ability than female students. This is a crucial finding because the lack of confidence exhibited by females may negatively impact their likelihood of continuing with STEM subjects. Brown, Brown, and Bibby (2008) demonstrate that most students in the United Kingdom choose not to study mathematics in secondary school because they dislike it or are anxious about it (i.e., they lack confidence). These results are mirrored in a study of Canadian adolescents, where males typically reported more confidence than females in mathematics despite their actual performance. Findings presented by Hango (2013) indicated that 50% of males perceived their mathematical ability to be 'very good' or 'excellent', compared with only 37% of females, yet females performed better than males on a mathematical task. Critically, those students who perceived their mathematical skills more positively were more likely to pursue a STEM degree at university (Hango, 2013). Despite the overwhelming evidence that females are equally as capable in mathematics as males, the results from this study suggest that endorsing the stereotype that males are better at mathematics, or the effect of anxiety about confirming this stereotype, may be preventing cohorts of capable females from entering STEM careers.

Interestingly, upon the comparison of individual differences on each instrument (see tables 3 and 4), judges consistently scored both sexes as more creative on the Verbal Creativity task compared to the Mathematics Creativity task. Additionally, students themselves rate their Verbal Creativity (Metacognition) as higher than their Mathematics Creativity (Metacognition), suggesting confidence issues with the Mathematics Creativity task for all students, regardless of sex. Drawing on current research that suggests a large portion of Australian students experience Mathematics Anxiety (MA), (defined as feelings of fear or anxiety in the presence of a Mathematics task) (Australian Academy of Science, 2019), it is proposed that the wording of the Mathematics Creativity task (i.e., 'design an equation') may have inadvertently elicited MA in both males and females. Considering MA is a key indicator of the likelihood to continue with other mathematics-based courses in school, further research is needed to investigate this relationship in the context of mathematical creativity (Gunderson et al., 2018; Maloney et al., 2010).

What to Do About Stereotype Threat?

Existing literature provides compelling evidence of the benefits of sex equality in a modern STEM workforce with creativity at its core (Australian Mathematical Sciences Institute,

2019; Deloitte, 2016). It is, therefore, crucial to address the ST issues associated with mathematical creativity. Researchers such as Miller, Eagly, and Linn (2015) suggest that in order to reduce ST, people must either directly observe (e.g., through social interactions) or indirectly observe (e.g., through media campaigns) reinforcing counter-stereotypes (e.g., females in STEM roles) in order to alter persistent sex stereotypes. In Australia, campaigns such as the Australian Mathematical Sciences Institute's CHOOSEMATHS initiative provide female STEM role models to young girls, and many school-based initiatives also exist. Schools and teachers are encouraged to engage with programs such as CHOOSEMATHS as a means of showcasing strong female role models for STEM.

Additionally, past literature, including the *Teaching for Creativity in the Common Core Classroom* book (Beghetto et al., 2014), outline specific lesson plans for educators to teach all subjects, including mathematics, creatively. Such examples include integrating typical divergent thinking tasks such as the Mathematical Creativity task presented in this study to students in their everyday mathematics classrooms. Encouraging flexibility and originality in answer and question design for students can help promote mathematical knowledge and creative competencies (Beghetto et al., 2014). In their study, Niu and Zhou (2017) provided Grade 3 Chinese students with a divergent thinking-based task whereby students were prompted to generate multiple solutions to questions provided within their everyday mathematics classroom. These authors found that both student creativity and mathematical reasoning ability were enhanced in response to the divergent thinking task. Students may also experience an increase in motivation and engagement when presented with such creativity tasks (Beghetto et al., 2014). However, despite some previous research outlining potential suggestions as to how to overcome ST in female students, there is a lack of correlational research that examines the direct impact of a creativity-based task on females reporting ST. Therefore, further work is necessary to examine the impact of creativity-based interventions aimed at altering negative stereotyped beliefs in mathematics.

Limitations and Future Research

There were some limitations to this study. Participants attended a high socioeconomic status private school, limiting the ability to generalise results. Therefore, further research is needed to attempt to replicate these results with students from a more diverse socioeconomic background. Additionally, the students in the present study attended a high achieving school compared to the normal distribution of achievement across Australian schools. Maloney,

Schaeffer, and Beilock (2013) suggest that people who place strong importance on success in a domain are more likely to perform poorly under ST than those who do not place a high degree of importance on success in the domain. It is, therefore, possible that ST is more evident in this high achieving population.

Implications

Considering the importance of mathematics and creativity skills in the current global economy, all students would seemingly benefit from a targeted approach to eliminating sex discrepancies in mathematics. Though females did not underperform on the Mathematics Creativity task in comparison to males, Stereotype Threat could be undermining their confidence in their ability to perform. This is cause for concern, as research indicates that 75 per cent of the fastest-growing occupations require a STEM-based education, for which mathematical skills are crucial (Becker & Park, 2011). Females' lack of confidence in their mathematical ability may translate to a lack of confidence to pursue other STEM subjects, thus perpetuating the current sex disparity in all STEM fields. It is vital to continue investigating the relationship between sex and creativity in other STEM fields.

3.6 Conclusion

This research contributes to our current knowledge about creativity and mathematics and suggests that female students are experiencing ST in mathematical creativity. Moreover, the issues surrounding MA (or at least a lack of confidence in mathematical creativity abilities) is crucial to education research when considering the importance of mathematics and creativity skills for all students. Now that this chapter has identified the problem, chapter four will demonstrate how teachers endorse these inaccurate stereotypes.

Chapter 4: Teacher Beliefs Regarding the Relationship Between Sex and Mathematics (Study 2)

The research described in this chapter designated Study 2, addresses the findings from Study One (Chapter 3). Part of the study described in this chapter was published in Patston et al. (2017) (see Appendix K for full journal publication). Consequently, this chapter simply focuses on investigating teacher beliefs regarding sex differences in mathematics. Content analysis was used to systematically uncover key themes and abstract concepts embedded in the teacher interviews. This chapter is currently being prepared for submission to the International Journal of Qualitative Methods.

4.1 Introduction

4.1.1 Background and Motivation for the Study

As society transitions into the Future of Work, many jobs will require a firm foundation of STEM knowledge and skills if the anticipated challenges in healthcare, defence, environmental protection et cetera are to be solved. The role of mathematics will be crucial in this new era (Beilock & Maloney, 2015). Recent guidelines for Australian Mathematics curricula set by the Australian Curriculum Assessment and Reporting Authority (ACARA) (2016) reflect this concern through the tasks, evaluation and content knowledge they include. Comparative international evaluations revealed that Australian students underachieved in mathematics when compared to students from other countries in the OECD (OECD, 2012). These results give impetus to the development of further research that seeks to identify and understand different variables that may affect student mathematics performance. Possible strategies for future action by schools and communities can then be implemented to encourage improvement.

A complex set of factors can hinder students' mathematics achievement and, when considering interrelated variables, attitudes are identified by many researchers as an important focal point (Aiken, 1970; Bussey & Bandura, 1984). As suggested by Mata, Monteiro, and Peixoto (2012), the classroom culture and ethos can significantly determine student attitudes and disposition towards mathematics and can account for a large variance in mathematics scores. These researchers note that attitude has the potential to influence an individual's willingness to learn and to receive the benefits of mathematics instruction. Of greater concern is the propensity for this negative attitude to become permanent as students experience repeated failures with mathematical tasks. By the time many students reach secondary school, Brown et al. (2008) report, many students struggle to stay motivated to continue with mathematics as the pressure to perform well increases together with the frequency of over-demanding tasks. This punitive cycle is confounded further by teachers whom themselves have a negative attitude towards the subject.

Extending this sentiment further, a recurrent theme throughout mathematical studies is sex differences in attitudes and self-concepts. Within mathematics, boys are widely reported to have higher self-concept and attitudes towards mathematics than girls, although research has consistently shown limited differences in mathematical ability between sexes

(Mata et al., 2012). Even though positive attitudes have been widely reported as a significant predictor of mathematical success, the disproportionately small number of females in STEM vocations remains a matter of concern to society. Sex disparity in mathematics course-taking and STEM career participation is observed in many countries, including Australia. The under-representation of women in STEM fields in Australia is worthy of attention, with Roberts (2014) reporting that, in 2011, women accounted for only 28 per cent of the STEM-employed population in Australia. The disconnect between males and females reporting similar mathematics achievement scores and fewer girls undertaking mathematics-related careers raises the probability that factors other than biological sex differences play a critical role in females pursuing STEM careers (Gunderson et al., 2012).

It is well established that stereotypes regarding females and mathematics exist (Beilock et al., 2010; Gunderson et al., 2012; Maloney et al., 2013). Moreover, the notion of Stereotype Threat, or a confidence gap, is considered a key indicator for discrepancies in female mathematical performance and participation in related disciplines. As noted by Cvencek et al. (2015), boys and girls as early as second grade express explicit and implicit 'mathematics-is-male' stereotypes. Similarly, in an older sample (with a mean age of 27 years), Nosek and Smyth's (2011) results from 5,139 volunteers showed that females demonstrated stronger implicit negativity toward mathematics than males, and equally strong implicit sex stereotypes. Their findings demonstrate that for women stronger implicit 'mathematics = males' stereotypes predict greater negativity toward mathematics, lower participation, weaker self-ascribed ability, and subsequent diminished mathematics achievement. In contrast, these factors were weakly correlated in the opposite direction for males. These authors also note that implicit stereotypes have greater predictive validity of mathematics achievement than explicit stereotypes.

Research shows unequivocally that the majority of elementary school teachers in the West are female (Australian Bureau of Statistics, 2014; National Education Association, 2003; UNESCO, 2016) and that teachers are a highly mathematically anxious population (Hourigan, Leavy, & Carroll, 2016). Literature also highlights those female students who have teachers who endorse 'traditional' stereotypes about mathematics are more likely to hold negative sex-based stereotypes (Beilock et al., 2010). In addition, research demonstrates that early adverse experiences with mathematics can lead to lower levels of STEM course-taking for female students (Beilock et al., 2010). Therefore, unpacking how, and why, sex

contributes to the formation of negative stereotypes is paramount to ensuring archaic and inaccurate labels no longer impact girls. Equally important is understanding the effect of teachers' attitudes on students' attitudes and behaviours which is mediated through the interactions between these groups. Becoming cognisant of this interplay is vital for advancing theoretical knowledge and designing interventions that target the negative cycle perpetuated about females and mathematics.

4.1.2 Aims and Objectives of the Study

Under-representation of females in Mathematics-based STEM programs is a key concern, and the need to understand how to develop effective measures to address this situation remains an ongoing challenge (Roberts, 2014). The marginalisation of females in STEM careers is entrenched in historically and culturally held beliefs and much of the search for effective solutions remains uncharted. Whilst no particular ideology is heralded as being systematically successful in reversing the trend, across the range of policy and practise levers available there is undoubtedly a benefit to educating teachers about the negative role of Mathematics Anxiety. The importance of having a consistently positive mindset towards mathematics cannot be underestimated in raising the national level of female participation in STEM fields (Roberts, 2014). Accordingly, this study aims to understand teacher attitudes regarding the relationship between mathematics and sex. Previous research suggests that when mathematically anxious individuals are female elementary school teachers, their MA carries negative ramifications for their female students (Beilock et al., 2010). This aim of this study is to explore the attitudes and beliefs of teachers to understand how they view sex differences in mathematics. It is proposed that these interviews will provide insight into teacher attitudes towards mathematics which may lead to effective interventions that target the development of positive mathematical attitudes in female students, in turn improving STEM involvement for females.

4.2 Methodology

While many studies explore the impact of teachers' attitudes towards mathematics, and interventions have been proposed to target underlying beliefs, further elucidation of the mechanisms of social transmission of sex-related attitudes towards mathematics is warranted. In order to explore this concept in a focused way, a series of structured, qualitative interviews

were conducted which asked four questions surrounding teacher attitudes towards mathematics and sex stereotypes.

4.2.1 Object of Interest

- What attitudes do elementary school teachers hold regarding the relationship between mathematics and sex?

  This question was addressed through four main research questions.

4.2.2 Main Questions

- When you hear the word ‘Mathematics’ what comes to mind?
- Can you describe any sex differences in Mathematics? For example, is a particular sex better at Mathematics?
- How do you think your sex influences your confidence teaching Mathematics?
- To what extent do you agree with the statement: ‘Boys are good at Mathematics, girls are good at reading’? Why?

4.2.3 Justification of Question Choice

The structured interviews were framed using questions to encourage interviewees to respond in an unhindered fashion to reveal their implicit and explicit beliefs. This study used Hourigan et al.’s (2016) research on 345 pre-service elementary teachers as a foundation for exploring how teachers’ attitudes and beliefs about mathematics can affect students. Hourigan et al.’s (2016) qualitative approach involved asking participants the following question: ‘When you hear the word mathematics, what comes to mind?’ Their study focused on altering pre-service teachers’ attitudes to teaching mathematics after they had received mathematics education as part of their university program. These researchers noted that the data from this question “served to gain insight into the characteristics of entrants and to facilitate the development of a program which was led by student need” (p. 332). To gather similar information with the aim of informing a subsequent pilot study that utilises a creativity-based intervention to alter teacher attitudes towards mathematics (Chapter 5 of this thesis), this study used the same question. Of particular interest is the fit between data emerging from this question and the opportunity to generate further theoretical knowledge surrounding attitudes to and stereotypes of mathematics.

A focus on the role played by teachers' attitudes and behaviour also led to the question: 'To what extent do you agree with the statement "Boys are good at mathematics; girls are good at reading"? Why?' Whilst this question has a quantitative element it was chosen based on Gunderson et al.'s (2012) conceptualisation of female teachers' attitudes and how teacher attitudes can determine the choices made by male and female students to pursue mathematics-related courses and careers. These researchers investigated students and explored the phenomenon of Stereotype Threat and implicit and explicit attitudes, both of which have been shown to negatively impact females' interest and performance in mathematics and STEM-based careers. The authors found that female students endorsed the statement 'mathematics = males' if their female teacher held negative attitudes towards mathematics. The rationale for framing the question in the same way as Gunderson et al. (2012) was to determine if in fact, teachers also endorsed this statement or if students only hold this belief. Additionally, it was essential to understand why/why not teachers agreed/disagreed with the statement.

Two further questions were asked in this study to capture teacher implicit and explicit attitudes regarding their own sex and the teaching of mathematics. The use of implicit and explicit measurement methods when stereotypes are measured in sensitive domains, such as sex stereotypes, is supported in the literature (Cvencek et al., 2015). This distinction is made as human behaviour is not only guided by deliberative, conscious processes, but also by more automatic, non-deliberate, and faster processes; these two processes can be captured by two corresponding types of measures, termed *explicit* versus *implicit* measures (Cvencek et al., 2015). Furthermore, although much research to date has focused on US schools, Mathematics Anxiety has been shown to surface during students' educational pathways at all levels across the globe.

Participants:

The participants for this study include educators employed at multiple school sites across Australia. The understanding of teachers' attitudes is based on Bandura's theory of social learning which posits that people learn from one another by observing, imitating and modelling others' behaviour (Bussey & Bandura, 1984). The idea that students model their teachers' behaviour made it necessary for the participants in this study to be 'in-service' teachers, rather than pre-service teachers enrolled in an undergraduate program. Teachers taught in Australian classrooms ranging from Grade 1 through to Grade 7. Participants ranged

in age from 18–24 through to 55–64 years and had a variety of teaching experience. Four teachers were considered ‘early career’ having less than three years’ experience and teachers had a range of specialties and varied in employment status from contract to full time. Associated with a focus on teacher attitudes towards mathematics is pedagogical content knowledge, which is necessary for educators to transfer subject matter into a method by which topics are best understood by students (Hourigan et al., 2016). Consequently, participants had to be cognisant of the revised Australian Mathematics Curriculum and possess teaching qualifications at a Bachelor or Master’s level. Additionally, although the issue of sex and mathematics has been studied for decades, investigations of the causal links between teachers’ beliefs and students’ mathematical attitudes and behaviours in Australian schools have been rare. Consequently, Australian teachers were examined in this study to raise awareness of these issues and offer practical assistance to the Australian school community. As a result, it is suggested that findings can be generalised only to the participants engaged in the study, however, the findings can also provide a basis for future studies in the field.

Sample Size:

It is generally accepted that 6 to 12 participants are necessary to achieve a purposive and relatively homogenous sample and to achieve data saturation in a qualitative study (Guest, Bunce, & Johnson, 2006; Hayward & Tuckey, 2011). 14 teachers participated in this study which included 10 females and 4 males. The sex ratio of participants is representative of the current teaching environment in Australia, reported as being 70% female and 30% male (Australian Bureau of Statistics, 2012). Table 5 highlights the demographic variables for this sample. The individual columns relate to each participant response, i.e. 14 in total. The headings of the rows represent each demographic question, i.e. 9 in total. Please note that ‘elementary school’ teachers in Australia are called ‘primary school’ teachers and refer to themselves as such in the following tables.

The 9 demographic questions that teachers were asked are provided below.

1. In what year did you complete your teaching degree?
2. What qualifications do you possess? i.e. Bachelor of Education etc.
3. Do you possess a STEM degree?
4. What was your specialisation at university?

5. What is your current employment status?
6. What year level do you presently teach?
7. What subject do you like teaching the most?
8. Please specify your sex
9. Please specify your age range

Table 5

Demographic information for all 14 teachers on all 9 questions

Teacher	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
1	2004	Post Graduate Certificate in Education	Yes Bachelor of Applied Science	Conservation of Cultural Materials	Full time	Grade 6	Science/IT	Female	55–64
2	2017	Masters of Special Education (Deaf and Hard of Hearing)	No	Special Education	Full time	Reception–Grade3/4	Mathematics	Female	45–54
3	1994	Bachelor of Education (Elementary)	No	Primary	Full time	Reception/Grade 3	English	Female	45–54
4	1986	Diploma of Teaching	No	Sociology	Full time	Reception/Grade3/4	English	Female	55–64
5	2016	Bachelor of Education (Primary)	No	Outdoor Education and English	Full time	Reception/Grade 1	All	Male	25–34
6	2014	Bachelor of Marketing Management, Graduate Diploma in Teaching and Learning	No	Marketing	Full time	Grade 1	English	Female	25–34

Teacher	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
7	2003	Bachelor of Education (Junior Primary & Primary)	No	Children's Literature	4 days a week	Grade 3	History	Female	35–44
8	1983	Bachelor of Education	No	Psychology	2 days a week	Grade 2	Science	Female	55–64
9	2016	Bachelor of Education – Primary	No	Catholic Studies	Full time Contract	Grade 3	Science	Female	55–64
10	2015	Bachelor of Education/ Primary	No	All subjects from Reception to Grade 7	Full time	Grade 6/7	Maths/English	Male	25–34
11	2017	Bachelor of Primary/Middle Education	No	French and English	Full time Contract	Grade 2/3/4	Literacy	Female	18–24
12	1991	Bachelor of Education Primary	No	Children's Literature and Drama,	4 days a week	Gifted and Talented	Enrichment	Female	45–54
13	2006	Master of Education	No	Graphic Design	Full time	Grade 7	All of them!	Male	35–44
14	2012	Grad. Dip. Education, Bachelor of Business	No	Primary	Full time	Grade 6	Mathematics	Male	25–34

Procedure:

Initially, participants were recruited based on personal relationships I have with teachers at school sites in South Australia. These teachers were contacted via email. Once consent was obtained, the interview occurred via telephone according to a detailed script (see Appendix F). Phone interviews occurred with four participants. These interviews were documented with recording software and were kept on a password-protected iPad. Interviews lasted on average 10 minutes. The interviews were then uploaded to Temi software and transcribed.

In order to increase the response rate, I opted to place the questionnaire online via the Qualtrics platform. A further 10 participants were then recruited via email invitations. A 'snowball' method for recruitment was then utilised whereby one participant was recruited and then that participant provided details of other teachers who also wanted to participate. Participants who completed the survey online were provided with a link where they typed their responses to questions. Once the phone and online interviews were complete, all 14 surveys were then copied into NVIVO software Version 12.

Since the questions were modelled on prior surveys (e.g., Gunderson et al., 2012; Hourigan et al., 2016), data were analysed similarly, as discussed below.

Choice of Content Analysis as the Data Analysis Method

In order to extract and analyse the meaning of the narratives provided by the participants a content analysis methodology was used. Fraenkel and Wallen (2006) define content analysis as "a technique that enables researchers to study human behavior in an indirect way, through an analysis of their communications" (p. 483). The purpose of content analysis is to study the verbal communication and social behaviour of participants without influencing it. Content analysis allows a researcher to interpret what is being communicated, why it is being communicated, and with what effects (Babbie, 2004). Content analysis is characterised by a codification process, which involves placing coded data into key categories and then into more abstract concepts (A. Cropley, 2002).

Content analysis was chosen as a method to analyse this interview data for several reasons. Firstly, sex differences in mathematics is a contentious topic and one could assume that providing answers in a strictly quantitative manner could induce social desirability bias in teacher responses, therefore not accurately reflecting their opinions. Alternatively, content

analysis of qualitative interviews allows both implicit and explicit attitudes to be identified and therefore provides rich data that quantitative data would not generate for this topic (Cvencek et al., 2015). Secondly, content analysis was chosen based on its methodology of 'making constant comparisons' which forces the researcher to be immersed in the data and therefore minimises the risk of subjective interpretations from the researcher (Babbie, 2004). This is important for this study, as it highlights accurate teacher attitudes and social behaviours. Thirdly, content analysis allows for themes and relationships between concepts and categories to be explored objectively, and these can form the basis of further research (Fraenkel and Wallen, 2006). Analysing the data from the interviews in this manner allows study three (Chapter 5) of this thesis, i.e. a pilot study to be conducted in an unbiased manner.

Overall Approach to Content Analysis and the Coding Process

A content analysis approach was adopted, where the data grounded or embedded in the information collected from teachers was systematically analysed to infer themes and attitudes. After the 14 interviews had been conducted, the raw data were transcribed, coded and clarified, which is referred to as 'cleaning the data' (Glaser, 2002). Secondly, a process of analytic induction was carried out, which consisted of a succession of 'question and answer' cycles, exploring the relationships among existing units in the participants' statements (i.e., constant comparative analysis) (Glaser, 2002). This systematic process resulted in broad themes which reflected the central issues in the study. This 'raw' data was then organised into an elementary structure consisting of clusters of individual content units related to particular *categories* (A. Cropley, 2002). Next, by examining the data and collecting new data, the categories were clarified and more closely defined, in order to ensure that they had been correctly understood. This is known as *saturating the categories.* After refining of the categories, more general and overarching categories that encompassed several of the earlier categories were formulated. These overarching categories are known as *concepts.* Next, connections among the concepts were identified. These final relationships were then linked back to current and existing research (including Bandura's social learning theory). The relationships that were uncovered in this study were then tested in a subsequent study (see Chapter 5 for a discussion of Study Three, a pilot study on altering attitudes). Figure 2 highlights this four-stage process, which was undertaken for each participant and each question, and each stage is explained in further detail in the following sections.

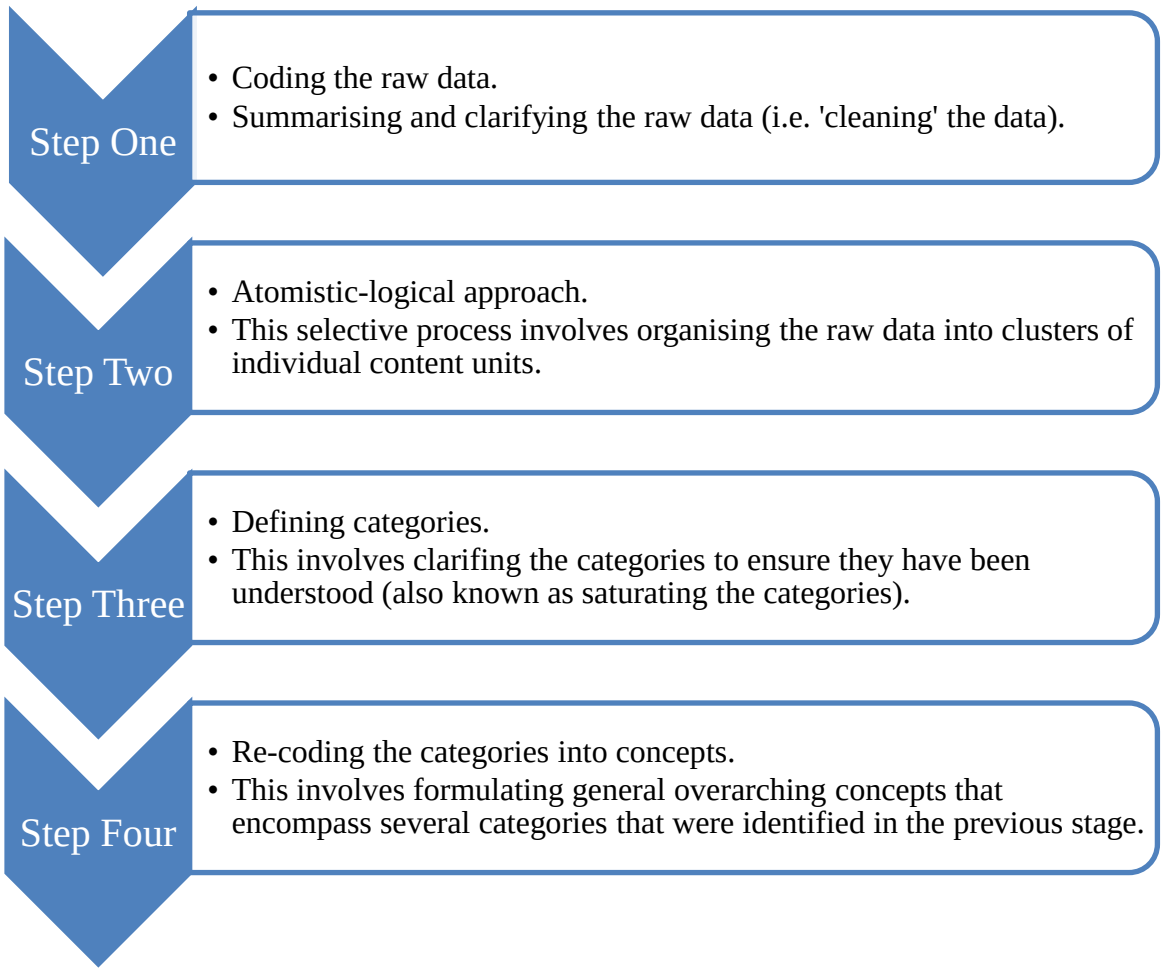


Figure 2 Example of content analysis process that was undertaken for each question and each participant in this study

Coding the Raw Data (Step One)

The first step in qualitative analysis is often called *coding*. Coding is necessary because the 'raw' text of an interview often contains information and material that cannot be used for analysis. This irrelevant information usually involves: (a) meaningless or unintelligible text (for instance, expressions such as 'Ah,' 'Like,' or 'Mmmm?'); (b) repetitious text (whilst repetition may indicate the intensity of a participant's views, so it may well be important, it does not introduce new themes); or (c) irrelevant ('irrelevant' in the present context means that a statement does not refer to the specific object of interest). This process is referred to as 'summarising' the data. Next, the data must be clarified. This process involves restating the text in a way that makes the meaning unambiguous without altering the participant's meaning. This may involve turning slang into standard language.

Atomistic-Logical Approach (Step Two)

Once the data had been clarified and summarised in Step One, the responses can be chunked into small units that contain brief statements which are related groups of words, thoughts, and ideas. These statements become *content units* whereby each unit contains a single idea. The content units are not interpretations from the researcher; they must be explicit words expressed by the respondent. In this way, reliability is enhanced as the researcher maintains objectivity. Each new sample is compared with those content units that are already created and new units are added when an existing statement does not fit. This process is referred to as systematic *deconstruction* and *reconstruction* of the original narrative. When the point is reached that there are no longer new content units arising, convergence has been achieved and parsimony requires that no further protocols be needed.

Table 6 is an example of Step Two that was conducted for one participant on the first qualitative question. This process initially involved observing content units based on raw data. This was achieved by chunking the raw data into smaller 'samples' for individual participant responses and these were coded.

Table 6

Example of Inductive Analysis process for one participant's response to question one

Sample units from interview transcript from one participant	Content Unit
Traditional thoughts developing across the strands of Mathematics	Traditional
But number always holds a traditional	Traditional
conventional	Conventional
Mathematics as a tool for exploring the world	Tool for exploring

Defining Categories (Step Three)

After Step Two, comparative analyses were conducted of the key content units that had emerged from each interview and for each question. The process of selective coding involves mapping similar responses within and across each group to produce a picture of generic mathematics attitudes/sex-based issues as abstract *categories*. This process involves general theoretical ideas that the content units refer to and providing abstract and scientific labels. Sometimes a unit belonged to more than one category. In these cases, a new category was created to address this duplication, and the unit(s) was transferred into that category. Table 7 highlights the process of moving from a content unit to a more abstract category. This process is repeated until no new categories emerge from the data.

Table 7

Example of turning content units into specific categories

Content Unit	Category
Learned Behaviour	Acquired Skills
Fear	Feelings
Social Misconceptions	Stereotypes

Recoding Categories into Concepts (Step Four)

Once Step Three had been undertaken several times and all the interviews examined, no new categories were emerging from the raw data; therefore, the categories could be recoded into somewhat more abstract concepts. The content units become the properties of the low-level categories, and those categories became the properties of the higher level, more abstract concepts (Glaser, 2002). Occasionally it became clear that categories themselves could be altered or merged, and this process unfolded as the coding developed. For example, two early categories of 'Traditional'' and 'Conventional' merged into the concept 'Cognition' when it was clear the units in each of these were so similar. Table 8 is an example of content units becoming categories and then concepts.

Table 8

Example of turning content units into specific categories and then more abstract concepts

Content Units	Category	Concept
Negative Feelings	Feelings	Affect
Fear		
Lack of Confidence	Self-Confidence	
Confidence Drop		
Sense of Self		

A diagrammatic illustration of the samples to a category to a concept is shown below as Figure 3. All four stages occurred as highlighted in Figure 3 for each question and participant.

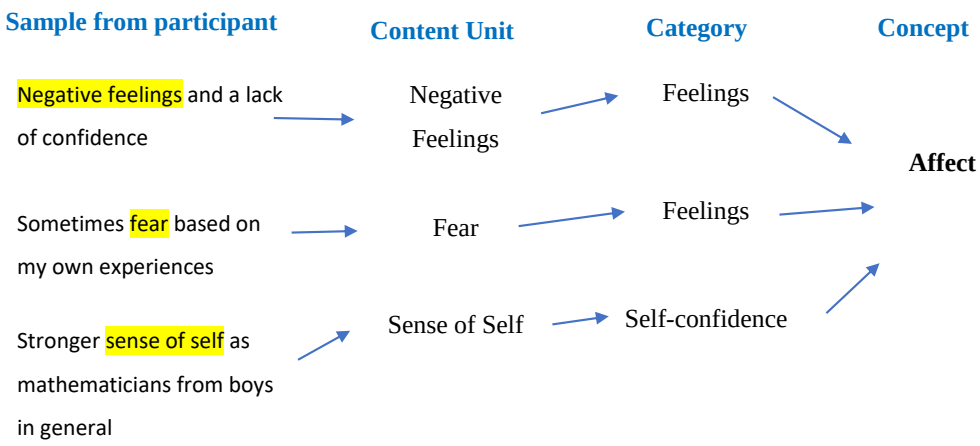


Figure 3 Sample from participant to concepts flow diagram

4.3 Results

The results below are presented sequentially. Table 5 (shown previously) provided the demographic information for all 14 teachers on each of the 9 demographic questions. Table 9 through to Table 12 present the raw data: that is, the transcript for each participant for each question in the order questions were presented to the participants. This data has been cleaned (summarised and clarified) as described in step two. Table 13 highlights the sample units from the participants, the final category and the final concept of each participant's responses. Note that each category and concept followed the same four-stage process, as highlighted in Figure 2. The identified themes of each question are highlighted in the discussion section. Please note that not every participant answered every question, so the number of responses fluctuates for each question.

Table 9

Raw responses from teachers on the question 'When you hear the word 'mathematics' what comes to mind'?

1. Problem solving
2. Numbers, mathematicians, complex theories, many different areas to teach, problem solving... the list goes on!
3. I suppose my traditional thoughts developing across the strands of Mathematics, data, geometry, statistics and probability the areas of Mathematics, but number always holds a traditional conventional, helping children be numerous, like learning literacy, helping children become numerous is, I suppose, a primary thought. But I think over the years of exploring education in general, and because I teach in a primary setting, I think of Mathematics as a tool for exploring the world. Like language. Like thinking skills, it's a mode for thinking skills.
4. **Teacher:** Numbers. Do you mean my feelings? **Researcher:** You can answer however you feel like you've answered the question. So yeah, you can talk about feelings or more logically or however you'd like to approach it. **Teacher:** I guess numbers, well I guess numbers, it's just like in my mind at the moment I'm thinking of natural Mathematics, which is just this framework that's used in some schools overseas and that is like quite different from what we've learned at uni. I guess that's what I

think of when I think of Mathematics. It's, I guess, numbers and I don't know. It's, it's hard to, it's hard to get your thoughts out.

Researcher: So, when you say natural Mathematics, can you expand on that a little bit?

Teacher: So, it's problem-based learning, but the structure of lessons, are kind of different, I guess. So usually you'd have like your engagement section where you get them into the activity, acknowledging their prior knowledge and things like that. But at the start of the natural math session, there's like a mental routine, which is I guess getting them familiar with the language that they will use in that unit of work. And then the next part of the session is like problem solving, it changes every lesson. So one lesson might be a whole lesson on problem solving, just with a question that's not highly scaffolded and they need to kind of figure it out themselves.

5. Textbooks. Yeah so when someone says Mathematics I just think of those big chunky textbooks that you had in high school.
6. Negative feelings and a lack of confidence.
7. Problems to solve. Sequential learning of facts and concepts, leading to a ‘big picture’ of mathematical knowledge.
8. Numbers, calculators, problem-solving.
9. Number knowledge.
10. Numbers, numeracy skills, logical mind work and problem solving. In the past I would’ve said things like equations, confusing and complex but since I began teaching that has changed. It is more holistic, and it’s helped me understand its value more.
11. The four operations come to mind, also problem solving for daily life, practical application, do I need to know this, when will I ever use this particular Mathematics.
12. Sometimes fear, based on my own experiences at high school.
13. Problem solving.
14. Problems, numbers, wooden blocks.

Table 10

Raw responses from teachers on the question 'Can you describe any sex (male, female) differences in Mathematics? For example, is a particular sex better at Mathematics? Why/why not'?

1.	I have never noticed a particular sex being stronger at Mathematics. My experience has showed me a relatively even balance.
2.	There aren't any. People's attitudes and abilities in Mathematics are determined by a number of factors and have a lasting impact on them.
3.	**Teacher:** I don't think a particular sex is better at math. I do think that the individuals bring an aptitude and some children have ease and comfort with Mathematics and some have a real reservation around Mathematics and I think that parents, because I work with, children 12 years and under, it's the close relationship with the family dynamic and I think parents have been very conventional attitudes about Mathematics and those convictions link to sex a little bit. **Researcher:** Okay, so you would think that if there were any differences it would be coming from the parents expecting or assuming that there are differences? **Teacher:** Yeah, potentially or certainly environmental factors. So I do notice differences in sex in Mathematics, I do notice a greater ease and confidence around Mathematics among boys. A stronger sense of self as mathematicians from boys in general. I feel as though there's something in the environment that makes it easier for them to explore the world that way or something's going on.
4.	**Teacher:** I'm trying to think of my class. My class is already male dominated, but I would say the males in my class are better at Mathematics probably. **Researcher:** All right. Okay. And is that in their results? **Teacher:** It's just that there's more of them, I guess. So, because there's more male children, they'd be at the same level but there's just one female in my class, who is at a really low level, and the others are probably at a similar level, but then there's some males that is low as well. I guess if you take away the male dominance in the class, they'd be equal.

Researcher: Just because you've got more males, you see them, I guess you see more results from them.

5. In my opinion no. I think it comes down to the individual student and their mentality towards Mathematics and numeracy and it comes down to their personal feelings towards Mathematics and the anxiety they hold or don't hold towards that.
6. No sex is better at Mathematics than another...but in junior primary no noticeable difference is seen but then as girls get older their confidence can drop in some circumstances.
7. No I do not believe either sex is inherently 'better' at Mathematics. I believe a lot of boys enjoy Mathematics as their favourite subject.
8. I've taught Year 1 for three years and have generally had male students with Mathematics as their strength area.
9. Nope, not that I've noticed in my classes. I do teach special education though, so I teach majority male students on the autism spectrum.
10. Sex doesn't play a part, both can be equally capable, maybe in the past fields of employment may have seen more males employed.
11. I don't believe a particular sex is better at Mathematics than another. I think we generalise too much about this, and this then promotes a self-fulfilling prophecy.
12. No difference just depends on their exposure and attitude.
13. I don't believe there are innate differences. I believe there are learned behaviours which result in differences.

Table 11

Raw responses from teachers on the question 'how do you think your own sex influences your confidence teaching Mathematics'?

1.	I don't believe my sex has any impact on my confidence teaching Mathematics.
2.	I don't feel it does influence it. It may have influenced me if there is indeed a societal misunderstanding that males are better at Mathematics, in that my teachers and parents might have thought I'd be better at it or given me more attention for it or something like that, but I don't believe my sex means anything directly about my ability or attitude.
3.	I wonder how sex has impacted but I definitely have my own story with Mathematics through junior school. That was actually what influenced my decision to teach and to teach in junior schools not senior schools. It was that I loved learning maths as a young primary student. I loved learning and I loved school. I loved the social relationships. I admired teacher mentors and I loved the content. It was quite conventional, but I loved it. And I remember feeling confident about myself across all areas of the curriculum except physical education, until I got to Year 4. And then I remember learning subtraction algorithms. I don't know why I remember that more than anything else that I had to learn. And I remember watching a subtraction algorithm on the board and asking this teacher, who I adored. And yeah, it was a comfortable classroom, it was a good classroom. There were boys. I remember there were boys who were quick, and we played a lot of those quick times games. And you wouldn't have thought it was my strength around that time that I enjoyed Mathematics as much as anything else. And I remember asking where this magic just appeared from, when you couldn't subtract a greater number from a smaller number, you just added one and added one. And I said, numbers are stable, you can't find numbers and the teacher said to me, you just do it and you will get the right answer. And I took that really personally because all of my other role models who are competent accepted that and operated that way and did really well and went on doing really well, including the girls. And I felt there must be something horribly wrong with me. And I began to doubt myself mathematically and I've struggled the next two years in Mathematics and I couldn't have separated it out there. I didn't know what I know now. And so I guess when they did reasoning tests and thinking tests, I could score highly, but when they tested mathematical skills I couldn't score highly because I was quite anxious. So I decided, I wanted to teach in primary and I

	wanted to give children authentic experiences that helps them think about the thinking and, and realise that there is pattern and process and that it's not magic tricks.
4.	Well, I was nervous about it finishing university, but now starting teaching, I quite enjoy trying to think of engaging ways to teach Mathematics. But I think, because it's a Year 2, 3, 4 class and because these kids are at quite a low level of Mathematics, so I feel confident in teaching it because I can understand it well. It's quite simple Mathematics but then, if it was an older class I think I would probably be a little bit nervous.
5.	It's a weird question because like I really struggled, it's one of the reasons I became a teacher, I really struggled all throughout school with Mathematics and English so I don't know I guess like yeah I don't really have an answer either way, I don't feel more confident teaching Mathematics because I'm a male.
6.	I think stereotypically males are better than females at Mathematics.
7.	I'm not sure it's my sex or my circumstances that caused me to lack confidence in teaching Mathematics. But I do know I didn't possess enough knowledge about teaching Mathematics after I graduated. I think the - [*college were the participant studied]* - didn't focus enough on teaching Mathematics...but then, most of my tutors were women! Interesting!
8.	I don't think it does. When I teach a concept, I try and relate it to the students and their everyday life experiences.
9.	My sex doesn't make me more or less confident, it's my own attitude, I have had great female mentors for my own personal Mathematics development as it relates to teaching.

Table 12

Raw responses from teachers on the question 'to what extent do you agree with the statement 'boys are good at Mathematics, girls are good at reading'. Why'?

1.	Disagree. My experience teaching hundreds of students has shown this to be incorrect. All students are different regardless of sex and this is true too for their strengths and weaknesses.
2.	I don't agree with it at all. There's nothing about the brain or how it works that is determined by what sex you are. As I've stated previously, any differences that may or may not occur are purely due to societal misconceptions about sex and are sociologically entrenched because of these misconceptions.
3.	I don't know. I do, I agree with that statement in the sense that I think boys are socially more comfortable as mathematicians. Yeah, I just don't agree that there's any particular reason for that other than social. And that, with girls, there's a whole lot of conventions and behaviours. Girls do tend to achieve some social and behavioural maturity ahead of some boys and reading is an independent task and it is a quiet task and I think it is something girls are able to access better than boys, not in terms of skills but in terms of pleasure and ability to sit and invest.
4.	**Teacher:** I don't agree with that statement because I think everyone has their own life experiences, they bring to those areas I guess, it depends on the parents as well. It doesn't matter if they're male or female, but a girl might be better at reading because the parents are reading to her every night. But then a male might also be good at reading because that happens. But, I feel, maybe with males in a metropolitan setting, they, that's like a stereotype that you noticed. **Researcher:** Are you in a country area? **Teacher:** Yeah. I'm in a remote area. In an Aboriginal setting. **Researcher:** So, would you suggest that you might see that statement, as in boys are better than girls at Mathematics, in a metropolitan school? **Teacher:** Yeah. But that's my only experience really of actually teaching apart from placement and has been in a remote setting.

Teacher: It's just archaic, it's generalisation. Every single person is individual and the way they process information is completely individual and in my experience it all just comes down to that child's attitudes towards learning and I think that's the biggest influence so regardless of sex I don't think any of that matters.

Researcher: Ok do you think there's maybe a difference because you teach upper primary by any chance?

Teacher: Possibly. I mean I don't have the experience teaching junior primary at a prolonged level. But you know there's lots of archaic old teachers.

5. I agree 100% that this statement is a common perception in life as I have heard it said many times. My own experiences as a teacher contradict this statement as I have found no differences in males' and females' ability in either subject.

6. In the past...Boys were encouraged by society to problem solve, build things, play certain games, etc. and girls were encouraged to play with dolls etc. and to sit quietly and possibly read...nowadays things are different and electronic devices dominate their lives. As a junior primary teacher I believe reading abilities have been pretty even between the sexes.

7. I do not believe this is true. I believe many boys enjoy Mathematics but are not necessarily better at it than girls.

8. I somewhat agree that boys tend to excel in Mathematics more so than girls, and girls tend to excel more so in Literacy than boys, however this is purely based on my teaching experience. Obviously, every cohort has various strength areas.

9. Not at all. I have seen both good at both... it's just not something I think rings true

10. In the past people may have had this view, stereotypes...both of my girls are very good at Mathematics and have completed Mathematics to Year 12, at university both daughters have had to use Mathematics skills in their study.

11. Disagree. My experiences with Mathematics are based purely on the lack of quality teaching I received at high school, in addition to the comments teachers made about me – that I would never be successful with Mathematics. That was the teacher's view of me, not my view based on my sex.

12. I believe girls are taught to use their imagination more and are encouraged to engage in literacy more than boys, so they often score better than boys. I also believe we don't have enough reading materials appropriate for boys to engage them. I don't believe the preferences for English or Mathematics are sex-linked. I believe girls are equally good at Mathematics, until they begin to feel it makes them 'geeky' and therefore less fun/acceptable.

4.3.2 Content Analysis Data Analysis

One conceptualisation of sex and mathematics that emerged from the teachers' remarks was labelled 'Social Factors'. Typical categories defining the concept were 'societal misconceptions', 'societal encouragement' and 'stereotypes'. Another different conceptualisation identified in the content units was labelled 'affect.' Typical categories defining this concept were 'self-confidence', 'feelings', 'emotion', and 'motivation'. A different kind of conceptualisation was observed in the cognitive view expressed by some of the teachers interviewed. This led to the concept of 'cognitive factors'. Typical categories here were 'thinking skills', 'knowledge', 'problem-solving' and 'usefulness'. These concepts are shown in Table 13 along with the content units from which they were derived, and the categories defined by these content units.

Table 13

Content units, categories and concepts derived from the qualitative data

Content Units	**Category**	**Concept**
Learned behaviours	Acquired skills	Cognition
Thinking skills		
Problem-solving		
Knowledge		
Prior Knowledge		
Aptitude	Innate ability	
Negative feelings	Feelings	Affect
Anxiety		
Fear		
Enjoyment		
Lack of confidence	Self-confidence	
Confidence drop		
Doubt myself mathematically		
Boys are more comfortable		
Motivation	Attitude	
Dependent on attitude		

A common perception	Stereotypes	Social factors
Stereotypically males are better		
Social misconceptions		
Boys are encouraged by society	Social expectations	
Less accepted in girls		
Boys are socially more comfortable		
Societal misunderstanding		
Sociologically entrenched		
Encouraged by society		
Role models	Family influence	
Environment		
Depends on parents		
Family dynamics		

Table 13 shows clearly that the teachers in the study understood the issue of sex differences in mathematics in terms of three fundamental dimensions (referred to as ‘concepts’ in the table): cognition, affect and social factors.

4.4 Discussion

The purpose of this study was to examine the object of interest: '*What attitudes do teachers hold regarding the relationship between mathematics and sex?'* This question was answered through content analysis interpretation of teachers' responses to four key questions. The results highlight that the teachers in the study understood the issue of sex differences in mathematics in terms of three fundamental concepts: cognition, affect and social factors.

Teachers held cognitively based opinions towards mathematics, often describing it as 'logical and numerical' which is in line with very traditional definitions of the subject. These traditional definitions are often opposed by definitions provided by mathematicians, who also define it as 'poetic' (Hardy, 1940) or as 'creative' (Poincaré, 1910; Sriraman, 2009). These numerical definitions are also in stark contrast to creativity-based definitions of mathematics which include words such as problem formation (problem finding), invention, independence and originality (Krutetskii et al., 1976). One teacher in this study specifically mentioned that *"traditional conventional views and thinking skills"* were what came to mind when she thought of mathematics. Additionally, the category of innate ability highlights a very close-minded approach to the subject. One teacher's response that *"I do think that the individual brings an aptitude"* is indicative of the belief that being capable at mathematics is not necessarily something that can be fostered, rather a student has the ability, or they do not. The relationships in this cognitive concept suggest that elementary school teachers in Australia hold very traditional and cognitive beliefs about mathematics. These cognitive beliefs are based on students receiving information and knowledge without having enough time to fully explore, understand and apply the concept before moving on to the next mathematical idea (Shehayeb & Anouti, 2018). Traditionally, mathematics has always been viewed as a rigid discourse, with many students and some teachers viewing it as having little practicality in everyday life. Teachers' practices, especially those teachers who are not confident in teaching mathematics, can contribute to students' negative attitudes if they are taught mathematical content just to pass mathematics exams, as opposed to teaching practices and strategies that aim to apply mathematics to real-life situations (Shehayeb & Anouti, 2018). Moreover, traditional teaching pedagogy stifles the flow and opportunity for creativity as a means of mediating positive mathematical attitudes in the classroom.

Another key result from the teacher qualitative interviews suggests that some teachers may have an implicit 'mathematics = males' attitude bias. This bias was most present in both

the affect and social factor concepts. One route through which teachers can convey messages about mathematics-sex stereotypes is through self-concepts. For boys, stronger mathematics-sex stereotypes correspond to stronger mathematic self-concepts, whilst stronger mathematics-sex stereotypes correlate to weaker mathematics self-concepts for girls (Cvencek et al., 2015). The present results extend the past work by Cvencek et al., (2015) by demonstrating that even when teachers do not hold explicit beliefs regarding sex differences in mathematics, they nevertheless acknowledge that student mathematics achievement is significantly associated with socio-cultural factors present in society. A comment such as *"I think stereotypically males are better than females at mathematics"* combines mathematics-sex stereotypes and mathematics self-concepts as a systematic relationship. Eagly (2013) demonstrated how sex stereotypes, when viewed from a sex-stratification viewpoint, can influence self-concept. The author noted that if young girls believe that they are not culturally linked with mathematics, this may be the avenue by which sex differences and stereotypes are internalised to develop self-concepts. Hence, girls will spend less time studying mathematics because they are not socially expected to excel in mathematics (Eagly, 2013). These findings support other research theories about domain-specific self-concepts which can operate implicitly. Cvencek et al.'s (2015) study of elementary school children highlighted that stronger implicit mathematics self-beliefs correlate to higher achievement for both sexes in standardised test-taking. Additionally, these researchers noted that stronger implicit mathematics-sex stereotypes were associated with teachers who themselves were anxious about teaching mathematics. Some theorists have suggested that implicit elements tap into learned associations that are automatically activated over long-term exposure (Cvencek et al., 2015). Results from this present study concerning teachers' negative attitudes towards mathematics are consistent with the findings from Cvencek et al. (2015). Both implicit and explicit negative associations with mathematics have a long history of being rehearsed in students' minds and are more likely to be linked with their own anxiety towards mathematical material which can carry on to negative behaviour towards STEM career choices (Hourigan et al., 2016). Given that some teachers did explicitly state that 'mathematics = males', it can be concluded that sex beliefs about mathematics are more detrimental to female attitudes. Accordingly, it is important to investigate these findings further.

Teachers often explicitly stated that males were stereotypically more 'mathematical' than females and were more comfortable around the subject. Often respondents provided a

dominant male positive sex bias or at least alluded to 'stereotypes' that mathematics is more male-dominated regardless of ability. For example, when participants expressed their belief that stereotypes do not exist, they also responded that the role of attitudes was more important than sex as highlighted by the following remarks: "*No sex is better at mathematics than another…but then as girls get older their confidence can drop in some circumstances"*. The incongruence of this response highlights how teachers do not believe that there are underlying biological sex issues, yet they believe that a lack of confidence can impact girls' ability to succeed in the subject. Based on widespread literature, it follows that teacher-student interactions and implicit negative attitudes from female teachers towards mathematics are very likely to be contributing to this anticipatory emotion.

This sample of teachers established clear differences in how male and female teachers perceived sex stereotypes. All four male teachers stated that there were no sex differences in mathematics, whereas nine out of ten female teachers reported sex differences in some way. The thoughts generated from this question suggest that male teachers possess somewhat non-traditional beliefs about sex differences, however, female teachers maintain very traditional, stereotypical beliefs. Expanding this sentiment further, even when female teachers did not report explicit stereotypical beliefs, they demonstrated implicit attitude biases towards mathematics being a male-dominated subject. This disconnect is congruent with literature that has historically reported how male and female teachers approach the subject (Beilock et al., 2010). Most elementary school teachers in Australia are female (70% female, 30% male) (Australian Bureau of Statistics, 2012), and many females (both teachers and students) experience Mathematics Anxiety and endorse the commonly held stereotype that boys are inherently better at mathematics than girls. The findings of this study reflect current literature which has detrimental implications for female mathematics success and STEM participation (Beilock et al., 2010).

Nonetheless, when investigating stereotypical influences on children's attitudes towards mathematics, one must look beyond basic one-to-one mappings between sex and children's attitudes (Gunderson et al., 2012). A crucial finding from this study was that only female teachers reinforced that they lacked a strong degree of mathematical confidence; the male teachers did not report the same low confidence. Researchers, including Ehrlinger and Dunning (2003), suggest that this lower confidence is common within the female population and is extremely detrimental to girls' self-concepts and mathematical achievement. Research

conducted in Study One of this thesis supports the findings from Ehrlinger and Dunning (2003) and highlights that young female Australians doubt their capacity to perform specific types of mathematics, such as mathematical creativity. Repeatedly, psychological and educational research has highlighted how beliefs can substantially influence learning. At the most basic level, Bandura's theory of social learning and concept of modelling suggest that teachers are transferring sex-mathematics attitudes to their students. A crucial finding of this research is highlighting this lower level of teaching confidence in female teachers and these findings suggest that future research should focus on heightening teacher awareness of the implicit ways in which they are impacting their students. This increased awareness, in turn, can help alter the environment for those who are at risk of lower mathematical achievement. These findings provide support for an attitude bias theory and propose that future interventions for teachers should target female mathematical attitudes and confidence, not female ability.

One surprising finding from the interviews was that teachers felt that parents strongly contribute to sex-based stereotypes, not themselves as teachers. Some teachers endorsed the statement that 'girls are good at reading and boys are good at mathematics'. However, teachers also noted that parents and society were responsible for the stereotypes around mathematics by suggesting that the statement is generally accepted. The following remarks provide an example of this: "*I agree 100% that this statement is a common perception in life as I have heard it said many times. My own experiences as a teacher contradicts this statement as I have found no differences in males' and females' ability in either subject"*. Or, as explicitly stated by another participant, "*I do, I agree with that statement in the sense that I think boys are socially more comfortable as mathematicians. I just don't agree that there's any particular reason for that other than social".* Since a relationship between mathematics self-concepts and achievement has been established, there may be a similar relationship between mathematical attitudes and STEM choices for those females who validate such beliefs. The endorsement of stereotypical or societal stereotypes by teachers in the study was alarming. As noted by Beilock et al. (2010), Mathematics Anxiety is not necessarily a proxy for diminished mathematical achievement, rather self-doubt and negative self-beliefs can impede the ability to access the mathematical knowledge a student possess. Sex stereotypes are highly salient to mathematical achievement, with girls more likely to notice their teacher's negativity and anxiety towards mathematics (Gunderson et al., 2012). This is

particularly relevant to understanding the Australian context in that even if young girls excel in mathematics at elementary school, the stereotype that '*boys are good at mathematics, girls are good at reading'* can bias girls and have consequences for their mathematical performance.

4.5 Conclusion

In summary, teachers from this study lacked self-awareness regarding how their confidence, attitudes and self-concepts towards mathematics affect their students, particularly females. The interviews highlighted that teachers view mathematics in terms of three key concepts: cognition, affect and social factors.

Teachers endorsed traditional and cognitive views of mathematics, often describing it as logical and number based. Despite not always explicitly holding archaic or stereotypical sex-based beliefs, data from this study revealed that teachers do hold implicit stereotypical mathematics beliefs. Additionally, stark differences in attitudes between male and female teachers were concerning, with female teachers possessing more negative stereotypical attitudes than male teachers. In order to have a more comprehensive understanding of this topic, and to allow for the exploration of different routes to alter these attitudes, further research was undertaken to design an intervention based on the three concepts of cognition, affect and social factors. This work is described in Chapter 5.

Chapter 5: Examining the Impact of a Creativity-Based Intervention on Teacher Attitudes Towards Mathematics (Study 3)

The research described in this chapter designated Study 3, addresses the findings from Studies One and Two (Chapters 3, and 4). This study is a pilot intervention that used a creativity-based approach to increase positive attitudes towards mathematics in elementary school teachers.

5.1 Introduction

Background and Motivation for Study

Australia is undertaking the methodical reforms required to increase the progression of women in the STEM workforce. However, progress in ensuring sex equality in STEM careers in Australia is slow as Roberts (2014) reports, 32% of tertiary qualifications in STEM fields were awarded to females in 2000, and this had increased by only 1% by 2011. The *Women in STEM Decadal Plan* emphasises the economic benefits globally of closing this sex gap in STEM, noting that increasing female participation in STEM careers by 25% could increase the global gross domestic product (GDP) to US$5.3 trillion by 2025 (Australian Academy of Science, 2019). STEM disparity is often due to cultural and social stereotypes and a lack of understanding of what STEM careers demand. A myriad of proposals for rectifying STEM inequality has been put forward, including adopting a creativity-based approach to address negative attitudes towards mathematics. A crucial case for systemic and cohesive change must begin at the grassroots, therefore, action is required at both the teacher and student level (Australian Academy of Science, 2019).

For more than five decades, researchers have reported how teacher attitudes towards mathematics are significant influences on students' mathematical outlook and mastery (Aiken, 1970). Moreover, in the last 30 years, researchers in both the US and Canada have highlighted increasingly high levels of Mathematics Anxiety (MA) experienced by elementary (elementary) school teachers, which can negatively affect the likelihood of their female students pursuing a mathematics-based career (Brady & Bowd, 2005; Bursal & Paznokas, 2006; Hembree, 1990). It is well established that a teacher's attitude towards subjects, including mathematics, influences their instructional techniques, the way they organise the content to be taught, and consequently, their students' attitudes toward the subject (Fennema et al., 1990; Pajares & Miller, 1994). Teachers are responsible for

educating our future STEM workforce; therefore, addressing negative teacher attitudes is paramount if students are to pursue STEM careers. To encourage students to study STEM subjects, teachers need to both help students develop adaptive problem-solving skills and to relate mathematical challenges to the real world. Through the application of creative processes, learners are encouraged to take risks, build independence and advance innovation. As society and education progress through rapid changes, students must learn to process new stimuli imaginatively rather than regurgitate common knowledge regressively.

By examining concepts from a different perspective, one's mind is stimulated to process ideas deeply and critically, thus forming new connections (Gabora, 2017). Hence, creative models of understanding allow for new concepts to transcend traditional disciplinary boundaries to foster the forging of new interconnected thought patterns (Gabora, 2017). Gabora (2017) likens creativity to gaining deeper "webs of understanding" (p. 1). Regarding mathematics, educators are encouraged to pose questions and challenges whilst facilitating the opportunity for reflection to foster the development of novel links between ideas. Accordingly, in the process of evolving creative processes, educators must not propagate stereotypical ideas. The mixed signals female teachers and students broadcast regarding mathematics were highlighted in Study One (Chapter 3) and Study Two (Chapter 4). Results from both these studies demonstrate that sex differences in mathematical creativity and sex differences in attitudes towards mathematics are present in Australian students and teachers. Bandura's theory of social learning and the concept of modelling explain these findings by proposing that a student will mimic the behaviour of a same-sex teacher (Bussey & Bandura, 1984). Since elementary school teachers in many Western countries are predominantly female, there is a greater risk of female students modelling this harmful disposition from their female teacher (Australian Bureau of Statistics, 2012; National Education Association, 2003; UNESCO, 2016). Furthermore, the results from Beilock et al. (2010) suggest that a teacher who exhibits high MA also tends to hold low mathematics teaching self-efficacy. Consequently, this teacher can demonstrate their dislike of mathematics to students, and in doing so, confirm obstructive mathematical sex stereotypes (Beilock et al., 2010; Swars, Daane, & Giesen, 2006). Conversely, a teacher who has low MA and high mathematics teaching self-efficacy may have the aptitude to counteract these sex stereotypes and encourage positive mathematical attitudes. This suggestion is supported by research highlighting that competent female role models can encourage high levels of mathematics

achievement for female students (Marx & Roman, 2002). The research conducted by Beilock et al. (2010) represents an initial step towards establishing the role and impact that teachers' can have on the formation of students' mathematical motivation and interest. Since these types of sentiments are strongly correlated with student mathematical success, there is a vital need for creativity-based interventions to improve teachers' attitudes and advance student engagement.

Creativity and Mathematics

Global data has highlighted the need to revitalise mathematics in schools (National Council of Teachers of Mathematics, 2018). Taylor (2019) suggests that the student experience of mathematics is that it is irrelevant and uninteresting and that a focus on the skills of critical thinking, communication, collaboration and creativity are needed. Attempts to bridge the divide between current skills and those needed for successful 21st century living include efforts by the Australian Curriculum and Reporting Authority (ACARA) (2016), which has incorporated 'General Capabilities' into the Australian Curriculum, with 'Critical and Creative Thinking' as one necessary capability. By narrowing the gap between 'real mathematics and school mathematics' and broadening the divide between 'traditional' and 'discovery' mathematics, Taylor (2019) suggests students will be taught to negotiate the world through complex analysis and critical and creative investigation. Creativity, when applied to mathematics, has the potential to connect students to larger imaginative projects in response to life's challenges and triumphs (Taylor, 2019). The goal of educators must, therefore, be to create a sense of personal passion towards mathematics, thus ensuring that students can work collaboratively to problem-solve before embarking on STEM careers.

As discussed in Chapter 2, within the education context, the definition of creativity includes the concept of generating an artefact or product that is novel, effective, elegant and displays genesis (ability to shift paradigms) within an environment that is relevant to a social context (D.H. Cropley & Kaufman, 2012; D.H. Cropley & Cropley, 2011). More specifically, creativity can be defined in terms of processes that enable one to cognitively conceptualise the world by relating to it (Gabora, 2017). Creativity-based interventions are based on the definition of teaching *with* creativity and teaching *for* creativity.

Longitudinal research suggests that an increase in creativity can lead to a decrease in anxiety (Baas et al., 2008; Byron & Khazanchi, 2011). Anxiety functions by restricting

working memory and impacts one's ability to complete a task successfully (Ashcraft & Kirk, 2001). Byron and Khazanchi's (2011) meta-analysis assessed 59 independent research studies to conclude that anxiety is negatively correlated with performance on figural and verbal creative tasks. Researchers have also demonstrated that when one's creativity levels increase, anxiety levels are decreased (Byron & Khazanchi., 2010; Napoli et al., 2005; S. Shapiro et al., 2011).

Teaching Mathematics Creatively

In their recent analysis of global curricula, Patston, Kaufman, A. Cropley, & Marrone (2020 submitted for review) (discussed in detail in the journal publication highlighted in Appendix N) report that there is an increased emphasis in countries around the world on developing creativity in schools. However, these authors note that often creativity is misdefined or lacks a specific link to subjects, including mathematics. Taylor (2019) notes the common difference in describing mathematics as "calculations, procedures, or rules", as opposed to evoking "aesthetic" and "creative" ideas about literature (p.1). Additionally, recent educational research demonstrates that whilst educators perceive creativity across disciplines, it is often predominately viewed with an 'arts-bias' in countries around the world (discussed in detail in the journal publications highlighted in Appendix L and Appendix M) (Patston et al.,2018; Cropley, D. H., Patston, Marrone, & Kaufman, 2019). Gabora (2017) reports that often educators limit creativity to arts-based subjects through fear it will disrupt the classroom. Gabora (2017) also notes that although educators value creativity, they do not prioritise it. However, when teachers are encouraged to teach subjects such as mathematics 'creatively', there have been positive effects on student attitudes (Beghetto et al., 2014; Tok, 2015). To date, only a small number of empirical studies on teaching mathematics creatively have been conducted (Leikin et al., 2009; Leikin & Pitta-Pantazi, 2013).

While it is difficult to confidently establish cause and effect links between mathematics and creativity because of minimal evidence, attempts to establish relationships have been suggested by Bahar and Maker (2011). The researchers' investigation of 78 elementary students from first to fourth grades demonstrated that students' mathematics achievements were found to be positively and significantly correlated with creative mathematical performance (Bahar & Maker, 2011). Furthermore, Tok's (2015) study demonstrated that students who were exposed to a 'teaching mathematics creatively' based curriculum had higher mathematics grades and had less MA in comparison to students who

were taught ‘traditionally’. Plucker and Renzulli (1999) also found that a positive attitude towards a subject may be an indicator of creative potential.

Similarly, Sak and Maker’s (2006) investigation of first to fifth-grade students highlighted that students’ mathematical knowledge increased as their creative mathematical thinking skills also increased. Nonetheless, as noted by Gabora (2017), nurturing creativity in the classroom in an era when children are hyper-stimulated and easily distracted is not easy. Moreover, the dichotomy between curriculum requirements to develop students’ problem-solving skills through the promotion of creativity and the routine learning of procedures is discussed by Mann (2006). Mann’s findings suggest levels of creativity increase as students’ progress in grade level and mathematical knowledge, however, the pattern of growth in creativity diminished in the ninth grade when more advanced algebra was intensively taught using traditional ‘algebraic solution methods’. Since creativity has the potential to thrive in contexts where both constraint and liberty coexist, the results from Mann (2006) align with other researchers such as Tabach and Friedlander (2013) to suggest mathematical achievement is the strongest predictor of mathematical creativity. Similarly, a recent study conducted by Tubb et al. (2020) (discussed in detail in the journal publication highlighted in Appendix O) highlights that although mathematical creativity in student populations increases from year to year, there is a significant within-year decline in creativity. Haavold (2018) also compared the mathematical creativity of students across grades and examined students in Grades 8 and 11. The author found evidence that the older students (Grade 11) were more creative on a mathematics task (noting, however, a significant interaction between age and mathematical achievement).

In summary, the ideas proposed in the literature suggest a disconnect between educators’ claims that they value creativity and their ability to incorporate it into the mathematics curriculum effectively. Although it is difficult to measure the role of creativity in mathematics, as few studies have undertaken this research, there is overwhelming evidence that mathematically anxious teachers can impede the performance of their students, particularly for females. By nurturing the skills and attributes of creativity, educators have the potential to help students to approach mathematical tasks with confidence and excitement. Creativity can be effectively interwoven into a mathematics curriculum to help overcome anxiety and foster positive attitudes towards mathematics. However, there is a lack of holistic research that combines elementary school teachers’ attitudes towards mathematics and MA in

relation to creativity. This study aims to address the shortcomings of the literature by investigating the impact of a creativity-based classroom intervention on teacher attitudes towards mathematics.

Aims and Objectives of the Study

The need to address the persistent and highly negative disposition towards mathematics by females has become crucial. Low participation of females in mathematics is particularly problematic as in many cases mathematics is a prerequisite for studying STEM disciplines at a tertiary level. As a gateway discipline to STEM fields empowering students to improve their mathematical skills' is an opportunity for educators to have a substantial impact (Roberts, 2014). Thus, providing a platform for tackling the issue of sex disparities in STEM careers is the goal of this study. To effectively implement an intervention, one must understand the relationship between mathematics, sex and creativity. Understanding this relationship will help answer the key question: 'How do we encourage positive mathematical attitudes and creative abilities in students, particularly females?'

Misconceptions about mathematics can impede learning, as a fixed mindset[20] affects a learner's ability to believe they can achieve mathematical success (The Australian Association of Mathematics Teachers Inc. (AAMT), 2015). Such fallacies can create a classroom culture where it becomes accepted for females to proclaim that they are not as good at mathematics as boys. Unfortunately, these self-proclaimed beliefs often go unchallenged and contribute to a student's emotional alignment to mathematics (The Australian Association of Mathematics Teachers Inc. (AAMT), 2015). In the same way, a negative disposition impacts a student's confidence, motivation, attitude and behaviour towards mathematics beyond the classroom. Many teachers seldom realise how their attitudes and behaviour influence student achievement, as exhibited in Study Two, Chapter 4. A teacher's behaviour is keenly observed by students and acknowledging this influence is at the basis of this study. This study draws on findings from Study One and Study Two and will investigate how a creativity-based intervention affects both male and female teachers' attitudes towards mathematics.

[20] A fixed mindset in this context is defined as a closed, inflexible mindset and not Carol Dweck's Mindset Theory.

Expected Contributions of the Study

It is expected that this study will contribute to the theoretical knowledge regarding 'teaching mathematics creatively' and will improve teacher attitudes towards the subject. This increase in positive attitude will, therefore, allow teachers to model accurate behaviours which will consequently help their students to achieve their mathematical potential and make choices based on factors other than worry and fear (Buckley, 2013). Despite the link between attitudes and MA being widely researched, admitting to worrying or personal difficulties with mathematics should not be considered the norm. On the one hand, if a student excels at mathematics, they will often be labelled a 'nerd', whilst, on the other hand, admitting to a dislike or anxiety over mathematics is considered socially acceptable (Buckley, 2013). Such a contradiction reflects a culture that accepts and perpetuates the development of MA. This study will encourage teachers to foster the belief that stereotypes and negative cultural perceptions should not limit student mathematical choices.

The incorporation of creativity with teacher attitudes to mathematics provides greater insight into solving issues such as MA, negative attitudes towards mathematics and sex differences. This research has real-world implications for teachers, policymakers and students because if teachers learn to teach mathematics creatively and experience an increase in positive emotions towards the subject, they may then transfer these positive attitudes onto their female students (Cheryan & Plaut, 2010). Therefore, it is expected that this study will help influence the attitudes of individuals so that both teachers and students will invest more effort into mathematics, students will learn more effectively, and ultimately the sex gap in STEM will be bridged.

5.2 Methodology

To address the research gaps discussed in Section 5.1, this study is designed as a longitudinal pilot study in the form of a quasi-experiment and tests four hypotheses. The sex-related hypotheses refer to differences between the sexes (i.e., between male and female teachers). The intervention of this study is founded on Cropley's Fostering Creativity in the Classroom General Principles framework. The aim of Study Three is to investigate how a creativity-based classroom intervention affects teacher attitudes towards mathematics. The teachers had their 'mathematics attitudes', and Mathematics Anxiety (MA) levels quantitatively measured

both pre- and post- participation in the creativity-based intervention, and at a three-month follow-up.

Participants

A total of 13 teachers from two school sites in South Australia engaged in this pilot study. There were 10 females and 3 males. The sex ratio of participants is representative of the current teaching environment in Australia (i.e., 70% female, 30% male) (Australian Bureau of Statistics, 2012). Teachers had a variety of teaching experience ranging from 3 years' experience up to 37 years. Most were long-term teachers with the average teaching experience being approximately 12 years. Eight teachers were considered Junior Elementary (i.e., Reception to Grade 3) and five teachers were considered Upper Elementary (i.e., Grade 4 to Grade 7). Six teachers worked at a category 2 (low socioeconomic status) state school in Adelaide's northern suburbs and seven teachers worked at a private independent school (high socioeconomic status) in the eastern suburbs of Adelaide. The study is grounded on the pioneering work of Bandura, whose theory of social learning suggests that a student will model their behaviour after their teacher (Bussey & Bandura, 1984). Therefore, this study required 'in-service' teachers. It is proposed that these results can be generalised to in-service Australian elementary and middle school teachers.

Hypotheses

- H1: Teachers will have more positive attitudes towards teaching mathematics in response to the creativity-based intervention.
- H2: In response to the creativity-based classroom intervention sex differences regarding attitudes towards mathematics will be reduced amongst teachers.
- H3: Teachers' Mathematics Anxiety will decrease in response to a creativity-based classroom intervention.
- H4: In response to the creativity-based classroom intervention sex differences regarding Mathematics Anxiety will be reduced amongst teachers.

Support for Choice of Measures:

All teachers completed the Aiken Revised Mathematical Attitudes Scale and the Revised Mathematics Anxiety Rating Scale at three-time points: pre-test, post-test and at a three-

month follow-up to determine any changes in the teachers' perceived attitudes towards mathematics and their experiences of MA.

Teachers' attitudes towards mathematics were collected through the Aiken Revised Mathematical Attitudes Scale (Aiken, 1974). The Aiken scale consists of two (sub) scales measuring Enjoyment of Mathematics (E) and attitudes to the Value of Mathematics (V) (See Appendix H). The E scale consists of 11 survey statements (items), and the V scale contains 10 items. Responses to the items are presented on a Likert scale ranging from zero to four (0 = strongly disagree, 1 = disagree, 2 = unsure, 3 = agree, 4 = strongly agree), where zero indicates an extremely negative attitude, two represents a neutral attitude and four an extremely positive attitude towards mathematics.

Teachers' MA levels were measured through a revised version of the Mathematics Anxiety Rating Scale (MARS) (See Appendix I). The scale consists of 30 questions presented on a five-point Likert scale, ranging from 1 = not at all anxious through to 5 = very much anxious. A total Mathematics Anxiety score is calculated by summing all the values. The lowest score indicating no MA is a value of 30 and the maximum score indicating extreme MA is 150. Cronbach's alpha of .96 indicates high internal consistency, while the test-re-test reliability for the MARS 30-item scale was .90 ($p<.001$) (Richardson & Suinn, 1972).

The creativity-based classroom intervention was based on Cropley's *Fostering Creativity in the Classroom: General Principles* research (1997). Cropley's Fostering Creativity in the Classroom framework suggests that there are 3 general principles and 24 sub-principles that contribute to providing a holistic approach to creativity in the classroom. To date, there is no research as comprehensive and detailed as Cropley's, which can be applied to the aims of this study and, therefore, this framework was chosen. A detailed description of Cropley's principles is included in Table 14 below. The median reliability of all the principles are .82.

Table 14

Cropley: Fostering creativity in the classroom general principles

What should teachers foster in their students?	**Personality properties favourable for Creativity:**	**Creativity-fostering teachers are those who:**
Possession of a fund of general knowledge.	Task commitment, persistence and determination.	Encourage students to learn independently.
Knowledge of one or more special fields.	Curiosity, adventurousness, and tolerance for ambiguity.	Have a cooperative, socially integrative style of teaching.
An active imagination.	Independence and nonconformity.	Motivate their students to master factual knowledge, so that they have a solid base for divergent thinking.
Ability to recognise, discover, or invent problems.	Self-confidence and willingness to risk being wrong.	Delay judging students' ideas until they have been thoroughly worked out and clearly formulated.
Skill at seeing connections, overlaps, similarities, and logical implications (convergent thinking).	Drive to experiment and willingness to try difficult tasks.	Encourage flexible thinking in students.
Skill at making remote associations, bisociating, accepting primary process material, forming new gestalts, etc. (divergent thinking).		Promote self-evaluation in students.

Ability to think up many ways to solve problems (divergent thinking).		Take students' suggestions and questions seriously.
A preference for accommodating rather than assimilating.		Offer students opportunities to work with a wide variety of materials and under many different conditions.
Ability and willingness to evaluate their own work.		Help students to learn to cope with frustration and failure, so that they have the courage to try the new and unusual.
Ability to communicate their results to other people.		

Note that this table has been reproduced from information available in Cropley (1997).

Procedure

Teachers participated at their school site, and this study was conducted twice (once at each school site). Initially, teachers had their MA levels measured on MARS and their attitude towards mathematics measured on the Aiken attitudes scale. All teachers provided demographic information, including age, sex, years of teaching experience, and what year level and subject they predominantly taught. All questionnaires were delivered online via the Qualtrics survey platform. Following the completion of the questionnaires, all participants engaged with the intervention. The intervention was split into three, one-hour sessions (three hours total). The intervention was based on the Australian Mathematics Curriculum and Cropley's Fostering Creativity in the Classroom General Principles Research (see Appendix J for a detailed script of each session). After the intervention, all participants were re-measured on the MARS and Aiken scales. At a three-month follow-up, all participants re-completed the MARS and Aiken scales. Follow-up qualitative questions were also completed in order to elicit further information on teacher attitudes. Figure 4 demonstrates this process visually.

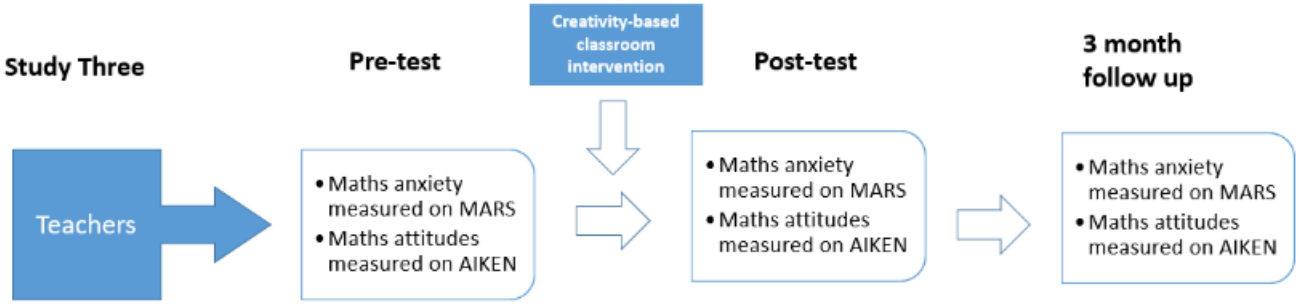


Figure 4. Flow diagram of research

5.3 Results

Data have been restricted to basic descriptive statistics due to the small sample size and investigative nature of the design. Median values are presented below, for each time point and sex, on MA and attitudes towards mathematics. The Attitude scale is calculated from both the Value and Enjoyment of Mathematics subscales which are presented in their subscale form. Tables 15 to 18 highlight the median scores for each time point and on each test. Please note that there was a fluctuation in teacher numbers as some teachers did not fill out the surveys at all time points.

Table 15

Median Mathematics Anxiety scores for each time point by sex

Sex	Time	N	Median
Females	1	10	75.0
Males	1	3	69.0
Females	2	4	80.5
Males	2	2	64.5
Females	3	6	90.0
Males	3	3	70.0

Table 16

Median Enjoyment of Mathematics scores for each time point by sex

Sex	Time	N	Median
Females	1	10	37.0
Males	1	3	35.5
Females	2	4	37.0
Males	2	2	37.0
Females	3	7	39.0
Males	3	3	36

Table 17

Median Value of Mathematics scores for each time point by sex

Sex	Time	N	Median
Females	1	10	36.0
Males	1	3	37.0
Females	2	4	37.0
Males	2	2	39.0
Females	3	6	37.0
Males	3	3	38.0

Table 18

Median Attitude (Enjoyment + Value) scores for each time point by sex

Sex	Time	N	Median
Females	1	10	74.0
Males	1	3	72.5
Females	2	4	73.0
Males	2	2	76.0
Females	3	6	76.5
Males	3	3	75.0

Figure 5 is a graph highlighting teacher attitudes towards mathematics at each testing time point (pre, post, 3 month follow up) and Figure 6 is a graph highlighting MA levels for teachers at each testing time point.

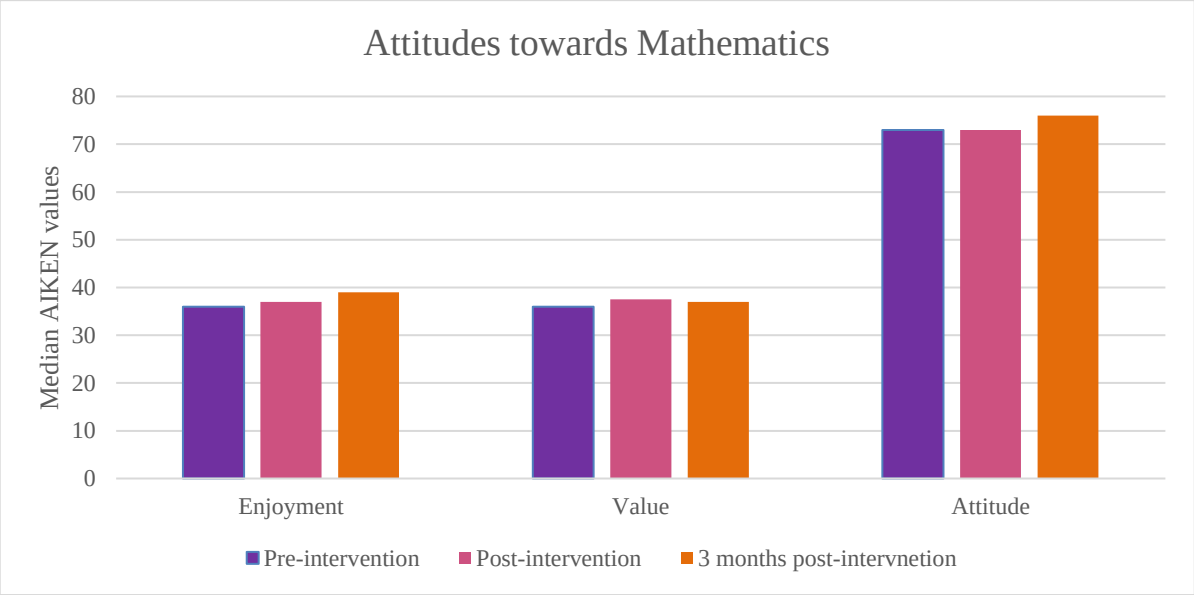


Figure 5 Median values for teacher attitudes towards mathematics as measured by the AIKEN at each testing time point.

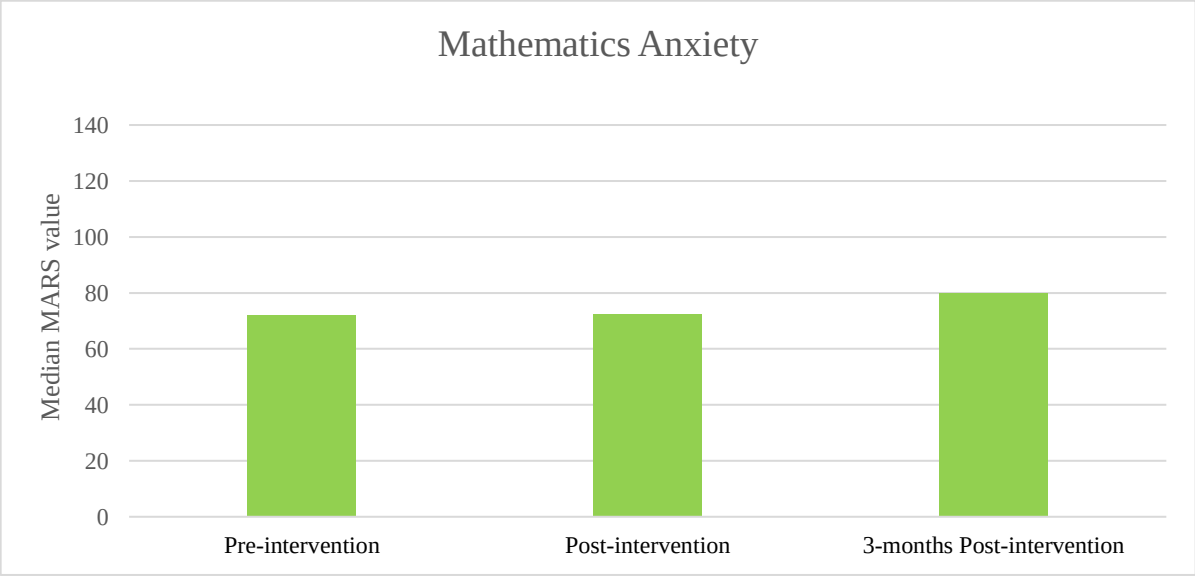


Figure 6 Median values for teacher Mathematics Anxiety levels as measured by the MARS at each testing time point.

Follow-up Qualitative Interview Questions

Due to the small numbers of participants and therefore, inability to calculate inferential statistics on the data, participants were asked additional qualitative questions at the three-month follow-up stage. The questions were:

1. How is creativity valuable in teaching mathematics?
2. How have your attitudes towards mathematics changed since engaging in the 'creativity in mathematics' workshops?
3. How do you think your students' attitudes towards mathematics could be improved if they were exposed to a creative approach to teaching mathematics?

Individual Responses to Question 1

Question 1: How is creativity valuable in teaching mathematics?

- *Participant 1:* "open ended questions that link to everyday life can assist people to become more creative in their approach and have a better understanding of the world and more able to solve problems."
- *Participant 2:* "Help you think creatively to solve problems and come from different angles."
- *Participant 3:* "It makes it fun."
- *Participant 4:* "Extremely valuable. It allows for a real connection between people and Mathematics."
- *Participant 5:* "Developing life-long innovative learners."
- *Participant 6:* "It allows students to think beyond the classroom and find relevance to their learning. It allows ownership and personalisation over their learning."
- *Participant 7:* "Creativity is very valuable in teaching Mathematics because it helps develop 21st century creative learners and equip them with problem solving skills: identifying the difficult; searching for solutions and formulating results in almost all domains of work and life."

Individual Responses to Question 2

Question 2: How have your mathematics attitudes changed since engaging in the 'creativity in mathematics' workshops?

- *Participant 1:* "Confirmed my beliefs and it's built a stronger appreciation of the desire to be more creative when approaching Mathematics."

- Participant 2: “Not a lot.”
- *Participant 3:* “It hasn't changed.”
- *Participant 4:* “I have more ideas and resources.”
- *Participant 5:* “I have started enjoying teaching Mathematics to my students.”
- *Participant 6:* “Working collaboratively, exploring resources.”
- *Participant 7:* “I have realised that creativity can be learned through looking at and working with the different characteristics of creative people. The workshops reinforced our current teaching pedagogy in the Junior Elementary to allow students to be creative and flexible thinkers and have a voice in their learning.”

Individual Responses to Question 3

Question 3: How do you think your students’ mathematics attitudes could be improved if they were exposed to a creative approach to teaching mathematics?

- *Participant 1:* “Students’ attitudes can be shaped to have a different mindset and to be able to have a go, where previously they may not.”
- *Participant 2:* “Help them to develop a love of Mathematics and see its real-world application in their daily lives outside of school.”
- *Participant 3:* “They will start enjoying Mathematics like other subjects.”
- *Participant 4:* “The children in my class love Mathematics as it is creative and fun.”
- *Participant 5:* “I use a creative approach to Mathematics.”
- *Participant 6:* “Life-long learners.”
- *Participant 7:* “Our students are already exposed to a creative approach and I think we need to continue to foster creativity in the classroom.”
- *Participant 8:* “It would help them be more confident and develop mathematical thinking.”

5.4 Discussion

This study investigated the effects of a creativity-based intervention on teacher levels of Mathematics Anxiety and attitudes towards mathematics. This study particularly investigated how male and female teachers differed in response to creativity-based training. The results are interpreted and discussed in the context of strengths, limitations and areas for future research.

There was a trend in data that is in line with Hypothesis 1. Teachers' attitudes towards mathematics were more positive in response to the intervention. Median scores of both perceived Value of Mathematics and Enjoyment of Mathematics increased post-intervention. Similarly, there was a trend in data that supported hypothesis 2. Sex differences regarding attitudes towards mathematics were reduced amongst teachers. If it were merely the case that both male and female teachers are equally mathematically anxious, one would expect to see similar results for both male and female attitudes post-intervention. In fact, Table 18 highlights that female teachers experienced a greater increase in positive attitudes than male teachers' post-intervention. Taken together, both H1 and H2, highlight the most important and interesting findings of this study, namely a shift in attitudes towards mathematics between males and females. Whilst the difference was minimal, females held more positive beliefs towards mathematics at the end of the intervention and more so than males. Enjoyment and value of mathematics were more likely to be aligned post-intervention for all participants, suggesting teachers held more consistent positive beliefs post-intervention. This finding is important in the context of past research. As previous literature has reported, issues such as poor attitudes, implicit beliefs, and/or stereotypes that can promote a negative culture and lack of enjoyment around mathematics (Beilock et al., 2010; Gunderson et al., 2012). When teachers and the broader community fuel negative beliefs, there are implications for female students who may experience Mathematics Anxiety and choose not to continue with mathematics-based subjects at a higher level (Beilock et al., 2010; Gunderson et al., 2012). This research provides preliminary data to suggest that a creativity-based intervention can mitigate these ramifications by positively shifting both male and female teacher attitudes towards mathematics. These findings can be extended to propose that creativity may support students to develop a more positive attitude towards mathematics and improve mathematical achievement.

The data did not support Hypothesis 3 or Hypothesis 4. Whilst male teachers experienced a decrease in anxiety immediately following the intervention; female teachers did not. The results suggest that, for both male and female teachers, Mathematics Anxiety increased by the third time point, i.e., three months post-intervention. The increases were small, and the median values still fell within a low to medium level of MA for both males and females. Considering that the increases were small, and the sample size fluctuated so significantly (i.e., from 10 females at Time 1; to 4 at Time 2; and 6 at Time 3), it is difficult to ascertain the cause of these changes. Considering that the biggest increase was between Times 2 and 3 (i.e., immediately following the intervention and at a three-month follow-up), this could suggest that teachers had a positive experience with the training, but not enough to ensure long-term change occurred. Research suggests that shifting attitudes is challenging, and these findings may indicate that teachers would have benefited from follow-up intervention sessions that target such beliefs (Petty & Cacioppo, 1986). It is also possible that anxiety increased over the school year as mathematical content increased in difficulty. Nonetheless, it is a positive sign to see a smaller increase in anxiety between Times 1 and 2, indicating that the intervention may have had a small impact on teacher anxiety.

Follow-up Qualitative Interview Findings

The answers to Question 1 support the belief that teachers held more positive attitudes towards mathematics post-intervention, as they found the link between creativity and mathematics valuable. One teacher noted that their attitude had changed dramatically by suggesting *"Mathematics is fun"*. From an educational perspective, it would be useful if creativity-based interventions addressing MA could be integrated into junior elementary school, due to the pliability of stereotypes and emergence of self-concepts at an early age (Cvencek et al., 2015). This would support socio-mathematical standards consistent with fruitful mathematical thinking and promote norms that identify mathematics as enjoyable and useful.

The responses to Question 2 indicate significant changes in some teacher attitudes with responses such as "*I have started enjoying teaching Mathematics to my students"*. It is interesting to note that the only respondent who reported that their attitude had not changed was a male teacher, which affirms the quantitative responses from males. Male teachers already held more positive attitudes than female teachers' pre-intervention. However, it is important to note the dramatic shift, as highlighted in the qualitative interviews towards

positive attitudes in female teachers, who started with slightly negative or less positive attitudes than their male counterparts. Considering this intervention was designed to lessen the sex gap between male and female teachers and their attitudes towards teaching mathematics, these qualitative findings help support this claim.

Responses to Question 3 support the idea that future studies are warranted to investigate the interplay between the transfer of teacher-student attitudes towards mathematics and the benefits of creative pedagogy. Teachers acknowledge the importance of encouraging creativity in the classroom with one participant noting that "o*ur students are already exposed to a creative approach and I think we need to continue to foster creativity in the classroom"*. Other responses suggest a strong relationship between attitudes and creativity, including "*students' attitudes can be shaped to have a different mindset and to be able to have a go, where previously they may not*." Also, the comment that a creative approach to teaching Mathematics could help students '*to develop a love of Mathematics and see its real-world application in their daily lives outside of school'* identifies key reasons for encouraging a creative approach in teaching mathematics. If teachers note the importance of this training, research must continue to investigate these critical questions.

The additional qualitative information highlighted that whilst teachers felt that the intervention encouraged them, they also noted that their school environment already adopts a creative approach to teaching mathematics. Therefore, the impact of this study may be minimised, as teachers note they already have experience using creativity in mathematics and therefore began with a greater understanding of this relationship. Whilst this may be an uncontrollable external variable in this pilot study, it does add weight to the idea that some schools and teachers are already adopting a creative approach to teaching mathematics. Additionally, the workshops may have served to remind teachers that they are, in fact, creative but are merely unaware of it.

Strengths and Limitations

There were several strengths to this pilot study. Firstly, using the wording, 'creativity-based workshop to help foster positive attitudes towards mathematics' may prime teachers towards experiencing positive emotions. Additionally, the fact that the teachers were told the impact would be positive may be beneficial, especially if they previously held negative attitudes, because it could help develop their confidence. Care was taken to specifically avoid using the

words ‘you will experience a positive change.’ Rather, the focus of the workshops was placed on words such as: ‘you may experience an increase in positive attitudes towards mathematics because research suggests that creativity can help lessen Mathematics Anxiety and therefore increase positive attitudes’ (see Appendix J for examples of wording used). Another strength is that the study examined both a Category 2 state school (i.e., a low socioeconomic status school) and a private school (high socio-economic status school). Therefore, despite the sample size being small, it was nonetheless varied. The sample size was also indicative of male to female proportions of elementary school teachers in Australia (i.e., females make up 70% of elementary school teachers). A further strength was that an unbiased sample was collected as teacher responses were not individualised. In order to maintain anonymity, teachers were not required to provide ID, nor was any identifiable information collected. Due to the intimate nature of this project (i.e., I collected the data and ran the workshops), it was imperative to maintain confidentiality. Additionally, it was more important to look at group differences rather than individual differences. Finally, because teachers failed to complete all the surveys, especially the follow-up 3-months later, the qualitative element was added, and teachers were interviewed. These interviews provided additional insight into the results and strengthened the pilot study.

Despite these strengths, there were some limitations to this study. The first obvious flaw is the lack of male participants; despite being proportionally represented, it is difficult to make inferences about male teachers in Australia with such a small number of male participants. The participation of more male and female teachers over time could provide a clearer view of a significant relationship between creativity and improved attitudes towards mathematics.

A further possible explanation as to why the results did not show a big change in attitudes may be because participants had been teaching for many years and were, therefore, more likely to have ingrained beliefs (Luft, 2001). Whilst the researcher attempted to recruit teachers with less than two years’ experience, a convenience sampling approach had to be adopted. Future research would benefit from examining beginning teachers as well as pre-service teachers in order to address inaccurate and negative beliefs before they become ingrained and harder to shift.

Future Research

This investigation highlighted the benefit that creativity-based interventions might have on increasing teacher attitudes towards mathematics and decreasing sex differences. Future research would benefit from repeating this investigation with a larger sample size, thus ensuring that more in-depth statistical analysis could occur. Additionally, measuring the impact of teacher attitude changes on their students' resultant attitudes is a clear gap in the literature. This study provides a framework and initial steps to start to explore this issue. The addition of teacher-student data is more straightforward now that this study has provided the baseline framework.

5.5 Conclusion

Negative attitudes towards mathematics are associated with MA, which in turn can result in the avoidance of mathematics. Such avoidance can limit individuals' opportunities and career pathways, particularly for females, as evidenced by the downward trend of girls pursuing mathematics into their senior high school years. This study takes initial steps in demonstrating the link between creativity and positive attitudes towards mathematics, especially for female teachers. This has the potential to not only be beneficial for students themselves but the future of our nation. Furthermore, as society transitions into Industry 4.0, where the importance of minimising female discrepancies in STEM participation becomes crucial, this study contributes valuably in closing the gap, thus ensuring all students emerge from education as successful, creative and mathematical citizens.

CHAPTER 6: General Discussion of the Thesis

6.1 Introduction

This thesis asked the question, ‘How do we encourage positive mathematical attitudes and creative abilities in students, particularly females?’ This question was examined through three studies that each explored a different element of the question. The results of this thesis present a wide range of advances that contribute practically and theoretically to society’s understanding of sex differences in mathematics whilst also establishing the role of creativity in mathematics. This thesis reveals several previously unestablished pathways whereby creativity and sex differences impact both student and teacher experiences with mathematics. The numerous theoretical innovations, practical implications and strategic translation of findings into applied resources for addressing negative attitudes towards mathematics will benefit students and teachers and will be discussed below.

The literature review in Chapter 2 identified three key gaps in present research:

> Gap 1: Limited research determining if there are sex differences in mathematical creativity in students.
>
> Gap 2: Limited research that examines how in-service teachers understand their role in perpetuating sex-based attitudes towards mathematics.
>
> Gap 3: Limited research that investigates how creativity can mitigate negative experiences with mathematics in both male and female teachers. In particular, there is limited research that explores how a creativity-based intervention affects teachers’ attitudes regarding mathematics and Mathematics Anxiety levels.

This research addressed these gaps by taking a more holistic approach to creativity and mathematics education research. It investigated the relationship between mathematics and creativity-based interventions, sex, and teacher and student attitudes.

6.2 Theoretical Innovations

Five advances in theory were achieved via the research undertaken in this thesis. Existing literature demonstrates the compelling evidence for the benefits of sex equality in a modern STEM workforce with creativity at its core (Australian Mathematical Sciences Institute, 2019; Deloitte, 2016). However, as highlighted in Chapter 2 and Chapter 3, current literature

fails to effectively address the issues associated with increasing mathematical creativity in our disadvantaged populations, including females. The first gap identified above was addressed in Study One by contributing to well-known sex-based theories and observing these biases in mathematical creativity. This thesis highlighted that sex-based stereotypes negatively affect female confidence in mathematical creativity. There were no sex-based stereotypes that affected female confidence regarding verbal creativity. Given the disconnect between females' self-rated ability to be mathematically creative and their actual mathematical creativity, it is plausible that females' perceptions may be the result of negative sex-based stereotypes towards mathematics. Interestingly, sex-based stereotypes did not impact female performance on the Mathematics Creativity task, however, females' confidence or sense of self-efficacy about their ability to be creative in mathematics was negatively affected. This 'confidence gap' and lower self-efficacy suggests that females may endorse sex stereotypes about mathematics, which is in line with current sex-based theories (Cvencek et al., 2015; Nosek & Smyth, 2011). The establishment of this sex-based stereotype is significant, as this lower confidence may have long-lasting and devastating effects on the likelihood of females continuing with STEM. Despite Study One highlighting that females are as mathematically creative as males, these results suggest that the endorsement of the stereotype of 'mathematics = males' may be preventing cohorts of capable females from pursuing STEM careers. This finding contributes significantly to the mathematics and creativity literature by demonstrating that achieving sex equity in STEM relies on addressing stereotypes and negative attitudes of females, as opposed to their ability.

The second theoretical advance was achieved by comparing the individual differences on each creativity instrument in Study One (see tables 3 and 4 in Chapter 3), which highlighted that judges consistently scored both sexes as more creative on the Verbal Creativity task in comparison to the Mathematics Creativity task. Additionally, students themselves had higher self-efficacy when assessing their Verbal Creativity (Metacognition) than when self-assessing their Mathematics Creativity (Metacognition), suggesting self-confidence issues with mathematical creativity for all students irrespective of sex. Drawing on current research that highlights that Australian students experience high levels of Mathematics Anxiety, it is proposed that the wording of the Mathematics task (i.e., 'design an equation') may have inadvertently elicited MA in both males and females (Australian Academy of Science, 2019). Considering MA is a significant indicator of the likelihood of

students continuing with other Mathematics-based courses in school, future research would benefit from investigating this relationship further in the context of creativity and mathematics research (Gunderson et al., 2018; Maloney et al., 2010). This theoretical contribution was unexpected, as it was hypothesised that there would be no difference in males' creativity on either task. Considering the importance of mathematics and creativity skills in the current global society, all students would seemingly benefit from a targeted approach to eliminate discrepancies in mathematics, whether these are confidence-based (for females) or ability-based (for males). This finding is particularly important in light of research indicating that 75 per cent of the fastest-growing occupations require a STEM-based education, for which mathematical skills are crucial (K. Becker & Park, 2011).

The third theoretical advance was highlighted in Chapter 4. The investigation regarding teacher attitudes towards sex differences in mathematics advanced current knowledge in mathematics education. The results from the qualitative interviews suggest that teachers may have an implicit 'mathematics = males' attitude bias. This sex bias was most present in both the affect and social factor concepts. One route through which teachers can convey messages about mathematics-sex stereotypes is through self-concepts. For boys, stronger mathematics-sex stereotypes correspond to stronger mathematics self-concepts, while stronger mathematics-sex stereotypes correlate to weaker mathematics self-concepts for girls (Cvencek et al., 2015). The present results extend this past work of Cvencek et al. (2015) by highlighting that, whilst not always endorsing explicit 'mathematics = males' attitudes teachers do acknowledge that student mathematical achievement is significantly associated with socio-cultural factors present in society. Comments from teachers such as '*I think stereotypically males are better than females at Mathematics'* combine mathematics-sex stereotypes and mathematics self-concepts into a systematic relationship. Both implicit and explicit negative associations with mathematics are often rehearsed in students' minds and are more likely to be linked with their own Mathematics Anxiety, which can, in turn, lead to avoidance of STEM career choices (Hourigan et al., 2016). Given that some teachers from the study explicitly stated that mathematics is a male-dominated field, it can be concluded that implicit and explicit sex beliefs about mathematics are more detrimental to females. The presence of this implicit sex-based stereotype was not previously established for Australian teachers, and this study has helped identify when, and where, these beliefs are observed.

Additionally, teacher attitudes towards sex differences in mathematics were also linked to three key concepts of cognition, affect and social factors. Teachers held cognitively based opinions towards mathematics, often citing it as 'logical and numerical', which is in line with very traditional definitions of the subject. These numerical definitions are also in stark contrast to creativity-based definitions of mathematics, which include words such as problem formation (problem finding), invention, independence and originality (Krutetskii et al., 1976). Additionally, the responses that contribute to the category of innate ability (See Table 13) highlights a very close-minded approach to the subject. One teacher's response of *"I do think that the individual brings an aptitude"* is suggestive of the belief that being capable at mathematics is not necessarily something that can be fostered and encouraged but rather is indicative of an innate ability. The relationships highlighted as cognitive concepts suggest that elementary school teachers in Australia possess very traditional and cognitive beliefs about mathematics. Moreover, traditional teaching pedagogy stifles the flow and opportunity for creativity as a means of facilitating positive mathematical attitudes in the classroom.

The fourth theoretical advance is the finding that male and female teachers differed dramatically in their views regarding sex differences in mathematics. In fact, most of the teachers who explicitly stated that there were no sex differences in mathematics were male. This highlights that male teachers hold somewhat non-traditional beliefs, however, female teachers maintain very traditional, sex-stereotyped beliefs. Expanding on this further, even when female teachers did not report explicit stereotypical beliefs, they demonstrated implicit attitude biases towards mathematics as being a male-dominated subject. This disconnect is congruent with literature that has historically reported how male and female teachers approach the subject. The majority of elementary school teachers in Australia are female (70% female, 30% male), and many females (both teachers and students) experience MA and endorse sex-based stereotypes. This study reflects a negative culture in Australian elementary school teachers that does not encourage mathematical success and STEM participation for females (Beilock et al., 2010). The finding that only the female teachers endorsed sex-based stereotypes has not previously been established in the Australian teaching population.

The fifth theoretical advance was establishing that teachers may be unaware of how their attitudes impact their students (Gap 2). Teachers consistently reported that parents and society were responsible for the stereotypes around mathematics and that they were not

responsible for perpetuating these beliefs. Female teachers often reported feeling a lack of confidence when teaching mathematics whilst male teachers asserted their confidence in teaching the subject. Since a relationship between mathematics self-concepts and achievement has been established, there may be a similar relationship between mathematical attitudes and STEM choices for those females who validate such beliefs. The endorsement of societal stereotypes by teachers in the study was alarming. As noted by Beilock et al. (2010), Mathematics Anxiety is not necessarily a proxy for diminished mathematical achievement, rather self-doubt and negative self-beliefs can impede the ability to access mathematical knowledge cognitively. Sex stereotypes are highly salient to mathematical achievement, with girls more likely to notice their teacher's negativity and anxiety towards mathematics. This is particularly relevant to understanding the Australian context in that even if young girls excel in mathematics at elementary school, the stereotype that '*boys are good at mathematics, girls are good at reading'*, can bias girls and carry consequences for their mathematical performance. Establishing that teachers are unaware of their role in shaping sex-based attitudes and are unaware that they hold implicit attitudes was a significant conclusion from this research. Based on this finding, additional research (Study 3) was conducted to address these negative sex-based attitudes.

In summary, teachers appear to be ignorant of how their lack of confidence, attitudes and self-concepts towards mathematics impact their students, particularly female students. Data from this study reveals that while teachers did not always explicitly hold stereotypical sex beliefs, they did hold implicit stereotypical mathematics beliefs. These inaccurate sex-based beliefs of teachers discourage students from challenging and overcoming these stereotypes. Additionally, stark differences in attitudes between male and female teachers were alarming, with primarily female teachers expressing negative stereotypical sex-based attitudes.

6.3 Practical Implications

One of the main aims of this research was to maintain a concerted emphasis on translating the research outcomes into applied interpretations that can assimilate into education practice. In order to make the content relevant, and as an evidence basis for practical solutions, a study was conducted that examined variables that would likely be of interest to academics, policy makers and educators.

The pilot study described in Chapter 5 was based on the theoretical findings highlighted in Chapter 2 and Chapter 4. This pilot study addressed Gap 3 and investigated the effects of a creativity-based intervention on teacher levels of Mathematics Anxiety and attitudes towards mathematics. This study particularly investigated how male and female teachers differed in response to a creativity-based intervention.

The results highlight that teachers' positive attitudes towards mathematics increased in response to the intervention. The findings also demonstrate that sex differences regarding attitudes towards mathematics were reduced amongst teachers after exposure to creativity-based training. If both male and female teachers were equally mathematically anxious, one would propose similar outcomes for both males' and females' attitudes post-intervention. However, female teachers experienced a greater increase in positive attitudes than male teachers' post-intervention. Whilst the difference was minimal, females held more positive attitudes towards mathematics after the intervention while also experiencing a larger increase in positive attitudes than males. The perceived enjoyment and value of mathematics were more likely to be aligned post-intervention for all participants, demonstrating that teachers held more consistent attitudes post-intervention. Given that the literature on MA, sex modelling and the negative stereotypes suggests that girls are more socially sensitive than boys, one can speculate that this study supports the relationship between female teachers' mathematics anxieties and girls' mathematics achievement.

This finding is important in the context of past research. As previously reported, it is often a matter of poor attitude, implicit beliefs, and/or stereotypes that can promote a negative culture and lack of enjoyment around mathematics (Beilock et al., 2010; Gunderson et al., 2012). When teachers and the broader community fuel negative beliefs, there are implications for female students who may experience MA and choose not to continue with mathematics-based subjects at a higher level (Beilock et al., 2010; Gunderson et al., 2012). This research provides preliminary data to suggest that a creativity-based intervention can mitigate the

ramifications of negative attitudes by facilitating the development of positive attitudes towards mathematics in both male and female teachers. Teachers will then model positive mathematical attitudes, consequently encouraging their students to mimic this positivity whilst also improving student mathematical achievement. Additionally, higher mathematics-ability and confidence is likely to encourage further continuation with STEM-based careers.

The long-term impact of a negative attitude towards mathematics is MA, with avoidance of mathematics being, in turn, a consequence of MA. Such avoidance can limit individuals' opportunities and career pathways, particularly for females, as evidenced by the downward trend of girls pursuing mathematics into their senior high school years. This study takes initial steps in demonstrating the link between creativity and attitudes towards mathematics, especially for female teachers; this is not only beneficial to students themselves but the future of every nation. Furthermore, as society transitions into Industry 4.0, where the importance of encouraging female STEM participation becomes more important than ever, this study makes a valuable contribution to promoting this equality.

6.4 Overall Contributions of this Thesis

Three studies were conducted in this thesis and the novel contributions of these studies can be summarised as follows. Study One established the relationship between sex differences in mathematical creativity. By examining over 1,000 students through a longitudinal observational study, the relationship between mathematical creativity and sex-based stereotypes was established. These findings have been written as a separate journal paper and are under review in the journal Developmental Science.

Study Two focused on understanding teacher attitudes towards sex differences in mathematics. The results from 14 qualitative interviews with elementary school teachers highlight that female teachers hold more implicit and explicit 'mathematics = males' stereotypes than male teachers. All teachers noted the role society plays in perpetuating negative sex-based stereotypes in mathematics, however, teachers felt that they did not contribute to sustaining such stereotypes. The theory generated from this study fills a crucial gap in current literature, with results suggesting teachers are unaware of their impact on their students' beliefs about mathematics. This gap needs to be addressed, as much literature has proposed that teachers pass on their attitudes and beliefs to their students, which can create long-lasting student anxiety that can carry on to career choices and daily lives. Thus,

educators need to be aware of this attitude-sex link and address their own implicit and explicit stereotypes. The results from this study will be submitted for publication in the International Journal of Qualitative Methods.

Study Three addressed the findings from Study One and Study Two and through a pilot study utilised a creativity-based intervention to alter teacher attitudes towards mathematics. Both male and female teachers experienced an increase in positive attitudes towards mathematics after exposure to the creativity-based intervention. Female teachers experienced a greater increase in positive attitudes than male teachers.

Additionally, Appendices K through O highlight research conducted in the fields of creativity, mathematical creativity and global creativity curricula. The 5 co-authored papers demonstrate dedication to these fields and highlight contributions to research beyond the PhD.

Taken together, the three studies from this thesis contribute to research in a novel and significant way. The findings provide evidence of why sex differences in mathematics are observed and demonstrate how to minimise these differences effectively. To reiterate, specific suggestions that educators could engage with to lessen the sex gap in STEM could include targeting ST in mathematical creativity as opposed to focusing on female ability in mathematics, as highlighted in Study One. Targeting ST could involve females observing other female role models that challenge these inaccurate stereotypes by being creative and mathematical. Furthermore, Study 2 demonstrates that female teachers require awareness that they possess implicit ‘mathematics = males’ attitudes. These female teachers should also engage in training that alters these inaccurate implicit beliefs. Finally, Study 3 has demonstrated that teacher attitudes towards mathematics may increase in response to creativity-based training. Therefore, teachers could be encouraged to adopt creative pedagogies in their classrooms when teaching mathematics.

Overall, this thesis has contributed significantly to the fields of creativity, sex and mathematics and has effectively addressed the initial question of ‘How do we encourage positive mathematical attitudes and creative abilities in students, particularly females?’

CHAPTER 7: Final Conclusions of the Thesis

7.1 Limitations of the Thesis

There were some limitations to this research. It was challenging to follow certain approaches when conducting the literature review (Chapter 2), such as conducting a systematic review or meta-analysis. The fields of mathematics, creativity and sex are extensive and conducting a systematic review or meta-analysis was beyond the scope of this thesis. Therefore, the literature presented may not identify the breadth of gaps in knowledge and practice regarding the fields of creativity, sex differences and mathematics education. However, minimising the effects of this limitation included adopting a systematic search in a narrative review format (see Appendix P for details of the systematic search).

Additionally, the participants who engaged in Study One (Chapter 3) attended a high socio-economic school, therefore, the results may not accurately reflect the broader student population. This issue is currently being addressed via a replication study of the same creativity factors at a more economically diverse Australian school. This study began late in 2019 and is in the data collection phase.

A limitation of Study Three (Chapter 5) was the failure of teachers to complete all 3 testing time points. The lack of responses made it challenging to conduct inferential statistics and data was restricted to descriptive statistics only. Therefore, the results cannot be generalised to participants beyond the study. To minimise the effect of this limitation and to provide depth to the participant responses, qualitative interviews were conducted. These interviews provided additional insight into the results and strengthened the pilot study. Future research would benefit replicating this study with a larger sample size.

As mentioned, there are potential limitations when characterising the statement ‘male and female differences’ as both ‘sex’ and ‘gender’ explain disparities in males and females. The variations between sex (biology) and gender (culture) emphasise a potential limitation as they consider various aspects of male and female differences, however, both cannot happen in isolation of each other. Importantly, minimising this limitation involved adopting a clear and concise definition of male and female differences which encompassed both sex and gender characteristics.

7.2 Future Directions for Research

In order to extend the findings from Study Two (Chapter 4), a quantitative survey has been designed, based on the categories and concepts derived from the interview responses from this study. This survey aims to capture teacher attitudes towards sex differences and will be validated through a factor analysis methodology. Responses to the survey questions are designed as a 5-point Likert scale where 1 = strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree and 5 = strongly agree. Initially, there will be 29 questions, as there were 29 identified content units. These questions are presented below in Table 19. Each question will be prefaced with the words 'to what extent do you agree with the statement…'

Table 19

Proposed quantitative questions for a survey regarding teacher attitudes towards sex differences in mathematics

Content Units	**Proposed question for the survey**	**The hypothesised factor that each question will load onto**
Learned behaviours	Mathematics is primarily a learned behaviour.	Acquired skills
Thinking skills	Mathematics requires thinking skills.	
Problem solving	Mathematics requires problem-solving skills.	
Knowledge	Mathematics requires knowledge of the topics to be understood correctly.	
Prior Knowledge	Mathematics requires prior knowledge.	
Aptitude	Students bring an aptitude to mathematics.	Innate ability
Negative feelings	Mathematics makes me feel positive.	Feelings
Anxiety	Mathematics can cause feelings of anxiety.	
Fear	Fear is often associated with teaching or learning mathematics.	
Enjoyment	I enjoy teaching and learning mathematics.	
Lack of confidence	Sometimes teachers feel a lack of confidence teaching mathematics.	Self-confidence

Confidence drop	Sometimes teacher confidence drops when teaching mathematics.	
Doubt myself mathematically	I think that I am a good mathematics teacher.	
Boys are more comfortable	Boys are more comfortable in learning mathematics.	
Motivation	I am motivated to teach mathematics.	Attitude
Dependent on attitude	Having a positive attitude is crucial to learning mathematics.	
A common perception	It is a common perception that there are sex differences in mathematics	Stereotypes
Stereotypically males are better	Stereotypically, males are better than females in mathematics.	
Social misconceptions	There is a social misconception that there are sex differences in mathematics	
Boys are encouraged by society	Girls are encouraged by society to pursue mathematics.	Social expectations
Less accepted in girls	It is less acceptable for girls to study mathematics in comparison to boys.	
Boys are socially more comfortable	Socially, boys are more comfortable as mathematicians than girls.	
Societal misunderstanding	Society perpetuates misunderstandings about sex differences in mathematics	
Sociologically entrenched	Ideas about sex differences in mathematics are sociologically entrenched	
Encouraged by society	Girls are encouraged by society to study mathematics	
Role models	Teachers influence their students' attitudes toward mathematics.	Family influence
Environment	The classroom environment influences how students learn mathematics.	

Depends on parents	Parents are responsible for encouraging their kids to study mathematics.	
Family dynamics	Family dynamics strongly influence how children approach mathematics.	

Additionally, this thesis has demonstrated that both teachers and students experience negative attitudes towards mathematics while also highlighting that creativity can mitigate these negative attitudes in teachers. Based on Bandura's social learning theory and the concept of modelling, future research could observe how altering teacher attitudes can subsequently affect student attitudes towards mathematics. Moreover, a similar study could involve observing how student attitudes towards mathematics change in response to engaging in a creativity-based intervention. Research into creativity-based interventions in both a teacher and student population can provide further evidence into overcoming the sex gap in STEM. Finally, it is proposed that a path analysis could be conducted on the data from study one. This type of data analysis could more clearly identify and highlight the unique relationships between sex differences, creativity and mathematics.

7.3 Conclusions

This thesis provides several significant theoretical and practical contributions to address the current gaps in knowledge and barriers to the fields of mathematics, creativity and sex. The theoretical contributions that emerged from the testing highlighted several pathways for the role of sex differences in mathematical creativity. The results support the extension of the impact of sex stereotypes beyond the subject mathematics and into the field of mathematical creativity in young female students. Results also support the extension of the pathway between negative teacher attitudes towards mathematics and implicit sex difference-based beliefs in mathematics. Results further demonstrate how creativity-based interventions are beneficial in minimising negative attitudes towards mathematics and decreasing sex differences between how male and female teachers' value and enjoy the subject.

The longitudinal methods used are rigorous and firmly situate sex as a factor that influences female confidence in being mathematically creative. The emphasis on the practical interpretation of creativity-based outcomes provides numerous implications for educators, including models for teacher and student engagement, as well as evidence for policy makers

to view creativity as a tool for overcoming sex discrepancies in STEM. The overall outcome of this thesis is a comprehensive assessment of the relationships between theories regarding mathematics, sex and creativity. Consequently, providing wide-ranging contributions to the academic and practical understanding of the three concepts and how society can address present issues with the under-representation of females in STEM-based education and occupations.

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Appendix A: Study One. Verbal Creativity Task (Metacognition)

Part 1: Pre-Task

This question is for you to predict how creative you think you will be in writing the title People have different opinions about if they see themselves as creative by using their imagination.

Please tick the answer which you think is the closest to what you believe about the task you are about to do

1 = Strongly Disagree, 2 =Disagree 3 = Neither Agree nor Disagree, 4 = Agree 5 = Strongly Agree

1. I am confident that I could creatively write a title for this picture
2. I think I can write a title which will be good
3. I can use my imagination to write a title
4. I think I will have many good ideas about how to write a title for a picture

Appendix B: Study One. The Creative Production Verbal Photo Caption Task

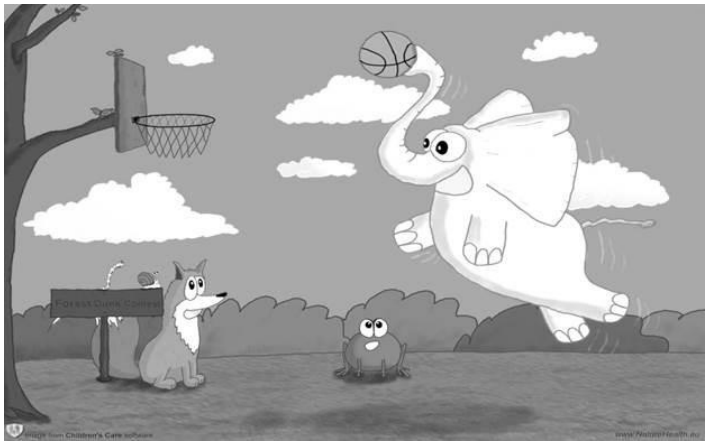
This measure is a verbal-based Creativity task adapted from Amabile (1982) and J. C. Kaufman, Baer, Cropley, Reiter-Palmon, and Sinnett (2013) and has been included as part of a larger Creativity-based study. The following survey was presented via Survey Monkey.

In this section, you will be asked to write a title for a picture.

What is the most creative title you can think of for the following photo?

You have two minutes to type in your ideas.

Time 1



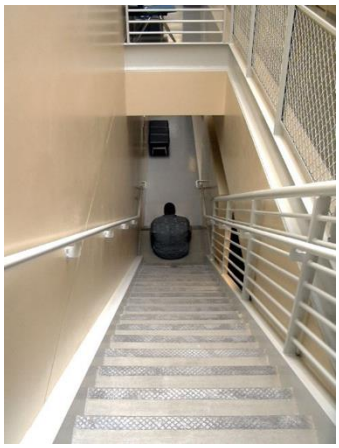
Time 2



Time 3



Time 4



Time 5

You are in charge of devising a slogan for a new candy bar. The company tells you that they want to appeal to as many people as possible. What would you choose as your slogan?

Appendix C: Study One. Creativity Rating Instructions for Judges

Once the students completed the tasks over the 2 years, independent judges (research students and schoolteachers) were asked to independently score participants' responses. Judges were presented with the following information:

Please rate each (Mathematics problem) for how creative you think it is.
Use a 1-6 scale, with "1" meaning that you do not think the answer was creative at all and "6" meaning that you think the answer was very creative.
Please compare the answers to one another, not to some other standard (i.e., what is a great answer). These were written by students between grades 6 and 12 who did not have notable experience or expertise in this area.
Please try to use the full scale. For example, don't rate all the answers either 1, 2, or 3.
If an answer is blank, simply leave the rating blank.
There is no need to explain or justify your ratings. Use your "expert" sense to judge each answer for its Creativity (not for accuracy, correct responses, etc.)
You do not need to agonize over these ratings, but it might be helpful to read a few answers before you start your rating (or go back and review your first ratings after you get a sense of the level of the answers).
You can change your ratings as much as you wish, but there is no need to spend a large amount of time on this -- just give your best expert judgment of the Creativity of each answer.

Thank you!!

Appendix D: Study One. Mathematics Creativity Task (Metacognition)

This measure is a mathematically based Creativity task adapted from Tidåsen et al. (2015) and has been included as part of a larger Creativity-based study. The following survey was presented via Survey Monkey. The following instructions have been adapted from Kaufman and Baer (2012).

In this section you will be asked to be creative in Mathematics. You will be given a number and asked to come up with a number of ways, using Mathematics questions or equations, to arrive at the number.

Part 1: Pre-Task

This question is for you to predict how creative you think you will be in writing the questions/equations. Please tick the answer which you think is the closest to what you believe about the task you are about to do.

1 = Strongly Disagree, 2 =Disagree 3 = Neither Agree nor Disagree, 4 = Agree 5 = Strongly Agree

1. I am confident that I could creatively come up with a number of ways to write Mathematics questions or equations
2. I think I can come with new and useful ways of writing Mathematics questions or equations
3. I can use my imagination to writing Mathematics questions or equations in many creative ways
4. I think I will have many good ideas about how to creatively write Mathematics questions or equations

Appendix E: Study One: The Creative Production Mathematics Task

Term 1- What is the **most creative way** you can use what you know in Mathematics to write some Mathematics questions or equations where the answer is 8 (for example, “4 x 2”, or “10 – 2” are **not** very creative answers)?

Term 2 – same intro, etc, “13”?

Term 3 – same intro, etc, “-5”?

Term 4 – same intro, etc, “1/3”?

Time 5 - same intro, etc, 3.66?

You have three minutes to write down your ideas. Be as creative as you can!

Appendix F: Study Two. Qualitative Interviews Script and Demographic Information

What attitudes do teachers' hold regarding the relationship between Mathematics and sex?

Warm up/demographic questions:

In what year did you complete your teaching degree?

What qualifications do you possess?

Do you possess a degree in STEM?

What was your specialisation at university?

What is your current employment status?

What year level do you presently teach?

What subject do you like teaching the most?

Please specify your sex:

Please specify your age range; 18-24, 25-34, 35-44, 45-54

Main questions:

When you hear the word 'Mathematics' what comes to mind?

Can you describe any sex differences in Mathematics? For example, is a particular sex better at Mathematics?

How do you think your sex influences your confidence teaching Mathematics?

To what extent do you agree with the statement boys are good at Mathematics, girls are good at reading. Why?

Prompts:

Can you tell me more about that?

Can you expand on that?

Demographic Information and Question responses

The Relationship between sex (Male and Female) and Mathematics

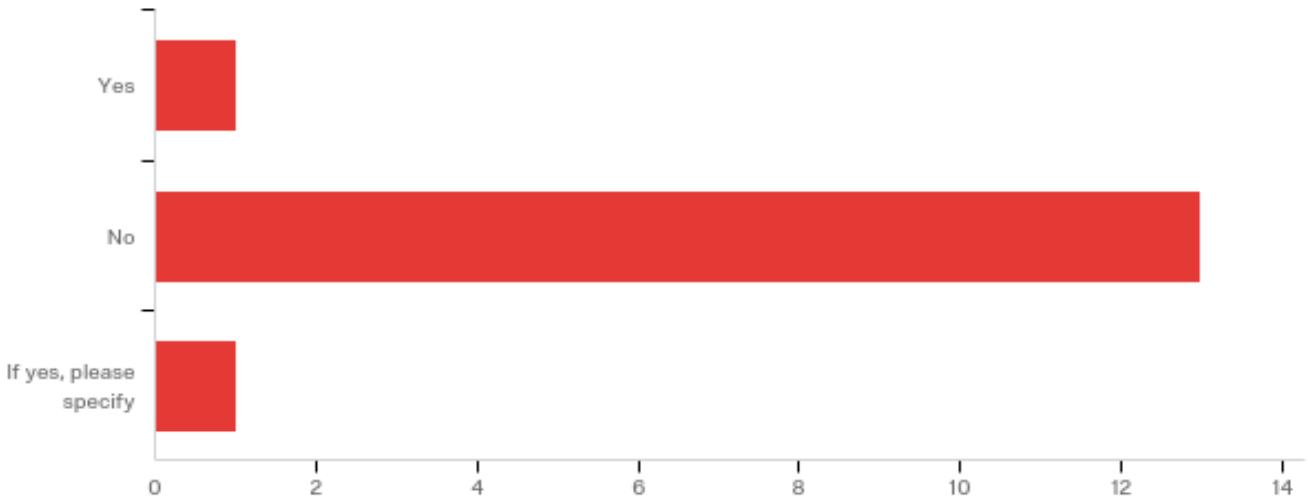
Demographic Question; In what year did you complete your teaching degree?

2012
2006
1991
2017
2015
2016
1983
2003
2014
2016
1986
1994
2017
2004

Q3 - What qualifications do you possess? i.e. Bachelor of Education etc.

Grad Dip Education, Bachelor Business
Master of Education
Bachelor of education Primary
Bachelor of Primary/Middle Education
Bachelor of education/ primary
Bachelor of Education - Primary
Bachelor of Education
Bachelor of Education (Junior Primary & Primary)
Bachelor of Marketing Management Graduate Diploma in Teaching and Learning
Bachelor of Education (Primary)
Diploma of Teaching
Bachelor of Education (Primary)
Masters of Special Education (Deaf and Hard of Hearing)
Post Graduate Certificate in Education,

Q4 - Do you possess a degree in STEM (Science, Technology, Engineering, Mathematics)?



#	Answer	%	Count
1	Yes	6.67%	1
2	No	86.67%	13
3	If yes, please specify	6.67%	1
	Total	100%	15

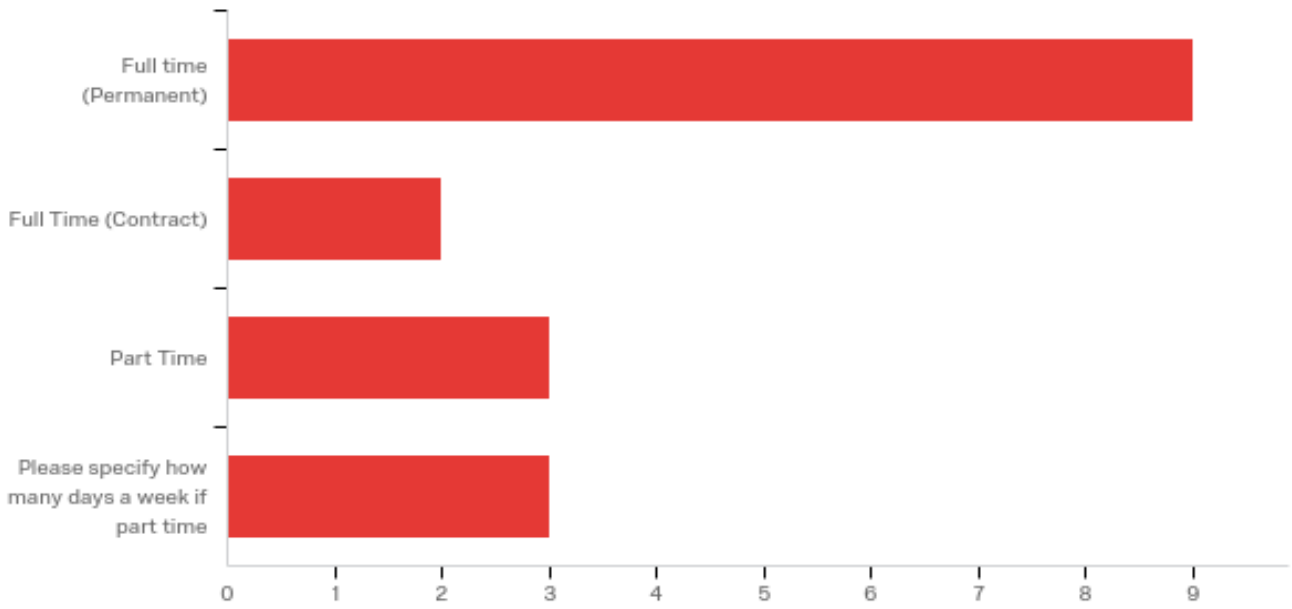
Q17_3_TEXT - If yes, please specify

If yes, please specify - Text
Bachelor of Applied Science

Q5 - What was your specialisation at university?

Primary
Graphic Design
Children's literature and drama.
French and English
Well I did the primary degree, so we had minors but no real specialisation. I teach all subjects from reception to year 7
Catholic Studies
Psychology
Children's Literature
Marketing
Outdoor Education and English
Sociology
Primary
Special Education
Conservation of Cultural Materials

Q6 - What is your current employment status?

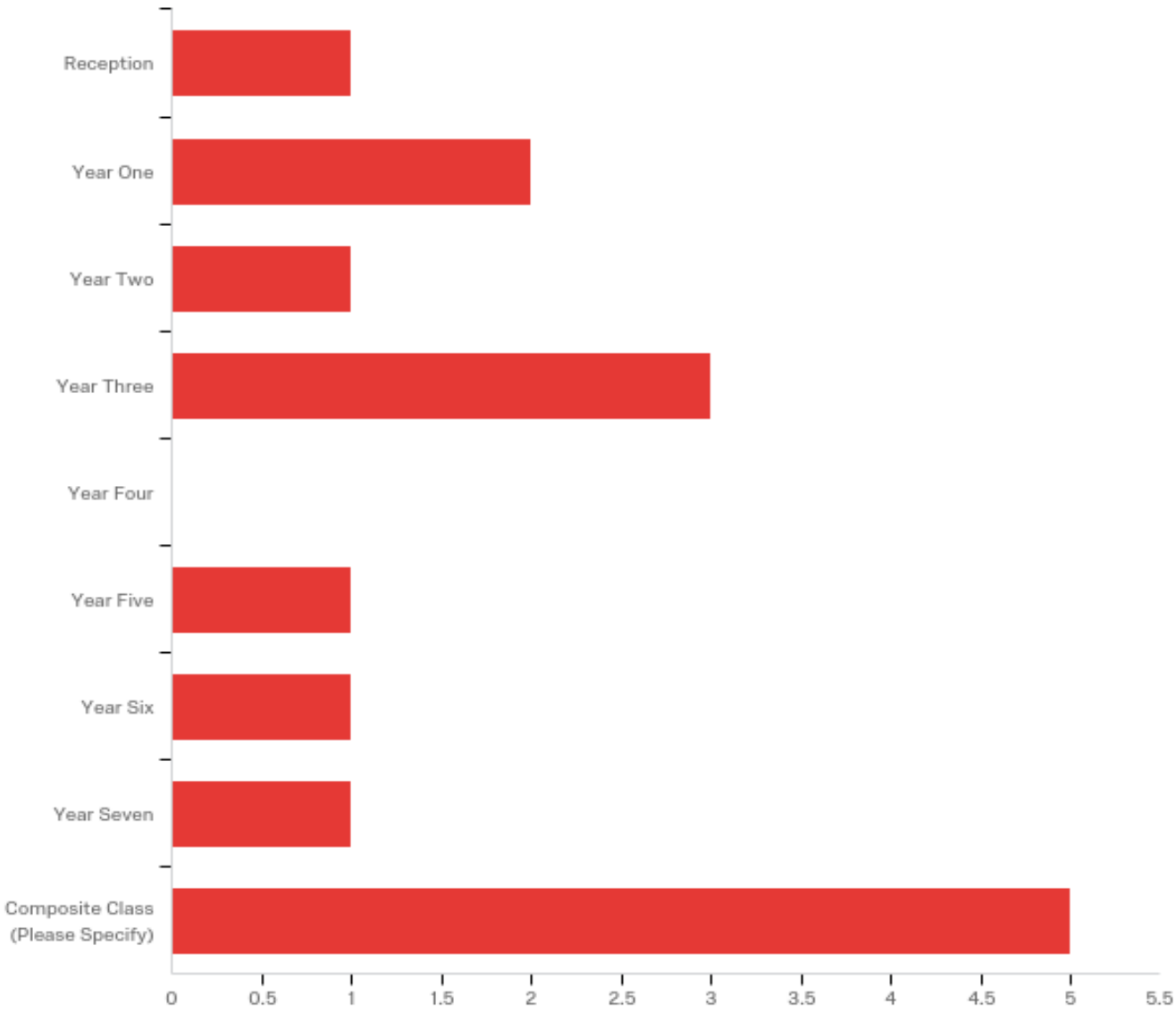


#	Answer	%	Count
1	Full time (Permanent)	52.94%	9
2	Full Time (Contract)	11.76%	2
3	Part Time	17.65%	3
4	Please specify how many days a week if part time	17.65%	3
	Total	100%	17

Q7_4_TEXT - Please specify how many days a week if part time

Please specify how many days a week if part time - Text
4 days per week
2 days per week
4 days a week

Q7 - What year level do you presently teach?



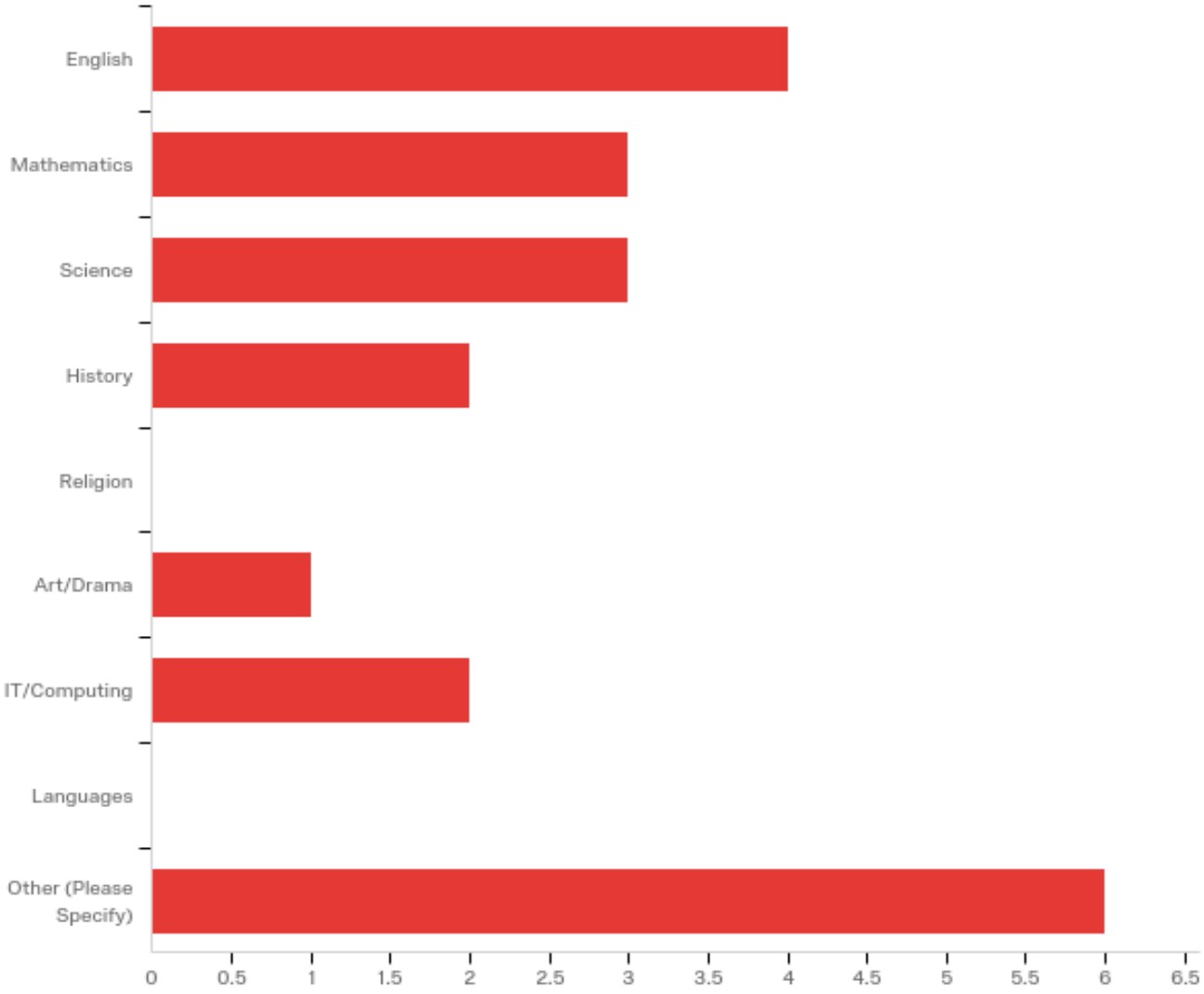
#	Answer	%	Count
1	Reception	6.67%	1
2	Year One	13.33%	2
3	Year Two	6.67%	1
4	Year Three	20.00%	3

5	Year Four	0.00%	0
6	Year Five	6.67%	1
7	Year Six	6.67%	1
8	Year Seven	6.67%	1
9	Composite Class (Please Specify)	33.33%	5
	Total	100%	15

Q8_9_TEXT - Composite Class (Please Specify)

Gifted and Talented department
Year2/3/4
Year6/7
year 3 and 4
Yr 3/4

Q9 - What subject do you like teaching the most?



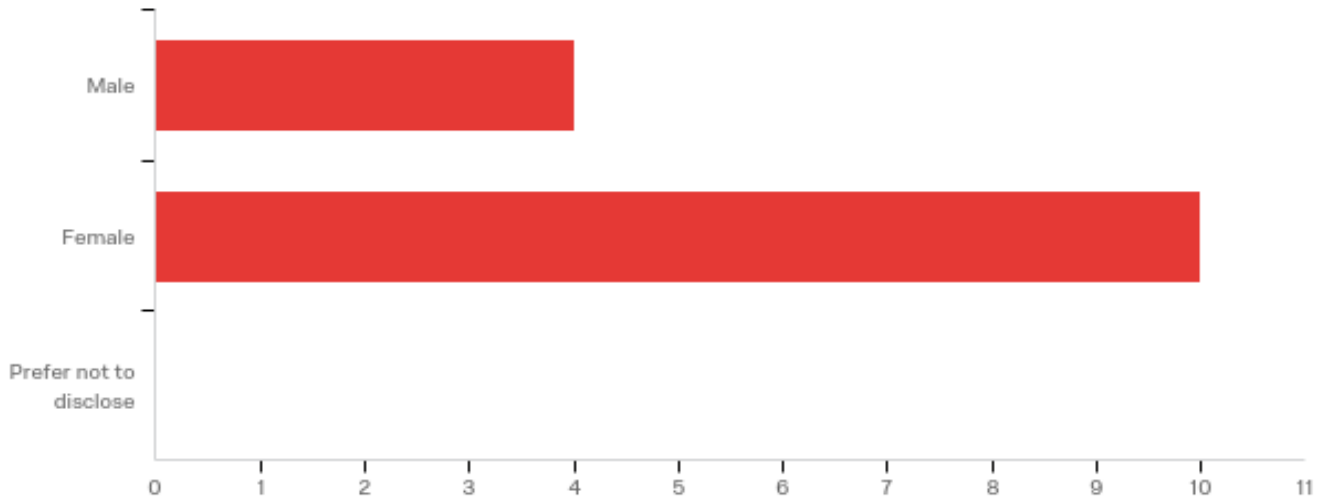
#	Answer	%	Count
1	English	19.05%	4
2	Mathematics	14.29%	3
3	Science	14.29%	3
4	History	9.52%	2
5	Religion	0.00%	0
6	Art/Drama	4.76%	1
7	IT/Computing	9.52%	2

8	Languages	0.00%	0
9	Other (Please Specify)	28.57%	6
	Total	100%	21

Q9_9_TEXT - Other (Please Specify)

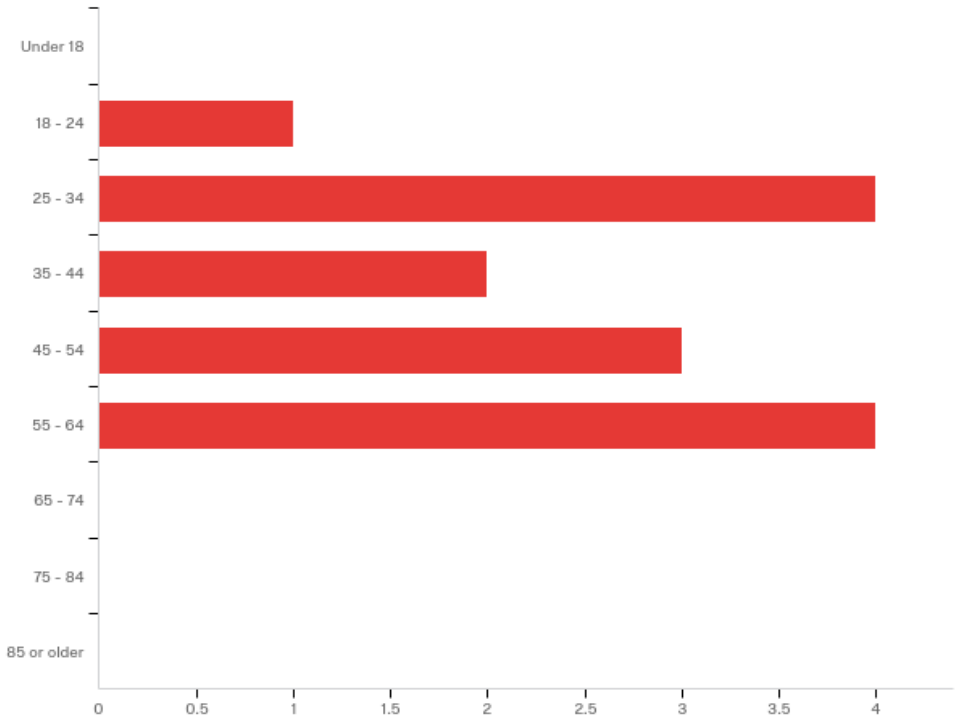
All of them!
Enrichment
Literacy
Mathematics/English but probably Mathematics
I am a Special Ed class teacher
I also like Mathematics using investigations approach

Q10 - Please specify your sex



#	Answer	%	Count
1	Male	28.57%	4
2	Female	71.43%	10
3	Prefer not to disclose	0.00%	0
	Total	100%	14

Q11 - Please specify your age range



#	Answer	%	Count
1	18 - 24	7.14%	1
2	25 - 34	28.57%	4
3	35 - 44	14.29%	2
4	45 - 54	21.43%	3
5	55 - 64	28.57%	4
6	65 - 74	0.00%	0
7	75 - 84	0.00%	0
8	85 or older	0.00%	0
	Total	100%	14

Appendix H: Study Three. Aiken Scale: Measuring Attitudes Toward Mathematics

Teachers' attitudes towards mathematics will be collected through the Aikens Revised Mathematics Attitude scale (Aiken, 1974). The Aiken scale consists of two (sub) scales measuring Enjoyment of Mathematics (E) and attitudes in the Value of Mathematics (V). The E scale consists of 11 survey statements (items), and the V scale contains 10 items. Responses to the items are presented on a Likert scale ranging from zero to four (0 = strongly disagree, 1 = disagree, 2 = unsure, 3 = agree, 4 = strongly agree), where zero indicated an extreme negative attitude, two represented a neutral attitude and four an extremely positive attitude towards mathematics.

Aiken, L. R. (1970). Attitudes Toward Mathematics. *Review of Educational Research, 40*(4), 551-596. doi:10.3102/00346543040004551

Questions from scale:

TABLE 2
Item Analyses for Individual Items

E-Scale	Correlation with E Total Score
E1. I enjoy going beyond the assigned work and trying to solve new problems in mathematics.	.58
E2. Mathematics is enjoyable and stimulating to me.	.77
E3. Mathematics makes me feel uneasy and confused.	.71
E4. I am interested and willing to use mathematics outside school and on the job.	.60
E5. I have never liked mathematics, and it is my most dreaded subject.	.72
E6. I have always enjoyed studying mathematics in school.	.63
E7. I would like to develop my mathematical skills and study this subject more.	.62
E8. Mathematics makes me feel uncomfortable and nervous.	.69
E9. I am interested and willing to acquire further knowledge of mathematics.	.71
E10. Mathematics is dull and boring because it leaves no room for personal opinion.	.63
E11. Mathematics is very interesting, and I have usually enjoyed courses in this subject.	.72
V-Scale	**Correlation with V Total Score**
V1. Mathematics has contributed greatly to science and other fields of knowledge.	.50
V2. Mathematics is less important to people than art or literature.	.45
V3. Mathematics is not important for the advance of civilization and society.	.52
V4. Mathematics is a very worthwhile and necessary subject.	.65
V5. An understanding of mathematics is needed by artists and writers as well as scientists.	.33
V6. Mathematics helps develop a person's mind and teaches him to think.	.58
V7. Mathematics is not important in everyday life.	.58
V8. Mathematics is needed in designing practically everything.	.59
V9. Mathematics is needed in order to keep the world running.	.61
V10. There is nothing creative about mathematics; it's just memorizing formulas and things.	.58

Appendix I: Study Three Mathematics Anxiety Rating Scale (MARS)

Mathematics Anxiety Rating Scale (MARS)

Teachers' mathematics anxiety levels will be measured through a revised version of the Mathematics Anxiety Rating Scale (MARS) The scale consists of 30 questions presented on a 5-point Likert scale, 1 = not at all anxious through to 5 = very much anxious. A total mathematics anxiety score is calculated by summing all the values i.e. the lowest score indicating no maths anxiety is a value of 30 and the maximum score indicating extreme maths anxiety is 150. Cronbach's alpha of .96 indicated high internal consistency, while the test-re-test reliability for the MARS 30-item was .90 ($p<.001$).

Each question is prefaced by the statement 'how anxious do you typically feel'

THE 30-ITEM SCALE'

1. Taking an examination (final) in a mathematics course.
2. Thinking about an upcoming mathematics test one week before
3. Thinking about an upcoming mathematics test one day before.
4. Thinking about an upcoming mathematics test one hour before.
5. Thinking about an upcoming mathematics test five minutes before.
6. Waiting to get a mathematics test returned in which you expected to do well.
7. Receiving your final mathematics grade in the mail.
8. Realising that you have to take a number of mathematics classes to fulfil the requirements in your major.
9. Being given a "pop" quiz in a mathematics class.
10. Studying for a mathematics test.
11. Taking the mathematics section of a college entrance examination.
12. Taking an examination (quiz) in a mathematics course.
13. Picking up the mathematics textbook to begin working on a homework assignment.
14. Being given a homework assignment of many difficult problems which is due the Next class meeting.
15. Getting ready to study for a mathematics test.
16. Dividing a five digit number by a two digit number in private with pencil and paper.
17. Adding 976 + 777 on paper.
18. Reading a cash register receipt.

19. Figuring the sales tax on a purchase that costs more than $1.00.
20. Figuring out your monthly budget.
21. Being given a set of numerical problems involving addition to solve on paper
22. Having someone watch you as you total up a column of figures.
23. totalling up a diner bill that you think overcharged you
24. Being responsible for collecting dues for an organisation and keeping track of the amount
25. Studying for a driver's license test and memorising the figures involved, such as the distances it takes to stop a car going at different speeds.
26. Totalling up the dues received and the expenses of a club you belong to.
27. Watching someone work with a calculator.
28. Being given a set of division problems to solve.
29. Being given a set of subtraction problems to solve.
30. Being given a set of multiplication problems to solve.

Appendix J: Study Three. Creativity sessions

As mentioned in text (Chapter 5) there were 3 creativity sessions provided for teachers. The script is outlined below. Please note that the text was accompanied by a series of power point slides.

Session one:

Slide one:

Introduction

Hi everyone, my name is Rebecca Marrone and I am a researcher and PhD student from UniSA and today you are all participating in a Creativity based workshop that is aimed towards increasing positive attitudes towards mathematics.

I will start with a little about myself. My background is psychology and I am passionate about researching how we can get more females to enjoy Mathematics. This is because I have a personal experience with this.

Here is a copy of my year 8 Mathematics report card. As you can see by the results I failed miserably, in fact the school did not even let me sit the remaining tests I was doing so poorly. As highlighted in red my work ethic and ability to perform the tasks was 'A' worthy. So, what was causing my failures? Simply put it is the concept of Mathematics Anxiety. Basically, the feelings of worry and trepidation I would experience in the presence of a Mathematics test caused me to completely freeze. I am sure everyone understands what anxiety feels like, the feeling of your mind going blank, your palms start sweating and complete and utter disaster ensues as evidenced here. Mathematics Anxiety is all these negative feelings in the presence of a mathematical task and for me specifically it was only in a test-taking situation. As you can see perfectly in my Algebra test results the first time, I sat the test I got 26% and safe to say my parents got called into the school to discuss that one! Fortunately for me I had a very considerate teacher who knew I could do the work, so he let me re sit another algebra test without the pressure of a test situation and I got 100%.

Slide 4: Athletics and Mathematics?

Luckily for me I was also into athletics at this time and I started to turn generic algebra equations into a creative problem for me to solve. For example, I loved the 100m sprint and so I would calculate that if I were running 100m in 12 seconds then my speed was 8.33m/s etc. This is a great example of a Creativity based approach to Mathematics and certainly this

experience helped me overcome my own Mathematics Anxiety. But I'll come back to the Creativity and Mathematics part a little later.

Unfortunately, I am a very common example of a female undertaking Mathematics. I'll mention that females are grossly underrepresented in STEM fields which is a key concern (Roberts, 2014), of educators and policy makers alike. Currently only 30% of the STEM workforce is female. A key reason cited by females themselves for not continuing with Mathematics based subjects such as STEM is Mathematics Anxiety.

Nature VS. Nurture

What I found very interesting at the time and still do was that I did not lack any ability, I certainly did not lack motivation it was simply the test taking situation that impacted me so greatly. So, in the age-old nature vs nurture debate what research supports is that females are just as good at Mathematics as males, yet they don't continue with Mathematics careers as often. Therefore, we must look at the impact of nurture on females developing negative attitudes towards mathematics.

The dislike of Mathematics begins in primary school when children are between the ages 5-12 years old. So how do we overcome these negative attitudes? One suggestion is taking a creative approach to Mathematics education.

What is Creativity?

Question: together let us define Creativity.

So, we will start with a simple definition of Creativity; the ability to generate novel (new) and effective ways of solving problems.

Often people think of the definition of Creativity as being seen in the arts subjects or as a form of self-expression however I am defining it as an ability to generate new ideas or problems or solve things in a new way.

This is a very relevant definition in the context of Mathematics. Mathematics is all about generating new and effective ways to solve problems either in a classroom setting or everyday life.

Characteristics of Creativity

- Novelty: 'Newness' is key
- Relevance and Effectiveness: Does the product achieve the problem it was intended to solve?
- Elegance: Workable and useful, well-made The eye is a fine architect, believe it – Werner von Braun

- Genesis: Does the solution represent a paradigm shift? Does it help us see the problem in a new light?

Slide: the characteristics of a creative product:

As we just mentioned "newness" is a key:

Novelty. Creativity should always lead to something new.

In education this can take on different shapes depending on the age of the student and class they are in. For example, a 5-year-old learning a new method to tie his shoe is novel, however it loses its 'novelty' once he learns how to do it every day for the rest of his life. Subjects such as art and self-expression allow children to explore novel ideas that don't have to be grounded in reality.

Even though a creative product must be novel, in education it sometimes and most often also be practical. Too much novelty is not always applicable to the real world and is sometimes more suited for the arts or literature etc. an example may be designing an air conditioner that also cooks food, this may make for a good storyline in a book but is not something teachers and students would dedicate time to pursuing in a Mathematics class. Thus, with novelty in education balance is key.

Relevance and Effectiveness.

Often in education we learn things because they are going to help keep us alive and functioning when we are adults. Therefore, as teachers we often ask the question 'does the lesson achieve the problem it was intended to solve i.e. did the child learn an appropriate way to count today?

The concept of **Elegance** is to display something that is useful and well made, to incite a 'why didn't I think of that' notion in the observers. To a certain extent elegance is concerned with the aesthetics of a product. In our education examples we may focus on elegance as the ability for the child to write neatly or catch a ball properly.

The final criteria is Genesis. Does the solution represent a paradigm shift? Does it help us see the problem in a new light?

Steve jobs and the iPhone. Revolutionised the way we listen to music, take photos and interact socially.

This is an excellent illustration of *genesis*, it transformed a society and solved new problems. Genesis is often the hardest to 'build into' Creativity and often emerges after a product has been designed.

Summary: As we can see the key concepts to evaluating if a product is creative or not is the concepts of effectiveness and novelty. Elegance and genesis are not necessary but add depth to a creative product.

However, if I were to say go away and design a more novel, elegant, effective product with genesis what would you do? The answer is that a creative product is born out of a series of creative processes that incorporate creative strategies.

Paper aeroplane example

We are now going to work together on an example of Creativity using this newfound knowledge.

Click Slide: Why Creativity?

The world is changing and so is education, children of today are being prepared for jobs that don't even exist, therefore traditional methods of education are no longer sufficient, students need to be creative, need to be able to think on their feet, solve problems and innovate. Modern workforce's list Creativity as a core skill required when hiring employees. The point of education is not to regurgitate inert knowledge bur rather to transform it, apply it, shape it and react to it in everyday life. As I have mentioned the lack of female representation in STEM is also a big concern and yet longitudinal research suggests that a creative approach to Mathematics is effective for increasing positive attitudes in females as well as multicultural students.

A teacher cannot be expected to teach 21st century skills in a 19th century environment. Modern schools are looking to increase co-operation with teachers and their students, engaging experts, pose problems and reflect and refine constantly on day to day practices.

Click Slide: State of Creativity in education: An Adobe survey

Hypothetically, what if we could eliminate every subject in ACARA and take away NAPLAN what would schools or classrooms look like? It would be students working together to develop their own interests, they may build robots or roller coasters, write and discuss poetry or literature or interview locals in their area to gain historical perspectives. It would-be student-centred learning in their own areas of interest. I mean literally it would be chaos because there is obviously a time and place for structure but how about a happy middle? Where the value of subjects and NAPLAN etc. is embraced but the students are motivated and encouraging themselves to learn and directing their own learning. Creativity can help achieve this. Often Creativity can be seen as a direct contradiction to education. Schools have strict curriculums and need to meet certain standards however when we asked

… teachers they all said they value Creativity they just cannot implement it, or they felt it was too difficult. So, it is not a lack of desire rather a lack of knowledge or access to certain creative ideologies.

Click Slide: What is Creativity in Mathematics?

We know that STEM is the future yet what we all know just based on common sense is that if you are anxious towards anything you cannot perform. Mathematics underpins every STEM subject and is encountered in everyday life.

Sure, we all don't have to solve quadratic equations every day but how about basic algebra (I need to travel 200km but only have $30 for petrol and food at $1.50 per Litre how far can I travel and what can I eat?) geometry (how do I park my car) home loans and so on.

If we are anxious to do these things, we not only open the door to make mistakes but also, we cannot live to our full potential.

Creativity helps us firstly overcome anxiety, it frees up our mind but also helps us look at generic things and make them different, adapt and overcome, which I am sure we can all appreciate.

The best thing for teachers, I think is that being creative does not add to your workload, is not expensive and is relatively easy to implement.

So why isn't Creativity found in every classroom? Well it is, when you let your students explore new topics free of judgement, let them solve problems using their own methods. My role here is to highlight and expand on things you are already doing; help provide concrete examples alongside ACARA and help develop your own confidence in Mathematics.

These workshops are as much for you as they are your students.

This series of workshops is aimed at teachers and yet your students are also being measured because of the simple theory of modelling, basically monkey see monkey do. If your students, see you with positive Mathematical attitudes then they themselves are more likely to express positive attitudes which research has shown can boost their grades.

ACARA outlines that the Mathematics curriculum is organised around the interaction of three content strands and four proficiency strands. The content strands are number and algebra, measurement and geometry and statistics and probability. The proficiency strands are understanding, fluency, problem solving and reasoning. So, these sessions will be specifically addressing these three content strands but for your specific year group, so today we have year… so it will be at this level. Moreover, as I have discussed the definition of Creativity

involves aspects of fluency, understanding problem solving and reasoning therefore will compliment these four proficiency strands nicely.

Click Slide: Character Strengths and Positive Education

Just a quick word on positive education and character strengths here. Positive Education is an approach to education that blends academic learning with character & well-being. As you can see Creativity is embedded into this theory as a character strength and I am going to demonstrate throughout this presentation that a creative approach to Mathematics hits on a whole heap of these other strengths also. You will observe at the bottom of my slides these logos as a demonstration of how Creativity in Mathematics is a great example of positive education.

So enough explaining let us get into it shall we? Any questions before we begin?

Working from Cropley 1997 general principles framework so we will go through it and tailor it specifically for you guys.

Today's workshops will focus on the heading 'what should teachers foster in their students?'

What should teachers foster in their students?
Possession of a fund of general knowledge.
Knowledge of one or more special fields.
An active imagination.
Ability to recognize, discover, or invent problems.
Skill at seeing connections, overlaps, similarities, and logical implications (convergent thinking).
Skill at making remote associations, bisociating, accepting primary process material, forming new gestalts, etc. (divergent thinking).
Ability to think up many ways to solve problems. (Divergent thinking).
A preference for accommodating rather than assimilating.
Ability and willingness to evaluate their own work.
Ability to communicate their results to other people.

Let us start with the first one 'possession of a fund of general knowledge'

This basically means that in order to be creative in an area we must understand this area. We cannot be creative in geometry if we do not know what it is right? So, this one is common sense. But how do we do this in the context of ACARA and the creative and critical thinking general principles research?

If we give a specific example here of at junior primary so by the end of year 2 or level 2 according to ACARA numeracy learning continuum the students are expected to identify and use combinations of coins and notes for simple purchases. And the critical and creative thinking learning continuum is identify and explore information and ideas from source materials so a combination of these 2 may be to set up a school store in the classroom where students can be rewarded with 'money' and have the option to purchase things i.e. sweets, pencils, etc. can foster team work i.e. work as a table or group to get money, etc.

Can be done throughout all year levels. Incorporate things like Mother's Day, Father's Day, Easter Christmas etc., things they can make and purchase for family.

Knowledge of one or more special fields:

This can follow on from the possession of a fund of general knowledge. For example, we need to know how to do addition and subtraction if we are dealing with money. So, we are combining and encouraging multiple skills in this shop example. As well as 'life skills' such as budgeting, and teamwork.

Eugen Semmer

In 1870 Eugen Semmer, a pathologist working in the Institute of Veterinary Science in Riga, published a paper in the widely-read German-language scientific journal, *Virchows Archiv* (which still exists today), reporting on the strange return to health of two horses that had been admitted to the clinic suffering from what we would now call "infections" (Semmer, 1870). He carefully examined the now-recovered horses (whose corpses he had expected to be examining) and discovered that while at the institute they had by chance been exposed to spores of the fungus *penicillium notatum*. He correctly concluded that the mold had been responsible for the horses inconveniently getting better, and explained how he had carefully cleaned out his laboratory and had succeeded in eliminating the troublesome *penicillium notatum*, which had been growing in dark nooks and crannies. No further sick horses would be recovering by accident in his clinic!

This is an example of narrow specialisation, Semmer was not looking to be anything more than a pathologist and did not have the insight to notice he'd discovered penicillin. If he had had had a broad mind, we would be talking about him in a much different context.

An active imagination:

This is an obvious one associated with Creativity. And can easily be applied to Mathematics. A lesson of 'free Mathematics' whereby the students come up with their own problems and solutions, i.e. can use the idea of identifying, describing and creating everyday patterns using their own interests. i.e. sports, dance, ICT etc.

Story telling i.e. build a playground using geometry. Or write an exchange between a shop keeper etc (money principle ACARA)

Design a playground (2D and 3D shapes ACARA)

Clocks, calendars and timetables sub-element from ACARA is a relatively easy example here. i.e. holiday making and planning. i.e. what season is best if I want to go swimming. What month is that? How do I get there?

Ability to recognize, discover, or invent problems:

Same as above.

Skill at seeing connections, overlaps, similarities, and logical implications (convergent thinking):

Within Creativity is the ideas of convergent and divergent thinking. There is a time and place for both. Convergent thinking is a problem-solving technique involving the bringing together different ideas from different participants or fields to determine a single best solution to a lucidly defined problem. In other words, this is a kind of thinking that concentrates on finding out the single best or frequently, correct solution to a problem or answer to a question. Convergent thinking is choosing one solution. For example, when answering a Mathematics equation, you need to put down one answer as the solution.

In order to do this the students, need to know how to solve a problem so general teaching strategy here.

Skill at making remote associations, bisociating, accepting primary process material, forming new gestalts, etc. (divergent thinking):

Slide 12: Convergence and Divergence

If you are familiar with creative theories, then you may have heard of the concepts of convergence and divergence.

- In simple terms, convergence is about finding the one right answer:
- 2 + 2 =?
- By contrast, divergence is about finding lots of possible answers:

- 4 = 2 + 2 or 3 + 1 or 0 + 4 or ...?

Divergent thinking involves the process of generating creative ideas by exploring many possible solutions. Common exercises include brainstorming.

Click Slide: Now is not the time!

Brainstorming can help us develop the ability to think up many ways to solve problems. (Divergent thinking): brainstorming has its restrictions; it only works if everyone feels involved but can often be dominated by stronger personalities. Another suggestion can be brain writing which works according to the same method as brainstorming but involves writing down multiple ideas before presenting them.

Importance of knowing when to use convergent or divergent thinking.

Click Slide: A preference for accommodating rather than assimilating:

Assimilation work of Psychologist Piaget

– Which is using an existing schema to deal with a new object or situation.

Accommodation

– This happens when the existing schema (knowledge) does not work and needs to be changed to deal with a new object or situation.

When a child learns the word for cat, they start to call all four-legged animals' cats. This is assimilation. People around them will say, no, that is not a cat, it's a cub. The schema for cat then gets modified to restrict it to only certain four-legged animals. That is accommodation.

An example in Mathematics may be seeing the value of Mathematics in everyday life i.e. it's not just about what you see in a classroom but how you see it in everyday life.

Ability and willingness to evaluate their own work: self and peer evaluation.

May get rewarded verbally for efforts trying different processes regardless of the 'correct' answers. Ask the students to reflect on what they did wrong.

Here is the value of intrinsic motivation. The issue is that students are often motivated extrinsically i.e. by grades and tests such as NAPLAN etc. however, Creativity can help foster intrinsic motivation. Intrinsic motivation is where the student learns to self-motivate to develop their learning. In the context of Mathematics, this involves the student developing positive attitudes towards mathematics and minimising anxiety towards mathematical tasks. This can be done by providing a safe classroom i.e. no punishment for poor grades or incorrect answers. Help students visualise a moment in which they felt very proud of

themselves and then teach the Mathematics lesson. Encourage students to value things other than grades i.e. learning the process.

The concept of mild competition; group competition, however teams should be constantly re arranged, and points given to things other than the right answer. Play and Creativity helps foster mild competition. However, grades or material rewards should never be attached to competitive games the kids derive satisfaction just from the games.

Enable learners to believe that their work will lead to powerful effects. Students won't remember everything you teach them – such is the limited capacity of the human brain. But the point is not to memorize every fact and concept. The point of school and homework is to cultivate an academic work ethic of sorts, so that someday, that million-dollar idea won't be so hard to realize.

Provide learning goals. Research has shown that when teachers give learners a goal, students experience a boost in self-efficacy (Bandura, 1988; Elliot & Dweck, 1988; Schunk, 1991). By providing clear learning goals at the beginning of class or before an activity, students may be more intrinsically motivated to work toward those goals.

However, I understand how extrinsic motivation works and may not be as effective as intrinsic motivation, but it is in everyday life. We make our sales we get our bonuses etc. therefore as teachers we need to find balance between extrinsic and intrinsic. Yes, we must reward our students and of course kids are motivated by treats just as adults are. We can motivate students who may be anxious with encouraging words and focus on their efforts not necessarily their grades or ability to solve problems correctly. Or not necessarily focus just on test results, how about including a mark or grade for effort and focus on that also. It's more about balance between the two.

Creativity and mindsets:

Growth and fixed mindset https://www.lexialearning.com/blog/6-tips-help-students-develop-growth-mindset-classroom

Follows on slightly from the notion of intrinsic and extrinsic motivation. The theory of mindsets is widely implemented in Australian classrooms. Carol Dweck suggests there are two mindsets, growth and fixed. She defines a growth mindset

What is growth mindset?

Growth mindset is the idea that, with effort, it's possible to increase intelligence levels, talents, and abilities. Students who demonstrate a growth mindset believe their abilities

develop over time, tend to seek out opportunities to gain new knowledge and broaden their skills, and do not typically shy away from challenges (Kazakoff & Mitchell, 2017).

In comparison, fixed mindset is the belief that intelligence and talents are static, leading students to believe that their potential for success is based on whether they currently possess the required abilities. These students are often tempted to give up when things get hard—they may run from challenges, see mistakes as failures, or approach success differently to their classmates with a growth mindset. According to Kazakoff & Mitchell, "Students who possess a fixed mindset are often preoccupied with the notion of high performance and will seek opportunities where they can prove their skills while avoiding situations where their weaknesses might be revealed."

In contrast, students with a growth mindset believe that they can learn to complete tasks, solve complex problems, or grow their intelligence, rather than assuming they "can" or "cannot" do something based on their current abilities.

Having a growth mindset is essential to lifelong success, and it is something that students can develop with practice.

Does growth mindset really help kids succeed?

2014 research by Claro & Paunesku revealed that students who demonstrate a growth mindset:

- perform better than students with a fixed mindset, significantly outscoring them in the areas of math and literacy.
- are more likely to recognize the importance of effort in academic success.
- seek out challenging academic tasks to enhance learning; and
- value critical feedback.

What do teachers think about growth mindset?

According to a 2016 national study of over 600 K–12 teachers conducted by the Education Week Research Center, almost all teachers (98%) believe that integrating growth mindset will lead to improved student learning.

Despite having an interest in and a willingness to implement growth mindset in the classroom, teachers feel they are not adequately trained to foster such a mindset in their students. Only 20% of study participants said they strongly believed they were good at fostering growth mindset, and 85% reported that they wanted more professional development in this area.

The idea that people want to implement growth mindset but may not fully understand how to do so is troublesome to Carol Dweck, the Stanford professor who coined the term.
Dweck has expressed her concern that misinformed people might encourage students to keep trying in order to "get it" (succeed in a task), despite the fact that developing a growth mindset is not simply about layering on praise. According to Dweck, "growth mindset is about closing the achievement gap, not about making low-achieving kids feel good in the moment but not learn in the long run." In other words, cultivating growth mindset is not just about praising effort. Rather, we need to teach children how to learn and use strategies to overcome challenges.
By making simple changes in the classroom, we as educators can begin to foster an environment in which students are not only aware of growth mindset but can actively take part in creating such a culture.
Here are a few tips for helping students develop growth mindset in the classroom.

1. Read books with characters who face challenges and develop strategies to overcome them.

A few examples include:

- Your Fantastic Elastic Brain: Stretch It, Shape It by JoAnn Deak, Ph.D.
- Beautiful Oops by Barney Saltzberg
- The Most Magnificent Thing by Ashley Spires
- What Do You Do With a Problem? by Kobi Yamada
- These books are perfect for read-aloud and class discussions. Start off the year with Your Fantastic Elastic Brain, which explains how the brain works and grows in a kid-friendly way, and then use the characters and storylines in the other books as the year goes on. Students will see characters who are faced with problems overcome adversity and handle mistakes and will refer back to these stories when they encounter similar challenges in class.

2. Conduct activities that give students the chance to practice phrases that promote growth mindset.

Openly discuss things students with a fixed mindset might say (i.e., "I'm no good at this" or, "This is too hard") and brainstorm alternatives (such as, "What other strategies can I try?" or, "It may take some time to figure this out").

3. Display visible reminders of growth-mindset vocabulary using inspirational posters and bulletin boards.

Anchor charts from the activity listed above make great classroom reminders. Alternatively, have students design their own motivational posters to encourage authentic learning. Bulletin boards may focus on the overall understanding of a growth mindset, or feature words and phrases associated with the positive attributes or actions of characters in literature. Boards featuring athletes, business leaders, and even presidents who have overcome challenges can be extremely inspiring, especially when these successful individuals' initial failures are mentioned.

4. When giving feedback to students, use prompts that facilitate a growth mindset.

Rather than awarding feedback such as "You are so smart" or "You did a great job getting an A," encourage higher introspection with prompts. Ask questions about students' processes ("What made you decide to try that method?"), how they can work to improve ("What do you think you can do differently next time?"), and what they took away from their mistakes ("When X occurred, how did you feel and what did you learn from it?"). By providing the opportunity for self-evaluation, students will discover more about their ability to work through to a solution and will pick up self-talk approaches and questions to ask themselves down the road.

5. Model growth mindset as an educator.

When we as educators are faced with a challenge or make a mistake, we can talk through the situation with students and demonstrate the path to learning, helping students make necessary connections in real-life situations. For example, if we waited too long to reserve a common learning space for a class period, we can explain the situation to students and ask for input on how resolve the issue. Students may suggest combining with another group, adjusting the lesson to fit another space, or some other creative solution. While this is a process that we could go through ourselves, involving students helps them recognize that everyone makes mistakes and it important to work through challenges in order to make progress.

By implementing simple activities and providing opportunities for students to develop the skills necessary to meet challenges head-on, we can help students find confidence in their academic journey and create an environment that promotes growth mindset.

https://www.transformingeducation.org/growth-mindset-toolkit/

Click slide: Teamwork (Ability to communicate their results to other people)

Insert examples of Mathematics games

BRAIN BREAKS

The Neuroscience of Brain Breaks

For new information to become memory, it must pass through an emotional filter called the amygdala and then reach the prefrontal cortex. When students' brains become anxious, highly confused, or overwhelmed, the activation of the amygdala surges until this filter becomes a stop sign. New learning no longer passes through to reach the prefrontal cortex and sustain memory. Even if students are not stressed by the pace or content of new learning, a point arises when the amygdala exceeds its capacity for efficient conduction of information through its networks into memory.

Brain breaks can be planned to restore the emotional state needed to return the amygdala from overdrive into the optimal state for successful information flow.

Brain Breaks Restore Brain Supplies

Neurotransmitters are brain chemicals that carry messages from one nerve cell to the next, across gaps between the cells called synapses. These message carriers are necessary to keep one's calm, focused attention and maintenance of a new memory. Neurotransmitters are in limited supply at each synapse and can deplete after as little as 10 minutes of continuing the same type of learning activity (attentive listening, practice drills, note-taking).

Brain breaks, by switching the type of mental activity, shift brain communication to networks with fresh supplies of neurotransmitters. This intermission allows the brain's chemicals to replenish within the resting network.

Timing

Brain breaks should take place before fatigue, boredom, distraction, and inattention set in. Depending on students' ages and focus development, brain break frequency will vary. As a rule, concentrated study of 10 to 15 minutes for elementary school and 20 to 30 minutes for middle and high school students calls for a three- to five-minute break.

Brain Break Strategies

Brain breaks do not require disruption in the flow of learning. Simply stretching, moving to a different part of the room, or singing a song can revitalize the brain. Use your learning goals and students' responses to guide you in selecting the best type of brain break. You might decide to use the time to boost mood or motivation, as well as restore the brain's peak performance.

Mood

To restore the emotional state needed to bring the amygdala back from overdrive, help students build habits of emotional self-awareness and mindfulness. Prepare them for

successful self-calming brain breaks by demonstrating and providing practice times as they build experience using mindful breathing or visualizations.

Neuroscience has yielded information on activities that increase restorative neurotransmitters such as dopamine. Some of these activities, such as laughing, moving, listening to music, and interacting with peers, make great mood-boosting brain breaks:

Read aloud from a relevant and engaging book.

Introduce physical activity such as jumping rope, singing a song with movements, or tossing a beach ball while students ask and answer questions to review the topic—these are all great dopamine boosters. They also increase the blood flow and oxygen supply to the brain.

Have students move in ways that they think a character in literature or person in history would at a designated event. Or move to imitate a biological, physical, or mathematical process.

5 Minutes

Simon Says, "Geometry!"

Ramp up this traditional game by having kids illustrate the following geometric terms using only their arms: parallel and perpendicular lines; acute, right, and obtuse angles; and 0-, 90-, and 180-degree angles.

Challenge: Increase the pace of the commands and see if your students can keep up

10 Minutes Even 10 minutes of fun math games can jump-start learning.

Hopscotch Math

Set up a hopscotch grid with a calculator layout. With older kids, you can include the square root symbol and negative integer sign. Students first hop on one number, then an operation, another number, the equal sign, and finally the answer. For double-digit answers, students can split their last hop so that their left foot lands on the digit in the 10s place and their right foot lands on the digit in the ones place. Challenge: The student taking a turn tosses a stone onto a number and must avoid that number in the equation.

15 Minutes

Teach quick math concepts with fruit, dice, even Twister!

Weighing in

Line up a variety of fruits and veggies, such as oranges, bananas, cucumbers, kiwis, tomatoes, and bell peppers. Ask students to predict the order of the foods from lightest to heaviest. Use a balance scale to test their predictions, then rearrange the foods according to their actual

weights. Challenge: Slice each fruit in half. Invite students to analyse how the density of the fruit or vegetable affects its weight.

Algebra: run the race, 100m in how many seconds is how many m/s etc.

Session two:

Personality properties favourable for Creativity:
Task commitment, persistence and determination.
Curiosity, adventurousness, and tolerance for ambiguity.
Independence and nonconformity.
Self-confidence and willingness to risk being wrong.
Drive to experiment and willingness to try difficult tasks.

These are properties for both you and your students.

Quick personality test to show how we can utilise every personality and still be creative (teachers did Big 5 personality test).

Task commitment, persistence and determination:

Creativity is not a spontaneous burst of genius as often people assume, it takes hard work, knowledge in the field and many trials and errors.

If we look at the example of Charles Goodyear, he supposedly discovered how to vulcanise rubber, paving the way for hard wearing and efficient car tires accidentally. He unintentionally dropped a mixture of sulphur and rubber onto a hot stove. This apparently effortless creative discovery is a good example of how divergent and convergent thinking blend harmoniously together.

What we often do not hear is that Goodyear had spent 5 years searching for a solution to the problem of stabilising rubber so that it could be used more effectively in the manufacturing of shoes. He did not take 2 unrelated random substances and decide to throw them on a stove. The fact he was heating and not cooling was the result of his earlier findings. In other words, his discovery of the stabilising effect of sulphur on the rubber only came about because of a combination of the application of a knowledge to a problem. Thus, providing evidence of how processes of divergent and convergent thinking often blend to make a creative and innovative product.

It is important to foster this in students and one way is to make Mathematics meaningful for them. Like my failure of algebra until it became relevant through sports example. Make the subject or topic relevant to the student. Let them write their own problems and equations and

ways to solve. Let them in science come up with their own problems relevant to them (school that used the problem of snow). This incorporates Mathematics.

Curiosity, adventurousness, and tolerance for ambiguity:

Curiosity is seen in the context of positive education as a character strength and aligns well with the Creativity and creative thinking general principle. Curiosity is all about seeking out new information, posing questions etc.

I understand how frustrating it can get for a teacher when kids keep asking questions as you are trying to teach. So how do we foster curiosity and maintain teacher sanity? The obvious answer is allowing specific time to foster curiosity i.e. let designate time for students to ask questions etc. which I am sure you all do so what else? Here is a great opportunity to allow cross curricula activities such as outdoor play, looking at geometry in the real world. ICT for researching different currencies around the world or how much each item should cost in their own classroom store etc. English, or writing where they can write a story about the relevance of Mathematics in their lives. Interview an engineer, scientist etc. for the older students or organise an excursion with Mathematics principles-built in. here are some specific exercises for boosting curiosity in your classroom though…

Exercises for Boosting Curiosity

Consider an activity you dislike. Pay attention to 3 novel features of this activity while you do it.

Practice active curiosity and explore your current environment, paying attention to anything you may often ignore or take for granted.

Teach students to be sceptics, not just assume what they see is correct but to conduct their own research.

Self-confidence and willingness to risk being wrong:

Self-confidence obviously comes when we get things right or feel a task is valued. Again, using my algebra and sports example encourage individuals to relate Mathematics to their everyday lives. Try to ensure even the most ridiculous questions aren't met with disapproval rather turn it into an activity to get the class back on track.

Self-regulation and perseverance character strengths from positive education are important here.

Self-regulation: manage your feelings. If you are confident and willing to be wrong, it obviously you display skills of perseverance and self-regulation.

If students feel like they can make mistakes in a safe space particularly with children who are ethnically diverse or lacking in confidence in a mathematical area this can really help them. Particularly important is the importance of non-graded tasks where kids can explore and can be wrong without fear of punishment. How about opportunities to complete in class Mathematics exercises with no grades assigned.

This principle applies to you as a teacher also. You must be confident in order to present the work. Let us look at your school environment and how it allows you as teachers to be curious, make mistakes etc.

Press:

In Creativity we refer to the environment as press. And this directly affects our ability to be creative.

So, if I ask you all 2 questions: What press practises are utilised in this school to aid Creativity? How does your school currently help you as a teacher be or express Creativity?

Exercise: Needle & Thread

10 minutes

The creative workplace

What does the creative workplace look and feel like?

Amabile and Gryskiewicz (1989) identified eight aspects that foster Creativity:

- Sufficient freedom
- Challenging work
- A supportive supervisor
- Appropriate resources
- Diverse and communicative co-workers
- Recognition
- A sense of cooperation
- A supportive organisation.
- **Boils down to 3 things; time, resources and support**

So how can we work alongside leadership and our fellow teachers to ensure we have a creative workplace to attend before we enter our own classrooms?

What hinders Creativity in the workplace?

- Feelings of being harshly judged or criticised

- Fear of failure
- Resistance from either the company or management to new ideas

How do we enhance Creativity?

We have already been through some of these for our classrooms but how can we work as a team with our fellow teachers to be creative?

- Collaboration= **brainwriting in collaboration with brainstorming**
- Play = games ideas
- Idea collection= collaboration within teams
- **Freedom to fail = no idea is a dumb idea**
- Space to think = minimise deadline pressures when thinking creatively
- Ego support = support from management

Activity:

Let us look at some ways as a teacher we can collaborate. There are schools around the world where each teacher has a different role. For example, I know teachers in Australia don't work from one curriculum and use the same lesson plans for everyone. Due to diversity we have differentiated curriculums etc. so let's say all year 2 teachers have to teach money well a good idea may be if there are enough teachers to do so 1 teacher takes the low kids, 1 the medium and 1 the advanced kids. So, math's lessons have to be scheduled at the same time, but this saves teachers time as they only have to develop one type of lesson plan.

This fosters teamwork within year level teachers also because meetings have to be scheduled and planned. Students work in different environments and with different students so is really encouraging teamwork with them. Children with lower abilities don't have to feel as isolated because everyone in their group is at the same level. They feel less fear and judgement from sharing ideas and being wrong etc. teachers because you are working with others your confidence can develop because you become an expert in your specific lessons. Allows more opportunities to be creative because you don't have to worry about 3 different lessons happening at once. This system has been put in place in schools primarily in the USA and Canada with teachers reporting increases in their own confidence and feeling like they aren't doing as much work that is usually required from them.

If we go back to the slide about what a creative workplace looks like then we can see this example helps free up time, resources and support.

Activity: Get crazy

5

GET CRAZY

Background

Look waaaaay down inside yourself. There are lots of hidden recesses down there, aren't there? Things known only to you and perhaps a few of your intimate friends. Things you normally don't show in polite company. That strange side only you know about. The side that views things differently.

If you look long enough, you may eventually discover the wacky you down there—the side of you that every now and then thinks of an off-the-wall idea. It's the side that makes a sudden leap of intuition, jumps to conclusions, and goes off the deep end (the side filled with clichés). You know it's in there, so admit it. Use it occasionally to your advantage. Get crazy, get zany, get ridiculous. View your problems with new eyes and use the steps that follow to help produce this same effect within the participants.

Objectives

- To help participants generate as many creative ideas as possible
- To help participants learn how to use the activities to generate ideas

Participants

Small groups of four to seven people each

Materials, Supplies, and Equipment

- For each group: markers, two flip charts, and masking tape for posting flip-chart sheets
- For each participant: one sheet each of three different colors of sticking dots (½" diameter) and one pad of 4 x 6 Post-it® Notes

Handout

- Get Crazy Handout

Time

45 minutes

Related Activities

- What If. . . ? [49]

Procedure

1. Distribute copies of the Get Crazy Handout to each participant.
2. Work through the sample exercise on the handout with the large group and answer any questions.
3. Have the participants write down the most crazy, ridiculous problem solutions they can think of. The crazier the better.
4. After about 15 to 20 minutes, tell them to forget about being crazy and zoom back to normality and get on with solving their problems and be practical.
5. Tell them to examine each of their crazy ideas to see what more practical solution it may suggest. They may not think of one for each crazy idea, but do the best they can.
6. Tell them to write down any ideas on Post-it® Notes (one idea per note) and place them on flip charts for evaluation.

Debrief/Discussion

Ask the groups to consider the following questions:

- What is a "crazy" idea? How does it differ from "normal" ideas?
- Is any idea really "crazy"?
- What effect does the type of problem have on deciding whether or not an idea is crazy?
- Would more difficult problems be more easily resolved using crazy ideas?
- What are the advantages of using crazy ideas? Disadvantages?

Also consider having participants debrief using the following questions:

- What was most helpful about this exercise?
- What was most challenging?
- What can we apply?
- How would you rate the value of this exercise to helping us with this issue?
- Will this exercise be helpful in the future for other sessions?
- What did you learn?
- What will we be able to use from this exercise?
- What ideas were generated, and which ones were most interesting?

Get Crazy Handout

Challenge: How might we get people to buy more of our product? First, get crazy and generate some ridiculous ideas such as the following:

- Threaten people with a "long vacation" if they don't buy your products.
- Pay them $1 million for every dollar they spend on your products.
- Promise them three magic wishes.
- Attach a subliminal advertising device to their televisions.
- Have your cousin Vinnie pay them a visit.
- Send your product to every home in the world as a holiday gift and invoice the homeowners.

O.K., those are pretty ridiculous. Now use each one to stimulate a more practical idea. Some examples:

- Offer free or partially funded vacations to people who place large orders.
- Develop a list of "magic wishes" with a lottery for customers to select one of the wishes; for instance, one wish might be to win one dollar every day for ten years.
- Offer discounts to people who pay with cash.
- Offer family discounts.
- Create a new product with a holiday theme.

Session three:

Creativity fostering teachers are those who:
Encourage students to learn independently.
Have a cooperative, socially integrative style of teaching.
Motivate their students to master factual knowledge, so that they have a solid base for divergent thinking.
Delay judging students' ideas until they have been thoroughly worked out and clearly formulated.
Encourage flexible thinking in students.
Promote self-evaluation in students.
Take students' suggestions and questions seriously.
Offer students opportunities to work with a wide variety of materials and under many different conditions.
Help students to learn to cope with frustration and failure, so that they have the courage to try the new and unusual.

Impact of press

Encourage students to learn independently:

Have a cooperative, socially integrative style of teaching:

Time and a place to learn together and independently.

Together, set up a school shop fosters money knowledge and teamwork. Kids can raise money for an excursion, a school lunch. Older students can have a treasurer, secretary etc. fosters business skills, marketing, they are motivated to learn and make it successful.

In a year 10 Mathematics class in Victoria a certain style of teaching was employed. Students were given a problem they did not know how to solve. Their homework was then to try to do as much as they could and then bring their efforts back to class the next day. Then they were randomly assigned to a small working group filled with students of mixed abilities and were told to share their findings and see if they could develop all their processes toward a solution. Each group then presented their work to the rest of the class and worked together to try and solve the problem. Teachers observed that even the less abled students were able to make some progress and the peer to peer teaching worked well. Teachers also noted motivation towards the subject increased. This could work well with the older students.

Motivate their students to master factual knowledge, so that they have a solid base for divergent thinking:

Delay judging students' ideas until they have been thoroughly worked out and clearly formulated:

This is a common sense one that is basically just about suspending grades and testing until the students have mastered the topic. Also, about allowing the student to respond and ask questions no matter how irrelevant they are and not making them feel in adequate for asking. Even if they get it wrong ask them to identify their process so it can be corrected. Can reward effort to develop confidence.

Help students to learn to cope with frustration and failure, so that they have the courage to try the new and unusual.

In order to be successful in life we obviously require a level of resilience. A great exercise here that is hands on and can be implemented an adapted across all the year levels is various adaptions of the Rube Goldberg machine tasks. Rube Goldberg was an American cartoonist, best known for his comics depicting complicated and overly engineered contraptions. One step triggers the next in a chain reaction until the desired final step is achieved. Students can be exposed to a task like this and only provided with household objects i.e. string, toilet rolls and disposable plastic cups. This was trialled in a Victorian school and kids went given any electronic devices or aids. The teachers observed that their students embraced the patience and problem-solving skills required to develop a solution to the problem. Students who usually had little patience with book tasks were more than happy to engage and repeatedly fail 10, 20 and even 50 times! Student’s motivation towards the tasks increased and they learnt the value of the Mathematics and physics behind the ideas.

Now for example this exercise is somewhat difficult to map onto ACARA guidelines at first glance. However, it lends itself to traditional problem solving and thinking outside the box ideas which underpins all Mathematics. By exposing the students to basic physics as well they can learn to shape their attitudes and minds at an early age. Can obviously be adapted for the different year levels.

Offer students opportunities to work with a wide variety of materials and under many different conditions:

Cross curricula: ICT, cooking, Sports, the arts, drama, science, English.

Mathematics is seen a lot in ICT in modern education.

Mathematics and ICT

- Every year level has varying elements of 2D and 3D shapes and objects. Google earth and mapping 2D, 3D measurements find perimeter of the student's house, favourite sporting venue etc.
- Older students are expected to display data of prisms and pyramids. Can use Ancient Egypt and tie in History and Mathematics whilst visualising online.
- Interpret Maps and Diagrams is very easily done online.
- Cultural diversity is so important today so kids could research their hometown or a friend and see it online on google maps. This will foster social equality and learning the value of diversity.

Mathematics and Cooking

May appear for older students. But if we take the example of setting up a school shop kids could raise money for a pizza lunch and then use it to learn fractions etc.

For older students' measurement to bake or even to make lemonade or ice blocks as a classroom activity for science on a hot summer's day.

Cultural diversity again, making damper, other ethnic foods.

Mathematics and Physical education

Perimeter of oval etc.

Like in my sports example of algebra and physics the questions can be simplified for the students but made relevant. i.e. if you are riding your bike etc. make it relevant for the kids.

This is where cultural diversity can be really enhanced again

Mathematics and the Arts

Colouring of patterns for younger students but in everyone has been shown in research to relax students before mathematical tasks, acts as a form of mindfulness

Structured mandala (ICT) can see this image that this can be done in an ICT lesson. Looks at geometry etc.

Art therapy is a growing field and looks at controlling emotions through the presence of art. This can be important if a student is anxious with Mathematics or before a Mathematics test. Research has shown that colouring this image for 10-15mins (Look up honours thesis info) can reduce anxiety and increase grades in students. This could be a helpful exercise before NAPLAN or a test. Particularly helpful for girls and boys benefited more from 'free colouring.'

Mathematics and Science

This has almost endless opportunities and you would be covering this in science lessons anyway. Science lends itself more naturally than Mathematics to Creativity,
Use the environment around them. For example, an American school experienced a snowstorm and blizzard, so all the kids were affected in one way or another. Teacher collaborated so all year three teachers for example and dedicated an entire term to 'solving the snow crises'. English lessons were spent writing letters to government. Mathematics and science lessons were dedicated to increasing infrastructure in the town. Forestry experts came and brought wildlife and spoke about issues with animals etc. The students felt engaged and had an impact on solving real life problems. Examples in South Australia could be the electricity crisis or blackout from a couple of years ago or even heat waves.

Mathematics and English

- Texts such as Roald Dahls 'George's marvellous medicine' lend themselves more easily to a Mathematics connection (year 2).
- STEM solves fairy tales books. 'Help Rapunzel escape from her high tower using a zip wire and a bit of gravity or work out how science and technology can help *Little Red Riding Hood* fix that wolf once and for all! This fun and quirky approach takes stories that young readers already know and love, but with the added twist of learning about STEM subjects along the way."

Numeracy

- Estimate the solution to a problem and then calculate the answer
- Identify quantities such as more, less and the same in everyday comparisons

Critical & Creative thinking

- Pose factual and exploratory questions based on personal interests and experiences
- Gather similar information or depictions from given sources

Even reading stories on famous mathematicians and scientists.

Mathematics and Geography

Google maps idea again/plan a holiday

Diverse cultures and landscapes.

Different currencies and money

Patterns in landscapes

Time zones

SOH 2000 indexing Creativity fostering teaching behaviour:

As I mentioned at the beginning teachers often find it difficult to validate and measure Creativity in their classrooms and therefore it can often get unintentionally pushed aside.

I am going to hand out a checklist that has been validated based on the Cropley Principles we have been going through. It is a 45-item checklist that can be used as a self-reported checklist for you as individuals to record your own Creativity levels in the classroom. It is important to remember that even though higher scores are related to a higher level of Creativity in the classroom there are different items and times to employ each idea and we cannot have a high score all the time.

Summary slide:

Drawing this all together we can see how a creative based approach to Mathematics is a well-researched way is to minimise negative experiences and increase positive attitudes towards mathematics.

I'd like to reiterate the importance of your own attitudes towards teaching Mathematics, it isn't about adopting all the suggestions I've laid out rather it's about choosing and adapting what you think will work when and with your own students.

Appendix K: Journal Paper: Teacher Self-concepts of Creativity: Meeting the Challenges of the 21st Century Classroom

This paper was the first output from a 2-year joint collaborative project involving UniSA, Geelong Grammar school and The University of Connecticut. This paper examines teacher self-concepts of creativity in a total of 2,093 student and professional teachers from six countries (or geographical regions). It was published in the International Journal of Creativity and Problem Solving as follows.

Patston, T. J., Cropley, D. H., Marrone, R. L. and Kaufman, J. C. (2017). Teacher Self-concepts of Creativity: Meeting the Challenges of the 21st Century Classroom. *The International Journal of Creativity & Problem Solving*, *27*(2), 23-34.

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Abstract

School systems around the world are, for a variety of reasons, moving towards a greater emphasis on creativity in the classroom. This paradigm shift raises important questions for teachers. Do teachers need to be creative themselves in order to develop creativity in their students? Is teaching a creative profession? Regardless of the importance and interplay between teaching creatively, and teaching for creativity, what role does teachers' belief in their own creativity play in this move to a more creative classroom? In this paper, we examine the creative self-concept of teachers across a range of countries, disciplines, and other variables, asking which groups of teachers, if any, may be best prepared for the reorientation of the 21st century curriculum towards creativity in the classroom?

Keywords

Creativity, self-concept, teaching, creative education

INTRODUCTION

Around the world, national education bodies as well as individual schools are calling for a shift from "traditional" pedagogy and standardized testing to a more "creative" education paradigm (Beghetto & Kaufman, 2016; Beghetto, Kaufman, & Baer, 2014). Teachers are being advised, if not compelled, to introduce creativity into their daily classroom practice in countries ranging from Australia (ACARA, 2010) to Iceland (MESC, 2011) and Hong Kong (HKCDC & HKEAA, 2007). Are teachers equipped for this change, and what preparation and development might be needed to support this fundamental re-orientation? Is there a risk that teachers are being set up to fail?

If teachers are expected to teach, nurture, model, and evaluate creativity in their students, does this imply that they should themselves be creative? Research certainly suggests that individuals – including teachers – who are more original are better able to evaluate their *own* creative ideas (Benedek et al, 2016; Silvia, 2008). However, this capacity for self-evaluation may not always translate into being able to accurately assess other people's – for example, students' – creative ideas (Grohman, Wodniecka, & Kłusak, 2006). At the same time, a number of studies have shown that people with more expertise or experience in a creative domain are more likely to excel at judging creativity in this same domain (Kaufman et al, 2014; Kaufman & Baer, 2012; Kaufman, Baer, & Cole, 2009 Kaufman, Baer, Cole, & Sexton, 2008). Together, these studies suggest that individual creativity in teachers is a necessary, but not sufficient, condition for meeting the demands of the 21st century classroom.

If creativity is a necessary, albeit insufficient, pre-requisite quality required by teachers to fulfill the expectations of modern classroom practice, then is this a reasonable expectation? Is teaching, in other words, normally considered to be a creative profession, capable of meeting these requirements? Although typical associations tend to see creativity as

linked with activities and professions in the arts (e.g. Hass, 2014), there is a great deal of research highlighting the role that creativity plays across a wide range of domains (Kaufman & Baer, 2005; Kaufman, Glăveanu, & Baer, 2017; Carson, Peterson, & Higgins, 2005), including both arts (e.g. Baer, 1991), science (e.g. Simonton, 2004), engineering (e.g. Cropley & Cropley, 2005; Cropley 2015), and other domains (e.g. Weisberg, 2006). In addition, there is much evidence to suggest that teachers are quite creative.

Teachers frequently are required to develop useful and novel solutions in a variety of contexts, consistent with most conceptions of creativity (e.g., Kaufman, 2016), demonstrating the importance of an ability to teach creatively. Further, several studies have found (much like established creators) that teachers qualify as strong judges of creative work, signifying their expertise in recognizing creativity (Baer, Kaufman, & Riggs, 2009; Kaufman, Baer, Cropley, Reiter-Palmon, & Sinnett, 2013).

Although teachers' ability to be creative may support creativity in the classroom, and while teaching may be a creative profession, the key to achieving the 21st century curriculum objectives in relation to creativity may be teachers' *beliefs* about their own creativity. Do teachers need to *believe* that they are creative in order to nurture or teach student creativity (Westby & Dawson, 1995; Saracho, 2012)? What role does teachers' creative *self-concept* play in the development of creativity in the modern classroom? While there is ample anecdotal evidence that teachers of different subjects perceive themselves as having qualities that are unique to their discipline, apart from some literature looking at teacher personality attributes between disciplines (Bastian, McCord, Marks, & Carpenter 2017), it is unclear whether these differences exist with regard to creativity, or creative self-concept.

Self-concept, in general, encompasses a set of ideas or beliefs which one has about oneself (Plucker & Stocking, 2001). The notion of *creative* self-concept is a more recent phenomenon, but one that continues to evolve and emerge (Karwowski & Kaufman, 2017) in

the field of creativity. Creative self-concept includes many related constructs, from creative self-efficacy (Beghetto, 2006; Karwowski, 2012), creative mindset (Karwowski, 2014), to creative personal identity (Karwowski, 2012; Farmer, Tierney, & Kung-Mcintyre, 2003). All, however, revolve around the central idea concerning the extent to which someone believes that he or she is a creative person. High creative self-concept extends to valuing creativity in one's self and others (Randel & Jaussi, 2003). Further, this construct is generally related to subsequent creative performance, whether on the job (Farmer et al, 2003) or in life (Karwowski & Lebuda, 2017). A teacher with a high creative self-concept is therefore more likely to be creative in his or her own life *and* the classroom and may be more likely to encourage and nurture creativity in others. "Teaching creatively" and "teaching for creativity" (Jeffrey & Craft, 2004; Brinkman, 2010; Gregerson, Synder, & Kaufman, 2012), while vital to the development of classroom creativity, may both depend on teacher creative self-concept.

The purpose of this exploratory study was to investigate individual differences in teacher creative self-concept across the following: (a) different subjects; (b) different school levels (primary/elementary and secondary); (c) teacher gender; (d) different professional levels (ranging from pre-service undergraduate teachers, through postgraduate education students, through to in-service teachers), and (e) different countries. Through this investigation, we hoped to gain insights into which group(s) of teachers, if any, are best prepared to tackle the new initiatives and responsibilities of the new national curricula, and why that might be the case.

METHODS

Participants and Procedures

A total of 2,093 student and professional teachers from six countries (or geographical regions) were recruited for the present study. Respondents identified their country/region of origin as: Iceland (n = 1,045), Australia (n = 657), Norway (n = 143), United Kingdom (n = 113), North America (n = 72), Russia (n = 31), while 32 respondents did not indicate a country/region of origin. Participants completed the survey online, and participation was voluntary.

A total of 1,569 females and 474 males completed the survey, with 50 respondents choosing not to identify gender. No data relating to the age or ethnicity of participants were collected.

A total of 188 respondents identified as undergraduate students (i.e. undertaking a Bachelor's degree, or equivalent in a range of subject areas), while 278 identified as postgraduate student teachers (i.e. undertaking a post-Bachelor's degree in Education). A further 1,404 respondents identified as professional teachers, and 223 did not give a response for this item.

Respondents were coded to one of four disciplinary groups, reflecting their main teaching discipline. A total of 646 respondents identified as Mathematics/Science/ICT teachers in Group 1; 385 respondents identified as Humanities/English/Language in Group 2; 354 identified as Arts/Crafts teachers in Group 3, for a total of 1,385 respondents teaching at secondary school level. A further 533 respondents identified as primary/elementary teachers in Group 4, while 175 respondents did not indicate a disciplinary grouping.

Measures

Participants completed an online survey with a single measure – the 14-item Self-Assessed Creativity (SAC) scale. The SAC is a modified form of items designed to measure creativity and imagination, which had its origins in the International Personality Item Pool (IPIP; see

Goldberg, 1999). Versions of this measure have been used in studies by Kaufman & Baer (2004), Kaufman, Bromley & Cole (2006), Reiter-Palmon, Robinson-Morrall, Kaufman & Santo (2012) and Kaufman, Pumaccahua & Holt (2013). Participants responded on a 5-pt Likert-type scale, with "1" indicating *Strongly Disagree*, 3 indicating a neutral response, and "5" indicating *Strongly Agree*. In this study, three items were removed for statistical reasons, the final eleven items had a scale reliability (Cronbach's Alpha) = .88

RESULTS

Means and standard deviations of Self-Assessed Creativity (SAC) are presented in Table 1.

Table 1: Self-Assessed Creativity (SAC) by Gender

	N	Mean	SD
Females	1241	3.60	.53
Males	405	3.52	.51
Total	1646	3.58	.53

A series of two-way, between-groups ANOVAs was conducted to explore the individual and joint effects of the independent variables (Gender, Discipline Group, Professional Level, Country/region of origin, and Teaching Level) on the dependent variable Self-Assessed Creativity (SAC). Table 2 shows the results for these analyses.

Table 2: Two-way ANOVAs

Variable	Group	*F (x, y)*	η^2
Self-Assessed Creativity	Gender	*F*(1, 1499) = 5.06*	.003
	Discipline Group	*F*(3, 1499) = 12.01**	.020
	Gender x Discipline Group	*F*(3, 1499) = .57	.001
Self-Assessed Creativity	Gender	*F*(1, 1458) = 1.57	.001
	Professional Level	*F*(2, 1458) = 1.82	.002
	Gender x Professional Level	*F*(2, 1458) = 1.30	.002
Self-Assessed Creativity	Gender	*F*(1, 1616) = .27	.000
	Country	*F*(5, 1616) = 3.00*	.010
	Gender x Country	*F*(5, 1616) = 1.63	.005
Self-Assessed Creativity	Gender	*F*(1, 1503) = 1.73	.001
	Teaching Level	*F*(1, 1503) = .99	.001
	Gender x Teaching Level	*F*(1, 1503) = 1.73	.001
Self-Assessed Creativity	Discipline Group	*F*(3, 1335) = 8.67**	.020
	Professional Level	*F*(2, 1335) = 3.64*	.005
	Discipline Group x Professional Level	*F*(6, 1335) = 1.14	.005
Self-Assessed Creativity	Discipline Group	*F*(3, 1492) = 3.48*	.010
	Country	*F*(5, 1492) = 3.47*	.010
	Discipline Group x Country	*F*(15, 1492) = 1.60	.020
Self-Assessed Creativity	Professional Level	*F*(2, 1440) = 9.95**	.010
	Country	*F*(5, 1440) = 7.62**	.030
	Professional Level x Country	*F*(9, 1440) = 4.95**	.030
Self-Assessed Creativity	Professional Level	*F*(2, 1341) = 3.43*	.005
	Teaching Level	*F*(1, 1341) = 6.71*	.005
	Professional Level x Teaching Level	*F*(2, 1341) = 1.36	.002
Self-Assessed Creativity	Country	*F*(5, 1504) = 2.78*	.010
	Teaching Level	*F*(1, 1504) = 2.36	.002
	Country x Teaching Level	*F*(5, 1504) = 2.61*	.010

*$p<.05$, ** $p<.01$

These results indicate statistically significant main effects for Gender, Discipline Group, Professional Level, Country and Teaching Level, but only two statistically significant interaction effects – for Professional Level x Country, and for Teaching Level x Country. Post-hoc analyses of the significant main effects are described below.

Post-hoc Analysis of Significant Main Effects

Gender

Post-hoc analysis (T-test) indicated that the main effect for Gender comprised a statistically significant difference in Self-Assessed Creativity (SAC) scores for females (M = 3.60, SD = .54) and males (M = 3.52; SD = .51). The effect size (η^2 = .003), however, was very small.

Discipline Group

Post-hoc comparisons using the Tukey HSD test indicated that the mean Self-Assessed Creativity (SAC) score for Group 1 (*M = 3.50, SD = .53*) was significantly different from Group 2 (*M = 3.60, SD = .54*), which was significantly different from Group 3 (*M = 3.78, SD = .49*). Furthermore, the mean score for Group 3 (*M = 3.78, SD = .49*) was significantly different from Group 4 (*M = 3.53, SD = .54*). The effect size (η^2 = .020) for this main effect was, however, small.

Professional Level

Post-hoc comparisons using the Tukey HSD test indicated that the mean Self-Assessed Creativity (SAC) score for Undergraduates (*M = 3.46, SD = .58*) was significantly different from Professional Teachers (*M = 3.59, SD = .49*), with no significant difference between Postgraduates (*M = 3.57, SD = .64*), and either of the other groups. The effect size (η^2 = .005) for this main effect was very small.

Country

Post-hoc comparisons using the Tukey HSD test indicated that the mean Self-Assessed Creativity (SAC) score for Australia (*M = 3.50, SD = .56*) was significantly different from Iceland (*M = 3.60, SD = .49*), North America (*M = 3.70, SD = .51*), and Russia (*M = 3.23, SD = .63*). There were also significant differences between Russia (*M = 3.23, SD = .63*), and Iceland, North America, Norway (*M = 3.64, SD = .39*), and the United Kingdom (*M = 3.58, SD = .60*). The effect size (η^2 = .030) for this main effect was small to moderate.

Teaching Level

Post-hoc analysis (T-test) indicated that the main effect for Teaching Level comprised a statistically significant difference in Self-Assessed Creativity (SAC) scores for primary teachers (*M* = 3.53, *SD* = .53) and secondary teachers (*M* = 3.59; *SD* = .53). The effect size (η^2 = .005) for this main effect was very small.

Post-hoc Analysis of Significant Interaction Effects

Professional Level and Country

The interaction effect between Professional Level and Country was statistically significant, *F(9, 1440) = 4.95, p = .00* (Table 2). This result suggests that the influence of Professional Level on SAC is different for respondents from different countries. However, this must treated with caution because the result appears to be heavily influenced by the small sample of Russian participants. Removing the Russian respondents from the sample resulted in a statistically significant interaction effect, *F(7, 1412) = 4.06, p = .00*, with an effect size (η^2 = .020) that is small (Figure 1).

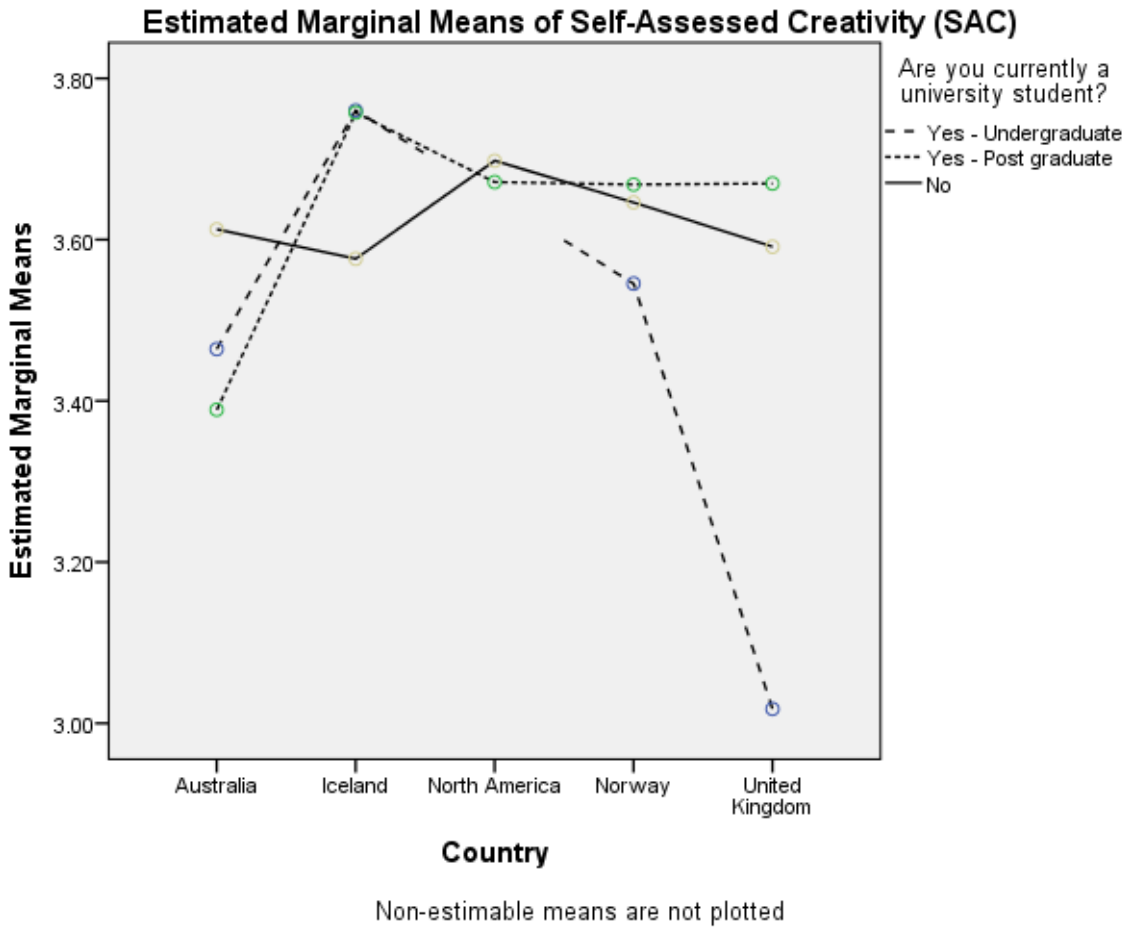


Figure 1: Interaction Effect, Teaching Level x Country

Teaching Level and Country

The interaction effect between Teaching level and Country was statistically significant, *F(5, 1504) = 2.61, p = .02*. This result suggests that the influence of Country on SAC is different for primary and secondary teachers. Once again, the result seems to be strongly influenced by the small Russian sample. The analysis was repeated, with Russian respondents removed, and showed a statistically significant interaction effect, *F(4, 1480) = 3.28, p = .01*, with an effect size (η^2 = .010) that is small (Figure 2).

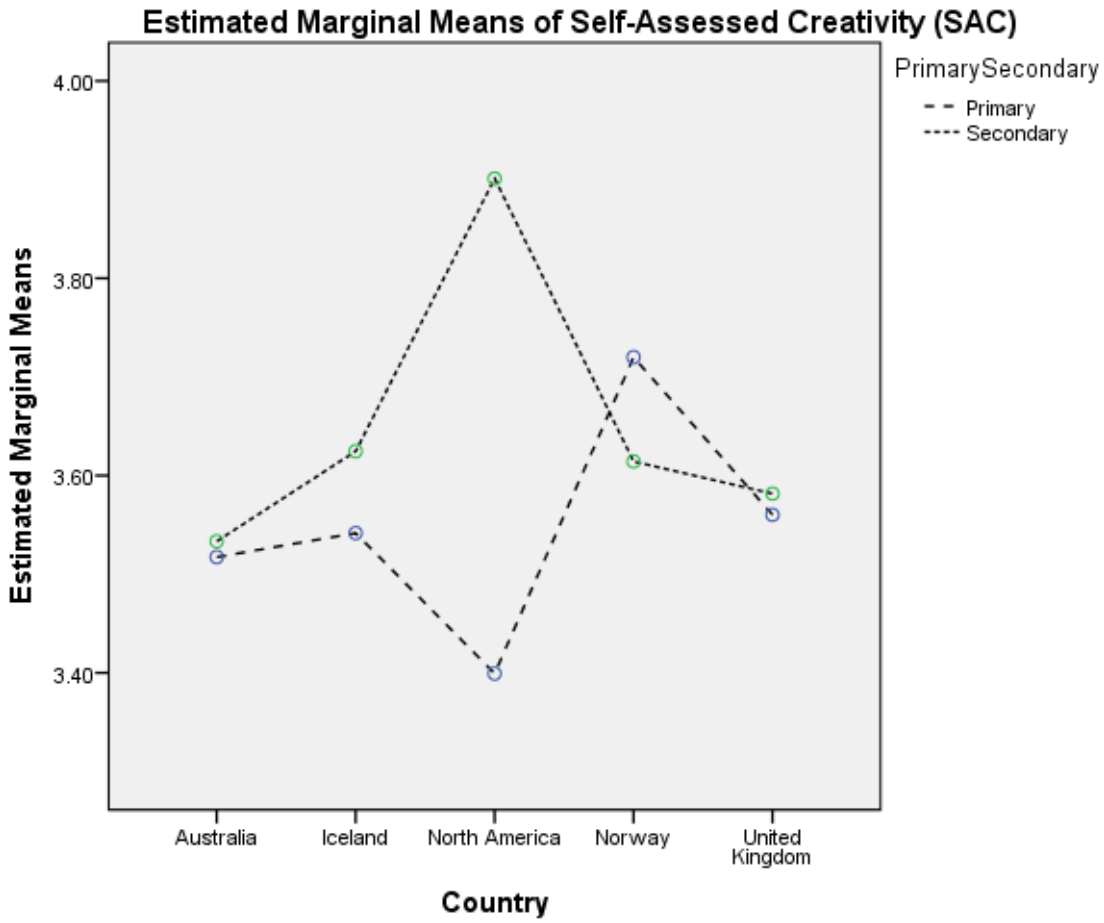


Figure 2: Interaction Effect: Teaching Level and Country

DISCUSSION

This study serves as an initial exploration of creative self-concept in teachers across many different countries, school discipline, and professional levels. We anticipate additional research will examine these similarities and differences in a more in-depth manner. We will now briefly address each component of the study.

Gender

The teachers in this study showed a small, positive self-concept of creativity (M = 3.58) on the SAC scale, with a statistically significant, but very small, difference between male (M = 3.52) and female (M = 3.60) teachers. Most creativity research proposes that there are no gender differences regarding creativity (e.g. Runco, Crammond, & Pagnani, 2010) and the

current results support this (for a more extensive discussion of related issues, see also Cropley & Cropley, 2009). Despite females displaying a significantly higher self-concept in this study, the effect size shows the differences were negligible. Moreover, there were no significant gender differences when observing each discipline level. This suggests that both males and females hold positive creative self-concepts regardless of whether they teach in widely different domains such as arts and crafts, or mathematics and science.

Discipline Group

A more nuanced picture of teacher creative self-concept emerges as the data are examined by discipline, professional level, and country. The results of comparisons by discipline, for example, indicated that teachers working in the broad domain of Arts and Crafts showed a statistically significant stronger positive self-concept of creativity (M = 3.78) compared to other disciplinary groupings, including elementary teachers. However, the small effect size (η^2 = .020) means that these differences are of limited importance. For practical purposes, there is no difference in self-assessed creativity across the different disciplines, suggesting, therefore that there is little in the way of an *arts bias* in teacher self-concepts of creativity. Indeed, this provides some evidence to refute Snow's (1959) "two cultures" concept; it might be argued that STEM disciplines see themselves as being as creative as Arts disciplines. Furthermore, despite mathematics and science teachers possessing the 'lowest' self-concept, the minimal effect size of this difference indicates that the stereotype of people not seeing mathematics as being creative (e.g., Kaufman & Baer, 2004) may not fully translate to a teacher population. Considering that research suggests that creativity should be embedded into STEM curriculums, it is positive to note that these teachers appear to have positive self-concepts and are not notably lower than other disciplines. Based on this positive self-concept the STEM teachers appear poised to encourage and adapt well to creative based curriculums.

Professional Level

In similar fashion, the data indicated a statistically significant, but very small, difference between undergraduate students (M = 3.46), and professional teachers (M = 3.57). Thus, for practical purposes, there is little difference in teacher self-concepts of creativity on the basis of maturity and experience in the profession. Both groups have a slightly positive self-concept of creativity, but this does not appear to shift markedly as student teachers transition into professional practice. It is well known that creativity often develops once an individual is confident in a particular field. This is because experience or knowledge within domains helps foster a sense of confidence to take risks and be creative. Considering working teachers and post graduates are more likely to have more experience teaching than undergraduates, they may be more confident, and therefore they have the 'right conditions' for creativity to flourish. Two explanations for the observed lack of difference require further investigation. On the one hand, teacher training may be failing to develop in student teachers those skills in recognizing and utilizing creativity that can then flourish as their experience develops (an explanation centered on cognitive *processes*). On the other hand, the ability of professional teachers to make use of their greater experience and confidence may be lost through, for example, unfavorable environmental factors (an explanation centered on the *press*). A third, and less palatable, explanation is that both student and professional teachers are uninterested in creativity, and little is done to alter this both in teacher training, and in-service development (this explanation focusing on the *person* – motivation, example). The result in this study suggests that not enough is being done to support the development of a positive creative self-concept in teacher training, with a flow-on effect to in-service teaching.

Teaching Level

Also comparable to the differences by professional level, there was a statistically significant, but negligible difference between primary/elementary (M = 3.53) and secondary (M = 3.59) teachers. One explanation of the lower scores for primary teachers in this study may be the pressure on this group to teach across the curriculum, and the necessity to understand a wide variety of subjects that may, or may not, be the teacher's area of specialty and training. Despite research suggesting that creative self-concept is not domain specific (Plucker, 2004) it is also well established that confidence in an area (i.e. a subject) enhances creativity. As we know, a person is more likely to be creative when they have a solid foundation of knowledge in a particular domain. This suggests that, if a primary school teacher has a strength in mathematics, and not humanities, then they are less likely to be creative in the humanities subject and might therefore be expected possess a lower creative self-concept than a specialized high-school teacher working primarily in one subject, or in one domain. This is further supported by the results of this study, suggesting that secondary teachers have a more positive self-concept than primary teachers, regardless of subject taught at secondary level (see also Baer, 1991). In addition, the finding is consistent with recent measures of self-perceived creative aptitude, which use a domain-specific structure (Kaufman, 2012; McKay, Karwowski, & Kaufman, 2017).

To encourage an increased positive creative self-concept amongst primary school teachers, it is suggested that teachers' development of 'expertise' across subjects be strengthened, helping the development confidence at teaching a range of subjects. This can be achieved through the provision of extra school resources including extra in-service training, and support from other teachers and school leaders. Moreover, simply educating primary teachers on the definition of creativity within each subject may be a key to encouraging their self-concept (e.g., Aljughaiman, & Mowrer-Reynolds, 2005).

Country

The only variable on which larger, significant differences were observed was the country in which the teachers work. Teachers in the United States showed the strongest positive self-concept of creativity (M = 3.70), compared to teachers in Russia (M = 3.23); however, these two samples were small (N = 72 and N = 31 respectively), in comparison to the overall sample. Regardless of this fact, the general levels of Self-Assessed Creativity remain only slightly positive. Deducing inferences about individual countries' self-concepts is difficult. Each country has its own curriculum and set of beliefs regarding the place of creativity within education, despite the general thrust for more creativity. Focusing only on working teachers (as distinct from student teachers), the results suggest that North American teachers had the highest positive self-concept, while the Icelandic the lowest, however the differences are minimal. Interestingly, all countries have slightly positive beliefs, suggesting that all countries value creativity at least to some extent. Important to note is that all countries examined are currently embedding 'creativity' within school curriculums in one form or another. This shift towards creative curricula requires that these teachers accurately understand the concept of creativity, (i.e. how can they teach to the new creative pedagogies outlined in their curricula if they do not understand the concept?). The results in this study support the notion of altering pedagogy towards creativity because research suggests that if a teacher is creative then they will possess a creative self-concept. In turn, this creative self-concept will help foster similar beliefs in their students, thus enabling them to receive a quality education.

These results appear to offer little in the way of clues as to how teacher self-concepts of creativity might be better supported and developed. There is no clear pattern indicating that any one country, or discipline, or other grouping is any better than any other at developing teacher self-concepts of creativity. Indeed, it may be said that there is a

remarkable degree of consistency across these groups – teachers of all types, levels, gender and nationality have a surprisingly consistent, and slightly positive, self-concept of creativity.

Not surprisingly, even interaction effects – e.g. the impact of professional level (Undergraduate, Postgraduate, Professional) on Self-Assessed Creativity, for different countries – while significant, were also small and therefore, of limited practical importance. The picture therefore remains highly consistent across the different grouping variables.

Future Work

Despite the results being positive, more effort into developing the teachers' self-concept would be beneficial, firstly for the teacher, and then for their students. Considering creativity can facilitate learning, it is important to develop the necessary skills to ensure optimal learning occurs. Aforementioned teachers who possess a positive self-concept are more likely to pass these positive beliefs onto their students. Therefore, future research into how to positively shape creative self-concept would benefit the education system. As it is well known that teachers often misunderstand the definition of creativity it is recommended that teachers be instructed clearly on creative ideologies as to deter incorrect understandings and maximize their creative self-concept. Further, although there are many benefits to understanding creative self-concept and self-beliefs (Reiter-Palmon, Robinson-Morral, Kaufman, & Santo, 2012), there are nonetheless many potential flaws in such measures. For example, not everyone has strong insight into their own creative strengths or weaknesses (Kaufman & Beghetto, 2013).

CONCLUSION

The larger finding that teachers show more similarities than differences in creative self-concept may make for a less exciting conclusion yet has many positive implications. If future studies continue to show that teachers around the world and across discipline share beliefs

about creativity in the classroom, then potential interventions to increase creativity may not need to be as individualized or tailored to a specific country or discipline. The same core principles may be useful to all populations, suggesting the possibility of a more straightforward path toward increased creativity acceptance and nurturance in schools.

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Appendix L: Journal Publication: Teacher implicit beliefs of Creativity: Is there an arts bias?

This paper was the second output from a 2-year joint collaborative project involving UniSA, Geelong Grammar school and The University of Connecticut. This paper examines a total of 2,485 student and professional teachers from six countries (or geographical regions) and explores participants implicit beliefs of creativity. It was published in Teaching and Teacher Education as follows:

Patston, T. J., Cropley, D. H., Marrone, R. L., & Kaufman, J. C. (2018). Teacher implicit beliefs of Creativity: Is there an arts bias? *Teaching and teacher education*, 75, 366-374.

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ABSTRACT

The field of creativity remains misunderstood by the general public and implicit beliefs, in particular an *Arts Bias*, continue to permeate popular culture. This has the potential to derail efforts to embed creativity in the 21st century classroom, at a time when it is most needed. We therefore ask if teachers endorse such an Arts Bias in creativity. The present study found a lower than expected tendency towards an Arts Bias among teachers from more than seven countries. However, differences by discipline and level of self-rated creativity suggest specific pathways for enhancing efforts to embed creativity in the classroom.

Keywords

Creativity, implicit beliefs, teaching, Arts Bias, creative education

INTRODUCTION

There has been extensive research into the field of creativity since Guilford's (1950) seminal address to the American Psychological Association. Since that time, creativity research has established itself, in particular, in the field of educational psychology. Creativity research is therefore closely tied to an exploration of the cognitive and behavioural aspects of the production of novelty, and informs specialisations such as instructional design and curriculum development. Psychological studies of creativity have been conducted across a wide variety of domains (Author, 2017a), including engineering (Author, 2015; Author, 2017b), psychology (Author, 2016), business (Florida, 2012), science (Feist, 1998, 2004), mathematics (Author, 2004; Leikin & Sriraman, 2017), and education (Author, 2014a; 2017c), and complement other educational perspectives on creativity and imagination, such as Greene (2011), who takes a more experiential and aesthetic view of the production of novelty in domains such as dance. Creativity has therefore established itself as a mature field of study spanning Snow's (1959) so-called *two cultures*: art and science.

However, the field continues to be misunderstood or misconceived by the general population (Glăveanu, 2014), in ways that may undermine and undervalue the quality and quantity of empirically rigorous work in the field. A pervasive *positive valence* linked to creativity has been noted (e.g. Author, 2014b), and has been referred to as a "benevolence bias" (Author, in press). Among the key misconceptions that bedevil the systematic study of creativity are: (a) the notion that creativity is a genetically endowed gift bestowed on a select **few (**Ukkola-Vuoti et al., 2013)**; (**b) that it is the realm of the *mad* genius (Simonton, 2002), or simply, geniuses (Baas, Nijstad, & De Dreu, 2015**); (**c) that creative insight occurs only in moments of divine inspiration (Weisberg, 1986); and, (d) that it is only for the young (Trilling & Fadel, 2009). One other key fallacy has been identified by Plucker, Beghetto, and

Dow (2004), namely that creativity is a form of "pop psychology". However, perhaps the most damaging is the misrepresentation of creativity as purely an artistic talent (Runco, 2007; Glăveanu, 2014).

Creativity is today often treated as synonymous with *the arts,* and with individuals – e.g. writers, painters, musicians – who are frequently labelled as *creatives***.** This cultural shorthand is often used as a descriptor of flamboyant extroverts, tortured rebels, or angry misfits – individualists and rule-breakers – who wait to be struck by their Muse. Unfortunately, such pejorative terms have led to a common misconception that creativity is a "special" talent, often associated with dysfunctional behaviour (Author, 2016; Sternberg, 2015).

Thus, the field of creativity is in many ways a curious one. Despite over six decades of systematic research, creativity continues to be influenced by strongly held yet often incorrect views and opinions – implicit beliefs, in other words – in the general population (Baas, Koch, Nijstad, & De Dreu, 2015; Author, 2013). Creativity seems to fall into the same area as diet, exercise, and parenting – many people have very strong, but often flawed, opinions which may have little or no empirical foundation, despite ample contradictory evidence being available (e.g. Bayne & Fernandez, 2010; McKay & Dennett, 2009). This is not a new phenomenon in science, and yet it has the potential to do great harm to efforts to change behaviours and practices for the better (Author, 2018). A classic example was Ignaz Semmelweis's efforts, in the 19th century, to reduce the incidence of puerperal fever – maternal mortality resulting from postpartum infections – through the practice of hand washing by obstetricians (Author, 2009a). Despite overwhelming empirical evidence in support of this practice, it was resisted by the medical profession because it contradicted conventional wisdom, and was also seen as insulting to doctors. It was not until years after

Semmelweis's death (in a mental hospital, no less) that the practice became the accepted norm.

Why does creativity retain such strong, yet flawed, associations? Perhaps it is simply easier, and even somewhat appealing, to think of creativity as a flash of *out-of-the-box* insight – a mysterious gift – rather than as a process involving application, methodology and cognitive effort (Author, 2016; Roskes, De Dreu, & Nijstad, 2012). While misconceptions based on faulty implicit beliefs may do little harm in some areas – other than frustrating creativity researchers' attempts to communicate their findings to a wider audience – in education, where there is a concerted push to develop students' creativity as a core competency in the 21st century, the persistence of incorrect implicit beliefs may be a serious hindrance. It is vital, therefore, to ask if, or to what extent, flawed implicit beliefs about creativity are held by teachers?

Education policy makers around the world (e.g. Heilmann & Korte, 2010) are calling for more creativity in education, for several important reasons. Cropley (1997) stressed that creativity is an essential component of the psychological functioning of young people, making it a necessary factor in a balanced and *democratic* education system. Rosenstock and Riordan (2017) highlight the role of creativity as a key *disposition* necessary in a modern, innovation economy, characterised by ubiquitous and rapid change. In a similar vein, Bakhshi, Downing, Osborne, and Schneider (2017) reported that skills such as creative problem solving, and also abilities including originality, will be amongst those in greatest demand in future workforces in the US and UK. However, some of the most compelling pressure for creativity in education is found in Frey and Osborne (2017), who concluded that occupations requiring a high degree of *creative intelligence* are the least likely to be automated in the 21st century. Therefore, as business leaders and politicians realise that the

global economy is shifting to a new paradigm, one in which people may be expected to have many careers and associated skillsets over their lifetimes (Wohlson, 2012; Zhao, 2015), and where creativity will be a prerequisite ability, so educators are being called upon to develop new skills, not least creativity, in students. This challenge is compounded by a steady shift towards a more constructivist approach to teaching and pedagogy (see Steffe & Gale, 1995), with emphasis on student-centred, individualised learning and progression plans (e.g. Biggs, 2001). Consequently, countries ranging from Iceland (Ministry of Education, Science and Culture [MESC], 2011) to Australia (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2010) are asking teachers to teach both *with* and *for* creativity. However, this shift in education implies that two conditions are already in place: (a) that teachers know *what creativity is*, and; (b) that teachers know *where creativity fits* into their curricula.

Fasko (2001) suggested that the ability of teachers to foster students' creativity, in fact, depends on the interaction between *two* key factors: (a) their own implicit beliefs, and; (b) the training they receive with the latter shaping the former. It is, of course, reasonable to expect teachers to teach knowledge and skills with which they are familiar. Unfortunately, the international push towards a more creative education paradigm has frequently not been either properly supported or adequately resourced by national education systems or even individual schools (Author, 2009b; Lucas, Claxton, & Spencer, 2013), suggesting a third factor – the environment – may also be at play. While teachers are trained in their specialist subject areas, and in the general principles of underpinning topics such as educational psychology and pedagogy, they are rarely explicitly educated in the field of creativity and creative education (Cachia, Ferrari, Ala-Mutka, & Punie, 2010). Consequently, the first exposure for many teachers to the teaching of creativity may be a national policy document stipulating a *requirement* for creativity in the curriculum, with little additional guidance or

support, for example, in the form of developmental models of creativity (e.g. Taylor, 1975; Rosenblatt & Winner, 1988; Urban, 1991; Barbot, Lubart, & Besançon, 2016). While it is therefore of critical importance to understand how teacher training and professional development shape implicit beliefs of creativity – not least, how *environmental* factors such as the available resources (e.g. time, materials, funding; see Amabile, 1996), and even the so-called "apprenticeship of observation" (Lortie, 1975), affect the development of creativity (Beghetto, 2010) the primary focus of this paper is the teachers themselves, and specifically, the views, opinions and concepts they hold in relation to creativity as they *embark on* a process of teaching students for this 21st century competency.

Understanding teacher implicit beliefs regarding creativity begins by exploring implicit beliefs in the general population. Lay people, of course, hold misconceptions about creativity (Glăveanu, 2014; Baas et al., 2015) as already outlined. However, do these general misconceptions also hold true for teachers? What are the implicit beliefs of creativity held specifically by schoolteachers, and are teachers equipped with the specific knowledge and skills necessary to introduce, successfully, creativity into their classrooms? Will the 21st century push for creativity in the classroom fall on fertile ground, or will it be frustrated by factors that could, if properly understood, be addressed as part of teacher education and in-service training?

There is some cause for optimism in this process. Mullet, Willerson, Lamb, and Kettler (2016) found reasonable evidence, in a comprehensive review of related studies, that teachers believe creativity is important, and that creativity can be facilitated (e.g. Myhill & Wilson, 2013; Vedenpää & Lonka, 2014; Zbainos & Anastasopoulou, 2012). Similarly, recent research on creative mindsets, their relationship to creative self-efficacy and creative identity, and the relationship between teacher implicit beliefs and student creativity (see Hass, Katz-Buonincontro, & Reiter-Palmon, 2016; Karwowski, 2014; Paek & Sumners, 2017), suggest that the issue under investigation here is far from uniformly negative – indeed, there

are many positive findings. However, the primary concern in this study is the potential impact of *faulty* implicit beliefs – specifically, an arts bias – on teachers.

One of the most commonly held misconceptions of creativity in the literature is that it resides predominantly in the arts (Runco & Bahleda, 1986; Glăveanu, 2014). This view poses some difficulties for those attempting to implement new creative pedagogies in classrooms. The first concern is that under the Arts Bias misconception, creativity is often thought of only at the highest levels of human endeavour: what Author (2009c) describe as *Big C* creativity. For classroom teachers, the view for over one hundred years is that all students have potential and capabilities in some areas, which can be developed through education (Dewey, 1916). Although there are some genetic predispositions that may inhibit development in some areas, most now believe that the majority of students are capable of development through education. With some small exceptions therefore, the Darwinian view of education is dead (Phillips & Siegel, 2013). An exception, however, seems to be found in the field of creativity, possibly driven by faulty implicit beliefs. In other words, if teachers believe that only gifted, eminent artists can be creative, then it follows that creativity is not accessible to the majority, and therefore cannot be taught (Glăveanu, 2011).

It is now widely accepted in the literature that creativity can, in fact, be taught, nurtured and developed (e.g. Jeffrey & Craft, 2004; Esquivel, 2005; Feldman, 2009). However, if teachers hold an implicit bias (specifically a Big C, *Arts Bias*), it may lead them to believe that this is not the case, and if teachers do not understand the developmental trajectory of creativity (e.g. Rosenblatt & Winner, 1988; Urban, 1991; Cropley, 2001), then it follows that they may be less likely to teach either with or for creativity in the classroom. Given that very few students, in very few fields, can be expected to rise above the *mini-c* or *little-c* level by the time they complete their schooling (Author, 2009c), it is therefore essential that teachers are aware of the developmental phases and expectations of the creative process, and can address student needs in their classrooms accordingly.

There is one further problem that can result from misconceptions. For over fifty years (Torrance, 1963; Westby & Dawson, 1995; Karwowski, Gralewski, & Szumski, 2015) there have been consistent findings indicating that teachers say they support the idea of creativity being important in the classroom, but do not necessarily like the personality qualities (as defined by the literature) of creative students. One reason for this may be that teachers possess inaccurate concepts as to what constitutes creativity – flawed implicit beliefs, once

again (Aljughaiman & Mowrer-Reynolds, 2005; Fleith, 2000; Kampylis, Berki, & Saariluoma, 2009; Runco, 2003). It is important to note that in this regard, teachers are no different from business people or the average person (Mueller, Goncalo, & Kamdar, 2011; Mueller, Melwani, & Goncalo, 2012). However, it is becoming clear that this problem is not due to a malicious desire in teachers to hold back creative students. Rather, it may reflect a lack of information, support, and professional development from policy makers and education systems. It is a symptom, in other words, of faulty implicit beliefs. This raises the question as to whether teachers have the knowledge and skills to explicitly, or even implicitly, introduce creativity to their classrooms, as they are being asked to do by education authorities.

Further evidence of a disconnect between education policy and practice in relation to creativity can be found in a study by Davies, Jindal-Snape, Digby, Howe, Collier, and Hay (2014). They noted that "*A systematic review of 210 educational research, policy and professional literature studies from the period 2005-2011 identified only 17 publications which met the criteria for inclusion and contained findings relating to teacher roles in constructing creative learning environments*" (p 37). In the light of this evidence, it is hardly surprising if teachers appear to know little about what creativity is and lack support that enables them to introduce it effectively into their classes (Morais & Azevedo, 2011).

This problem may be exacerbated by a lack of teacher education in creativity during teacher training. Teachers arrive at their courses with belief systems regarding creativity that are not addressed – in this case, corrected – in their courses. A number of studies suggest that teachers hold a range of preconceptions about creativity and pedagogy, with many of these findings apparent in initial teacher education (Kampylis et al., 2009; Bolden, 2010; Crow, 2008; Newton & Newton, 2009). One common misconception is the difference between 'teaching creatively' rather than 'teaching for creativity'. For example, Newton and Newton (2009) found that student teachers' conceptions of creativity can focus mainly on practical investigations of matters of fact. It may be that this perceived conflict is one reason that teachers do not tend to teach creatively in the classroom (Schacter, Thum, & Zifkin, 2006). A second prevailing, and critical, misconception is that, as creativity lies only in the arts, it does

not have a place in other subject areas (Glăveanu, 2014; Saracho, 2012; Spiel & von Korff, 1988).

This combination of implicit theories, biases and misconceptions indicates that educational authorities may have some way to go in terms of teacher education before even hoping, never mind expecting, that creativity will find its way into classrooms around the world. Implicit theories influence behaviour (Glăveanu, 2014). Teachers who believe in the Arts Bias, a romanticised view of creativity going back to the Greeks (Sternberg & Lubart, 1999), may be less likely to nurture the roots of creativity at the mini-c and little-c levels in the classroom. Implicit theories can also be powerful and deeply entrenched. Teachers are no different to the general population when it comes to shifting ideas and transforming them into practice. Writing about the social sciences in general, Furnham (1988) noted that lay theories typically suffer from ambiguity and inconsistency, resulting in the fact that two individuals can hold mutually incompatible beliefs, with little discomfort stemming from that discrepancy. This contradiction makes it possible for teachers to say that they like having creativity in their classrooms, but at the same time demonstrate through their behaviour that they do not like qualities of creativity manifest in their students (Gralewski & Karwowski, 2018).

It is clear that education systems around the globe, including Iceland (MESC, 2011) Australia (ACARA, 2010), Estonia (Ministry of Education and Research [ME&R], 2014) and Hong Kong (Hong Kong Curriculum Development Council [HKCDC] & Hong Kong Examinations and Assessment Authority [HKEAA], 2007) are seeking to implement creative teaching into their classrooms. It is less clear that teachers have the prerequisite attitudes, let alone the skills, needed to implement this new pedagogic direction. Mullet, Willerson, Lamb, and Kettler (2016) provide an excellent review of some 18 individual studies of teacher perceptions of creativity, over the period 1999 – 2015. From these studies (e.g. Aljughaiman

& Mowrer-Reynolds, 2005; Chan & Chan, 1999; Liu & Lin, 2014; Odena & Welch, 2009), and others such as Andiliou & Murphy (2010), Gralewski & Karwowski (2018), and Rubenstein, Ridgely, Callan, Karami, & Ehrlinger (2018), some underlying negative issues can be identified. These include (Mullet, Willerson, Lamb, & Kettler, 2016) mismatches in teacher/researcher definitions of creativity, a lack of preparation for teaching/developing creativity among teachers, and a view that creativity is synonymous with the arts. The studies in this review have some limitations – either they are mono-cultural, or have small sample sizes, or are limited to single school subjects – opening up an opportunity for a larger, multi-cultural, multi-subject study, to further develop the understanding of the status and impact of flawed implicit beliefs of creativity among teachers on a broader scale.

Education is facing challenging times. Education systems are increasingly asking teachers to teach with and for creativity, but it appears from existing research that this pedagogic transformation – with respect to creativity, at least – may be inhibited by a combination of implicit beliefs that prevent the uptake of new pedagogies, and a lack of explicit definitions and professional development materials by education authorities. Related discussions on the relationship between implicit beliefs and pedagogical approaches – for example, Richardson (2003) – reinforce a need for a better understanding of the implicit beliefs of creativity among teachers.

Although self-assessments of creativity are often disparaged, they tend to have better reliability than might be expected (Author, 2009d; Author, 2012). Critically, however, the only way to test implicit beliefs and self-perceptions is by using such self-report measures (Author, submitted). It is important to emphasize that this study focuses on beliefs, perceptions, and unconscious biases; we are not using performance-based measures of creativity.

Building off of Richardson (2003), this study assesses implicit beliefs in a large sample of teachers from a range of countries and discipline areas, and asks the fundamental question: Do teachers endorse an *Arts Bias* in relation to creativity? Further, what variables impact a teacher's level of *Arts Bias*, from his or her self-beliefs about creativity, to gender, to subject taught?

METHODS

Participants and Procedures

A total of 2,485 student and professional teachers from six countries (or geographical regions) were recruited for the present study. Respondents identified their country/region of origin as: Iceland (n = 1,185), Australia (n = 657), Poland (n = 255), Norway (n = 154), United Kingdom (n = 113), North America (n = 72), and Russia (n = 31), while there were fewer than five respondents from each of Sweden, France, Italy and Hong Kong. Finally, 10 respondents did not indicate a country/region of origin. Participants completed the survey online, and participation was voluntary.

The sample of individuals who completed this survey consisted of a total of 1,911 females and 538 males, with 52 respondents choosing not to identify gender. There were 189 respondents who identified as undergraduate students who were planning teaching careers, (i.e. undertaking a Bachelor's degree, or equivalent in a range of subject areas), while 292 identified as postgraduate student teachers (i.e. undertaking a post-Bachelor's degree in Education), and 1,797 respondents identified as professional teachers. A total of 223 participants did not give a response for this item. Finally, no demographic data relating to the age or ethnicity of participants were collected.

After collection of the data, respondents were coded to one of four disciplinary groups, reflecting their main teaching discipline. A total of 701 respondents identified as

Mathematics/Science/Information & Communication Technology (ICT) teachers in Group 1 (abbreviated as Math/Science); 520 respondents identified as Humanities/English/Language in Group 2 (Humanities); 365 identified as Arts or Crafts teachers in Group 3 (Arts/Crafts), for a total of 1,385 respondents teaching at secondary school level. A further 516 respondents identified as non-subject-specific primary/elementary teachers in Group 4 (Primary), while 218 respondents did not indicate a disciplinary grouping.

Measures

Participants completed an online survey with two measures. The first was the *Arts Bias* scale. This scale was derived from a larger instrument (originally developed by Leong & Qiu, 2013) consisting of 43 questions addressing a range of facets of creativity across different disciplines and contexts, with a general focus on school education. Participants were asked to respond on a five-point Likert-type scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neither Disagree nor Agree, 4 = Agree, 5 = Strongly Agree) to indicate the extent to which each of the statements characterised their views about the nature of creativity in schools and education. Six items were extracted from this larger scale to form an *Arts Bias* scale. These items were:

- "Creativity is best demonstrated in the process of creating an artwork" (Q11);
- "Students should not take risks when being assessed in the arts" (Q21);
- "Creativity refers only to music performance or creating artworks" (Q24);
- "Acquiring basic knowledge in the arts is more important than fostering creativity" (Q25);
- "Creative expression is confined to the arts" (Q35);
- "Creativity refers only to music composition or creating original artworks" (Q42).

The *Arts Bias* scale showed solid reliability, with Cronbach's alpha of $r = .70$. The Corrected Item-Total Correlations ranged from $r = .17$ to $r = .60$.

Participants also completed the 14-item *Self-Assessed Creativity* (SAC) scale. This scale was designed by Ivcevic (2009; Ivcevic & Mayer, 2009), and included 14 items tapping into a person's self-concept of how creative he or she is. Participants responded on a 5-pt Likert-type scale, with "1" indicating *Strongly Disagree*, "3" indicating a neutral response, and "5" indicating *Strongly Agree*. The instrument has been used in past studies (e.g., Author, 2017d). In this study the fourteen items had excellent scale reliability with a Cronbach's Alpha of $r = .90$. Mean Self-Assessed Creativity for the sample was $M = 3.53$, $SD = .53$ ($N = 2184$). For the purposes of this study, the sample was split into four groups on the basis of quartile scores for Self-Assessed Creativity: Low ($M = 2.85$; $SD = .31$); Low-Medium ($M = 3.35$; $SD = .10$); Medium-High ($M = 3.71$; $SD = .10$); High ($M = 4.21$, $SD = .29$).

RESULTS

Tests of normality, including skewness and kurtosis, indicated that the *Arts Bias* data were normally distributed, and therefore suitable for further parametric analysis. Means and standard deviations for the Arts Bias scale, by gender, discipline and level of self-assessed creativity, are presented in Table 1.

Table 1: Mean Arts Bias score by group

Group	N	Mean	SD
Gender[21]			
Female	1671	1.87	.47
Male	490	1.93	.52
Total	2161	1.88	.49
Discipline			
Maths/Science	522	1.95[22]	.50
Humanities	353	1.81	.45

[21] Gender differences significant at $p < .01$

[22] Maths/Sciences was significantly higher than Humanities, $p < .0001$, and Primary, $p < .05$

Arts/Crafts	303	1.88	.50
Primary	450	1.87	.48
Total	1628	1.89	.49
Self-Assessed Creativity			
Low	512	2.00[23]	.47
Low-Medium	466	1.97[24]	.49
Medium-High	543	1.87	.44
High	408	1.67	.47
Total	1929	1.88	.48

Correlation of SAC and Arts Bias: -.251**

An initial Multivariate Analysis of Variance was conducted with the Arts Bias subscale as the dependent variable, and with discipline, gender, and self-assessed creativity level of the teachers as the independent variables. None of the interactions (e.g. gender x discipline) were significant. As a result, three follow-up Univariate ANOVAs were conducted with each variable (discipline, gender, and self-assessed creativity) serving separately as an independent variable. Significant differences are noted in the table above (Table 1). It is important to note that in Table 1, and the following discussions, *higher scores indicate more Arts Bias*. Specific analyses will be discussed separately below. No significant differences based on country of origin were detected in the sample.

Analysis of Variance – Arts Bias and Self-Assessed Creativity

A one-way, between-groups analysis of variance was conducted to explore the impact of self-assessed creativity on levels of Arts Bias, as measured by the 6-item Arts Bias scale (derived from Leong & Qiu, 2013). Participants were divided into four groups according to quartile marks of their self-assessed creativity (Group 1: Low Creativity; Group 2: Low-Medium Creativity; Group 3: Medium-High Creativity; Group 4: High Creativity). There was a

[23] Low was significantly higher than Medium-High and High, $p < .0001$

[24] Low-Medium was significantly higher than Medium-High and High, $p < .0001$

statistically significant difference at the $p < .05$ level in Arts Bias scores for the four self-assessed creativity groups: F (3, 2180) = 52.0, p = .0001. The effect size, calculated using eta squared, was .07 (medium). Post-hoc comparisons using the Bonferroni test indicated that the mean scores for Group 1 (Low) (M = 2.00; SD = .47) and Group 2 (Low-Medium) (M = 1.97; SD = .49) were significantly different from Group 3 (Medium-High) (M = 1.87; SD = .44) and Group 4 (High) (M = 1.67; SD = .49). In addition, the mean score for Group 3 (Medium-High) (M = 1.87; SD = .44) was significantly different from and Group 4 (High) (M = 1.67; SD = .49). These results indicate that teachers with higher levels of self-reported creativity were *significantly less likely to endorse the Arts Bias* than teachers with lower levels of self-reported creativity. In addition, people with high-medium self-reported creativity were *significantly less likely to endorse the Arts Bias* than the low and low-medium groups.

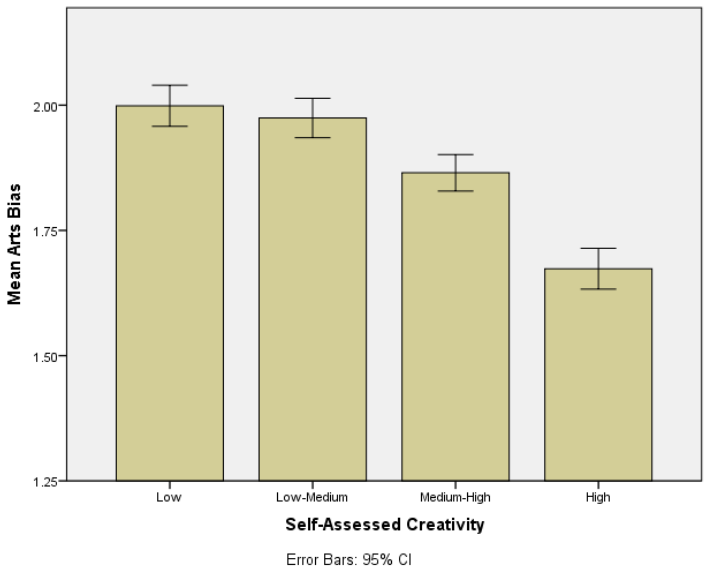


Figure 1: Arts Bias across Different Levels of SAC

Analysis of Variance – Arts Bias and Discipline

A one-way, between-groups analysis of variance was conducted to explore the impact of discipline on levels of Arts Bias, as measured by the 6-item Arts Bias scale (derived from Leung etc.). Participants were divided into four groups according to their discipline are (Group 1 - Math/Science; Group 2 - Humanities; Group 3 - Arts/Crafts; Group 4 - Primary

School). There was a statistically significant difference at the $p < .05$ level in Arts Bias scores for the four discipline area groups: F (3, 1624) = 6.46, p = .0001. The effect size, calculated using eta squared, was .01 (very small). Post-hoc comparisons using the Bonferroni test indicated that the mean score for Group 1 (Math/Science) (M = 1.95; SD = .50) was significantly different from Group 2 (Humanities) (M = 1.81; SD = .45) and Group 4 (Primary) (M = 1.87; SD = .48). These results indicate that Math/Science teachers were *significantly more likely to endorse the Arts Bias* than Humanities or Primary teachers.

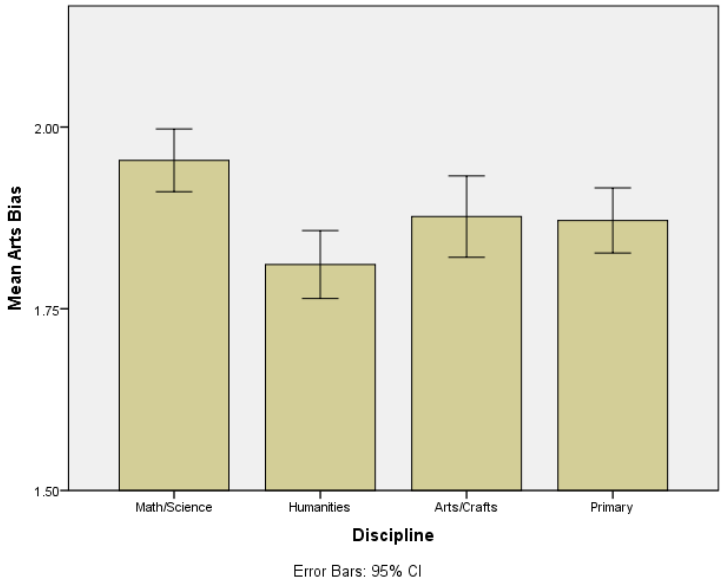


Figure 2: Arts Bias across Disciplines

Analysis of Variance – Arts Bias and Gender

A one-way, between-groups analysis of variance was conducted to explore the impact of gender on levels of Arts Bias, as measured by the 6-item Arts Bias scale (derived from Leung etc.). Participants were divided into two groups according to their gender (Group 1: Female; Group 2: Male). There was a statistically significant difference at the $p < .05$ level in Arts Bias scores for the two gender groups: F (1, 2159) = 7.19, p = .007. The effect size, calculated using eta squared, was less than .01 (very, very small). Analysis indicated that the

mean score for Group 1 (Female) (*M* = 1.87; *SD* = .47) was significantly different from Group 2 (Male) (*M* = 1.93; *SD* = .52). These results indicate that male teachers were *significantly more likely to endorse the Arts Bias* than female teachers.

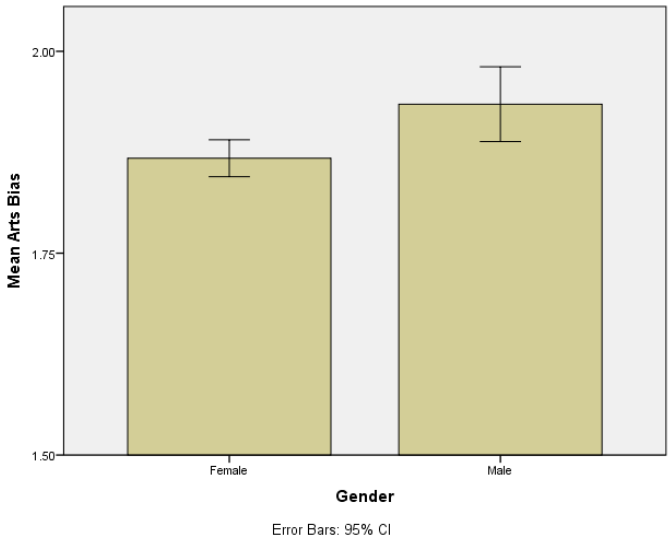


Figure 3: Arts Bias across Genders

DISCUSSION

This study serves as an initial exploration of implicit attitudes toward creativity – specifically, endorsement of the Arts Bias – in teachers across a number of different countries, across disciplinary boundaries, and between genders. The results are limited, to some degree, by the structure and scope of the questions in the scale used. Although there is no comparison group (i.e. non-teachers) enabling more definitive statements to be made, Arts Bias scores tended to be on the lower side for most teachers (*M* = 1.88, *SD* = .49). Furthermore, this is the case across the range of countries examined in the study, and is true regardless of the level of experience of the teachers surveyed. At first glance, this appears to be a positive characteristic of the sample group, suggesting that efforts to embed creativity in the 21st century classroom are likely to be relatively unimpeded by teachers' implicit beliefs in relation to the association between creativity and art. Teachers who understand implicitly that

creativity is found in science and mathematics, languages and humanities, as well as art and music seem well-placed to rise to the demand for greater creativity in the classroom.

Notwithstanding this generally positive finding, there remains the opportunity to ask if there are differences within this broad sample of teachers that may inform how creativity is embedded in the 21st classroom? For example, should the demand for teachers to teach both *for* and *with* creativity be presented uniformly, and to the same extent and depth, across all disciplines? Should the training and development that will support this be applied uniformly, or in a differentiated fashion, based on factors such as the discipline of the teachers? Moreover, in an era of shrinking resources and competing demands, is it possible to streamline the process of the training and development of teachers in creativity, expending those resources where they are most needed, and where they will have the greatest impact?

An obvious starting point is to examine possible differences in Arts Bias according to teacher gender. However, although our results suggest that male teachers subscribe to the Arts Bias to a greater degree than female teachers, the practical difference in levels was so small (eta squared was less than .01) as to be unimportant. Both groups, broadly speaking, do not endorse the Arts Bias, and therefore this does not appear to offer any meaningful potential for differentiated training or development of creativity.

In a similar manner, the discipline in which the teacher operates, ranging from maths and science through humanities and the arts, and including generalist primary/elementary teachers, shows statistically significant, but very small differences that appear to offer little to differentiate training and development of teachers in relation to creativity (eta squared for this test was equal to .01). One possibility does emerge from the data – the higher level of Arts Bias among math/science teachers, coupled with the statistical distribution of their results (M = 1.95; SD = 0.50), indicates that there are meaningful numbers of math/science teachers who

either are uncertain or who positively endorse the Arts Bias. While these numbers are small, this does offer a strategy for how schools and policy makers might direct training and development resources to greatest effect. Math/science teachers may need additional help, in comparison to other discipline groups, to overcome implicit biases that may impede the development of creativity in their discipline. It is also possible, however, given the low levels of *Arts Bias* endorsement overall, that this finding occurred for a different reason. Math/science teachers may be less likely to strongly agree or disagree to any particular statement, either because they are considering all possibilities or because they are less likely to simply be agreeable and respond with extremes (Author, 2011).

One variable, however, emerges from this study as a potential differentiator for teacher training and development in creativity. The finding that teachers with higher levels of self-assessed creativity were significantly less likely to endorse the Arts Bias – with a medium effect size (eta squared was .07) – offers a strategy for successfully embedding creativity in the 21st century classroom. In other words, the more creative the teacher believes him or herself to be, the less they associate creativity solely with the arts. This suggests that the foundation of creativity in the 21st century classroom may be in training teachers themselves to embrace and develop their own creativity. Although this study suggests that teachers are not excessively constrained by an Arts Bias, their ability to teach both for and with creativity is enhanced by their own ability to be creative. This suggests that it is not enough merely to explain to teachers what creativity is. To be effective teachers both for and with creativity, teachers must develop their own skills in creativity. Teacher education must therefore be designed to ensure that this occurs, seeking to ensure that training and development is both theoretical and practical – apparent across the full spectrum of subjects – and providing teachers with opportunities to develop and exercise their own creativity in their profession.

CONCLUSIONS

Somewhat counter to expectations, teachers in this large, multi-cultural study of teacher implicit beliefs of creativity did not strongly endorse an Arts Bias. Generally speaking, scores indicated a possible rejection of the notion that creativity is synonymous with art, music, or other related activities. This suggests that efforts to embed creativity in the 21st century classroom will fall on favourable ground. However, the findings of this study also suggest that there remains work to be done, in particular when drilling down to the level of different discipline areas, before teachers hold views of creativity that are consistent with the literature. When this happens, the opportunity for embedding creativity in the classroom will be maximized. Around the world, teachers are being asked to be more creative and teach creative skills to their students. Yet at the same time, it is suggested from the distributions of the data that many teachers still retain some uncertainty about the nature and definition of creativity, and hold implicit views that, if not blocking creativity in the classroom, impede efforts to develop this vital 21st century skill. Our findings suggest that the greatest opportunity for correcting misconceptions of creativity, and speeding its appearance as a core part of school education, will be for education authorities and schools to develop the creativity of individual teachers through practical training and development. In addition, special attention should be paid to ensuring that teachers of STEM-based disciplines – e.g. mathematics – are given opportunities to understand the role that creativity plays in solving scientific and technological problems.

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Appendix M: Journal Publication: Essential, unexceptional and universal: Teacher implicit beliefs of Creativity.

This paper was an output from a joint collaborative project involving UniSA, Geelong Grammar school and The University of Connecticut. This paper examines a total of 613 English-speaking, professional teachers and explores participants implicit beliefs of creativity as guided by the 4P's creativity theory. It was published in Thinking Skills and Creativity as follows:

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ABSTRACT

Guided by four key elements of creativity theory (the 4Ps), framed in an educational context (Results, Investigation, Students and Environment), this study examines implicit beliefs in a large sample of teachers across a range of discipline areas. The study finds that teacher implicit beliefs of creativity reflect a more differentiated and operationalized framework of *five* factors. Furthermore, these implicit beliefs are *not* indicative of a narrow, arts-biased understanding of creativity. Notwithstanding these results, the study also found differences among teachers by gender, discipline, level (elementary versus secondary), and even by the teachers' assessment of their own creativity. The implications of these results for teacher training and development are discussed.

Keywords

Creativity, framework, implicit beliefs, teaching, creative education

INTRODUCTION

Creativity has an increasingly important place in education (Beghetto & Kaufman, 2014, 2016). The OECD has been calling for creativity to be included in school education for nearly ten years (see Lucas, Claxton & Spencer, 2012). While acknowledging that creativity can be taught, learned and assessed, the OECD approach focuses primarily on creativity as a set of thinking skills. UNESCO, somewhat in contrast, proposes eight principles for nurturing creative thinking (Kampylis & Berki, 2014). These principles offer broad definitions, using terms such as *skills*, *environment*, and *motivation* (Kampylis & Berki, 2014, p. 6). The UNESCO approach also debunks some key misconceptions, actively promoting the idea that creativity builds upon domain-specific knowledge, and that it can be taught and assessed in all subjects (Kampylis & Berki, 2014, p. 9). The UNESCO principles are a step in the right direction, seeking to bridge the gap between the theory of creativity, and its practical application in schools.

One of the underlying drivers of an accelerating interest in creativity in education is the pressure exerted by the so-called *Future of Work*. The World Economic Forum's analysis of the impact of the Fourth Industrial Revolution on jobs in the 21st century (WEF, 2016), leaves no doubt that as the *digital transformation* of societies takes hold, creativity (and related abilities in critical thinking and complex problem solving) is becoming a pre-requisite for school education (Corazza, 2017).

The past twenty years, in fact, have seen an expanding interest in creativity integrated into curricula, with many countries explicitly or implicitly stating the importance of creativity (Ferrari, Cachia, & Punie, 2009). Although the field of creativity has been evolving since the 1960s, its intersection with education has been sporadic (Davies et al., 2014; Cropley, 2001). Given that it now appears to be in a new phase of perceived relevance and importance, it is

important to understand what teachers think about creativity in terms of how it can be taught and learned. Many of the key issues regarding implicit and explicit teacher beliefs have been well-covered by Kampylis, Berki, and Saariluoma (2009). Understanding implicit beliefs – and ensuring that people do not have implicit beliefs about creativity that are not consistent with established research – can have real-world impact (Baas, Koch, Nijstad, & De Dreu, 2015). In particular, teachers' implicit beliefs about creativity can be related to their instructional practices (Hong, Hartzell, & Greene, 2009), and their assessment of student creativity (Aljughaiman & Mowrer-Reynolds, 2005; Gralewski & Karwowski, 2018). Patston et al (2018) therefore asked a key question: "Will the 21st century push for creativity in the classroom fall on fertile ground…" (p. 367)? Answering this question begins with an exploration of *teacher implicit beliefs* of creativity (e.g., Fasko, 2001), thereby utilizing one of the most efficacious properties of self-report creativity assessments (Kaufman, 2019).

Sternberg (1985) was one of the first to conduct a large-scale investigation of implicit views of creativity. He found that laypeople saw creativity as being different from intelligence (although related); there emerged four factors: Non-entrenchment, aesthetic taste, perspicacity, and inquisitiveness. More recent studies of implicit beliefs have frequently focused on the prevalence of myths and misconceptions of creativity in the general population (e.g., Baas, Koch, Nijstad, & De Dreu, 2015). Certain research has also addressed the issue more specifically with regard to teachers (e.g. Mullet, Willerson, Lamb, and Kettler, 2016). Some studies of teachers have found that creativity is treated as synonymous with art (e.g. Runco, 2007; Glăveanu, 2014), as a rare and special talent (e.g. Ukkola-Vuoti et al., 2013), or associated with less desirable personal attributes (Chan & Chan, 1999). Of course, teacher beliefs vary on a number of factors. Private school teachers tend to have more favourable views of creativity and creative students (Eason, Giannangelo, & Franceschini, 2009). In a large, multi-cultural study of teacher implicit beliefs of creativity, Patston et al.,

(2018) found, that although teachers may not, as a group, subscribe to an *arts bias* view of creativity, there are, nevertheless, differences among teachers on the basis of their disciplines. Specifically, math and science teachers were significantly more likely to endorse an arts bias than humanities or elementary teachers. Furthermore, the implicit beliefs of teachers may also be a function of the teachers' own levels of creative self-efficacy, and self-rated creativity (Patston, et al., 2017).

As a clearer picture of teacher implicit beliefs of creativity begins to emerge, there remains one potential barrier to a deeper understanding of this issue, and to its application in teacher training and implementation into the classroom. Creativity has long been modelled as a complex system of interacting elements: in particular, the 4Ps first defined by Rhodes (1961). The 4Ps framework remains a centrepiece of the creativity literature, with over 1,800 citations to Rhodes's original work, and is the basis for a number of variations (see, for example, Amabile, 1996; Cropley & Cropley, 2010; Csikszentmihalyi, 2015; Sternberg, 2017). Is it true that implicit beliefs mirror academic theory in practice? In other words, if creativity is understood to be a function of: (a) motivation, dispositions, and affect (Person); (b) convergent and divergent cognition (Process); (c) novel and effective outcomes (Product), and; (d) factors associated with the physical and social environments (Press), then we might expect the implicit beliefs of creativity expressed by individuals to map onto these factors. Abdulla and Cramond (2017) point towards a similar issue: teachers needs to know about these elements of creativity, and how each is measured, if they are to embed creativity in the classroom. However, if quantitative studies of implicit beliefs of creativity do not address these four factors, then it is difficult to establish a relationship between the implicit beliefs of teachers, and prevailing models of creativity.

Even where quantitative instruments do address some, or all, of the elements of the 4Ps, a further problem remains. The language of the 4Ps is not geared toward classroom

practice, and may not adequately reflect teachers' understanding of what is meant by a "Product", a "Process", or a "Person". The term "Press", in particular, may have little meaning for teachers, further creating a barrier between the theory of creativity, and the practice of creativity in a classroom. The 4Ps represents a lens through which different disciplines view, and make sense of, creativity. However, before we can understand what teachers *see* when they view creativity through this lens, it must first be adjusted to reflect the language and concepts of their domain of practice.

To address these issues, and in an attempt to bridge the gap between creativity theory and practice in the domain of education, Patston, Cropley, and Kaufman (in press), as well as Cropley and Patston (2019), developed the *RISE Framework of Creative Education*. In simple terms, the RISE Framework is a translation from the language of creativity researchers (the 4Ps) to the language of teachers (R = Result; I = Investigation; S = Student; E = Environment), using terminology which is more suited to the school context, accessible by students and teachers. This paper explores teacher implicit beliefs of creativity through the lens of the RISE Framework of Creative Education. Do teachers' implicit beliefs of creativity, assessed through the RISE Framework, reflect the underlying 4Ps? Or do they reflect a more nuanced, domain-specific understanding of creativity in education? Equipped with a teacher-friendly model of the factors that are important for creativity, do teachers' implicit beliefs indicate a narrow, possibly arts-biased view, of creativity? Or, do teachers hold implicit views of creativity that reflect a broader understanding of creativity in the classroom? Are there differences among teachers by gender, discipline and/or the level at which they teach? Furthermore, do teachers' beliefs about their own creative ability influence their implicit beliefs? Finally, how do the results obtained on this new scale – derived from the RISE Framework – compare to studies of teacher implicit beliefs of creativity?

METHODS

Participants and Procedures

A total of 613 English-speaking, professional teachers were recruited for the present study. Participants completed the survey online, and participation was voluntary.

The sample of individuals who completed this survey consisted of a total of 411 females and 199 males, with 3 respondents choosing not to identify gender. There were 176 respondents who identified as primary (elementary school) teachers, whereas 437 identified as secondary (high school) teachers. No additional demographic data (such as age or ethnicity) were collected.

After the collection of the data, the secondary (high school) respondents were also coded to one of three disciplinary groups, reflecting their main teaching discipline. A total of 145 respondents identified as Science, Technology, Engineering, Mathematics teachers in Group 1 (abbreviated as *STEM*); 149 respondents identified as Humanities/English/Language in Group 2 (abbreviated as *Humanities*); 112 identified as Arts or Crafts teachers in Group 3 (abbreviated as *Arts*). A further 31 participants could not be coded into these three groups.

Measures

Participants completed an online survey with two measures. The first, and central measure based on the RISE Framework of Creative Education (see Patston, Cropley, & Kaufman, in press; Cropley & Patston, 2019), is the *Teacher Implicit Creativity Beliefs Scale* (*TICBS*). This scale consists of 24 questions addressing four key elements of creativity in education: Results, Investigation, Student, and Environment. Participants were asked to respond on a five-point Likert-type scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neither Disagree nor Agree, 4 = Agree, 5 = Strongly Agree) to indicate the extent to which each of the statements

(e.g., *Creativity can be found in many subjects (for example, science, history, and language*)) characterised their views about the nature of creativity in schools and education.

A factor analysis of the *RISE Framework* items was undertaken to explore the extent to which the 24 items loaded onto the latent variables: Result (Product); Investigation (Process); Student (Person); Environment (Press), ultimately derived from Rhodes (1961).

Prior to commencing factor analysis, the data were tested for their suitability. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy was 0.855, and Bartlett's Test of Sphericity resulted in an approximate Chi-Square value of 4403.461, df = 276 and a significance of $p < 0.001$, indicating that the data were suitable for factor analysis.

Maximum Likelihood was selected as the extraction method given the theoretical presumption that each of the four latent variables are orthogonal. Missing values were deleted listwise from the data, yielding 606 valid responses for each of the 24 *RISE Framework* items.

The criterion that was applied for accepting an item as loading onto a factor was that the loading should be >0.4, while items loading at <0.3 were regarded as failing to load onto a given factor. These criteria are consistent with accepted values (see, for example, Comrey & Lee, 1992).

The simple structure in Table 1 resulted in the exclusion of six redundant or irrelevant items from the *RISE Framework* scale. The majority of items in this structure have loadings rated as either ‘very good’ or ‘excellent’ (Comrey & Lee, 1992: >0.7 excellent; >0.63 very good; >0.55 good; >0.45 fair). Finally, the five factors in the simple structure shown in Table 1 account for 49.73% of the total variance.

Five ***Teacher Implicit Creativity Beliefs*** subscales resulted from this factor analysis, demonstrating reliabilities (Cronbach’s alpha) as follows: Factor 1 (r = .87); Factor 2 (r =

.79); Factor 3 (r = .68); Factor 4 (r = .69); Factor 5 (r = .56). Mean scores for the factors were as follows. Factor 1: M = 4.53, SD = .52 (N = 611); Factor 2: M = 3.32, SD = .98 (N = 613); Factor 3: M = 3.68, SD = .81 (N = 613); Factor 4: M = 3.45, SD = .98 (N = 613); Factor 5: M = 4.01, SD = .82 (N = 612).

Analysis of the factor loadings (Table 1) led to the factors being named as follows:

- Factor 1 = Creativity is **Essential** (creativity is an important element of education);
- Factor 2 = Creativity is **Technical** (creativity requires domain-specific knowledge);
- Factor 3 = Creativity is **Recognisable** (creativity can be assessed, measured, and tested);
- Factor 4 = Creativity is **Universal** (creativity is found in all subjects, not just the arts);
- Factor 5 = Creativity is **Unexceptional** (creativity is not limited to certain students).

Table 1: Factor Analysis of *RISE Framework* Items

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Engaging students' creativity helps their learning	.829				
Students can use their creativity to better understand the lessons	**.817**				
The classroom environment should nurture student creativity	.767				
Creativity is part of the learning process	**.654**				
The school climate can have an effect on student creativity	.646				
Children's creativity can be developed and improved	**.605**				
Creative students can help other students engage with their learning	.599				
Classroom discussions are more productive when the students use their creativity	**.582**				
One must have some experience with a subject area to be creative in it		.888			
It is difficult to be creative without a deep understanding of a given topic		**.746**			

A student will be more creative in an area once they have learned basic concepts in the area	.597			
It is possible to measure student creativity		**.859**		
Classroom assessments should be allowed to measure creativity		.552		
Creativity cannot be tested (R)		**.536**		
Artistic children are the most creative (R)			.741	
Creative students are the ones who write, draw, or play music (R)			**.702**	
Students who are more creative are more likely to demand too much attention or be disruptive (R)				.644
Creative students are more likely to be picked on or unpopular (R)				**.579**

Items noted as (R) were reverse-coded in the survey.

The second scale used in this study was the *Teacher Creative Self-Awareness* (TCSA), which consisted of an adaptation of the three-item *Creative Self Efficacy* scale (Tierney & Farmer, 2002), and the three-item *Creative Personal Identity* scale (Farmer, Tierney, & Kung-McIntyre, 2003). Three items, drawn from these scales, focus specifically on aspects of teacher creative self-awareness: explicit statements of how they *see themselves as teachers*, not what they believe, think or like about creativity. These three items were selected for the present study:

- I am confident in my creative teaching abilities;

- I am a creative teacher;
- I am good at creative teaching.

Participants responded on a 5-pt Likert-type scale, with "1" indicating *Strongly Disagree*, "3" indicating a neutral response, and "5" indicating *Strongly Agree*. In this study, the three items for this *Teacher Creative Self-Awareness* (TCSA) scale demonstrated excellent scale reliability, with a Cronbach's Alpha of $r = .91$ and Corrected Item-Total Correlations ranged from $r = .79$ to $r = .85$. Mean *Teacher Creative Self-Awareness* (TCSA) for the sample was $M = 3.91$, $SD = .85$ ($N = 410$). For the purposes of this study, the sample was split into three groups on the basis of evenly spaced visual binning cut-points for *Teacher Creative Self-Awareness* (TCSA): Medium TCSA ($M = 2.98$; $SD = .62$; N=145); High TCSA ($M = 4.00$; $SD = .00$; N=115); Very High TCSA ($M = 4.73$; $SD = .29$; N=150). These group labels (Medium, High, and Very High) were selected to reflect the fact that even the lowest scores were above the midpoint of the TCSA scale.

RESULTS

Tests of normality, including skewness and kurtosis, indicated that the data on all scales were normally distributed and therefore suitable for further parametric analysis. Means and standard deviations for the five *Teacher Implicit Creativity Beliefs* subscales, listed by gender, discipline, level and TCSA are presented in Table 2.

Table 2: Mean *Teacher Implicit Creativity Beliefs* scores by group

GROUP		Factor 1 (Essential)			Factor 2 (Technical)			Factor 3 (Recognisable)			Factor 4 (Universal)			Factor 5 (Unexceptional)		
		N	**Mean**	***SD***	***N***	**Mean**	***SD***	***N***	**Mean**	***SD***	***N***	**Mean**	***SD***	***N***	**Mean**	***SD***
Gender	**Female**	410	4.59	.44	411	3.31	.97	411	3.69	.79	411	3.48	.98	410	4.06	.81
	Male	198	4.44	.61	199	3.36	.98	199	3.68	.80	199	3.39	.98	199	3.90	.83
	Total	608	4.54	.50	610	3.32	.98	610	3.69	.79	610	3.45	.98	609	4.01	.82
Discipline	**STEM**	145	4.27	.74	145	3.51	1.00	145	3.58	.80	145	3.46	.94	145	3.94	.80
	Lang	147	4.58	.40	149	3.51	.94	149	3.80	.76	149	3.53	.93	149	3.99	.80
	Arts	112	4.65	.33	112	3.14	.93	112	3.78	.81	112	3.21	1.09	112	3.95	.81
	total	404	4.49	.56	406	3.41	.97	406	3.72	.79	406	3.42	.98	406	3.96	.80
Level	**Primary**	176	4.55	.69	176	3.07	1.00	176	3.54	.87	176	3.50	1.08	176	4.16	.84

	Secondary	435	4.52	.44	437	3.42	.95	437	3.74	.78	437	3.43	.94	436	3.95	.80
	Total	611	4.53	.52	613	3.32	.98	613	3.68	.81	613	3.45	.98	612	4.01	.82
TCSA	**Medium**	144	4.29	.66	145	3.46	.92	145	3.46	.72	145	3.38	.85	145	3.88	.74
	High	115	4.59	.46	115	3.20	.95	115	3.66	.84	115	3.72	.87	114	4.00	.85
	Very High	150	4.66	.45	150	3.24	1.12	150	3.82	.89	150	3.44	1.06	150	4.10	.85
	Total	409	4.51	.56	410	3.31	1.01	410	3.65	.83	410	3.50	.93	409	3.99	.81

An initial Multivariate Analysis of Variance was conducted with the five *Teacher Implicit Creativity Beliefs* subscales, derived from the factor analysis of the RISE Framework items, as the dependent variables, and with gender, discipline, level and TCSA levels of the teachers as the independent variables. A number of the interactions (see Table 3) were significant, in addition to main effects. Specific analyses are discussed separately in the sections below.

Table 3: Two-way, between-groups Analysis of Variance

Variable	**Group**	***F (x, y)***	***p* (two-tailed)**	***η^2***
F1 (Essential)	Discipline x Level TCSA x Level	$F(2, 398) = 42.47$ $F(2, 403) = 4.17$	.0001** .016*	.18 (large) .02 (small)
F2 (Technical)	**Gender x TCSA** **Discipline x Level** **TCSA x Level**	***F*(2, 401) = 5.11** ***F*(2, 400) = 5.03** ***F*(2, 404) = 4.33**	**.006*** **.007*** **.014***	**.02 (small)** **.02 (small)** **.02 (small)**
F3 (Recognisable)	Discipline x Level	$F(2, 400) = 3.57$	.029*	.02 (small)
F4 (Universal)	**TCSA x Level**	***F*(2, 404) = 3.76**	**.024***	**.02 (small)**
F5 Unexceptional)	Gender x TCSA Discipline x TCSA	$F(2, 400) = 3.05$ $F(4, 267) = 6.07$	.048* .0001**	.02 (small) .08 (med-large)

η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988); *$p < 0.05$; **$p < 0.001$

The interactions for F1 (Discipline x Level) and F5 (Discipline x TCSA), with large effect sizes, are shown in Figures 1 and 2. However, interactions for F1, F2, F3 (Discipline x Level) should be disregarded as there were insufficient numbers of primary teachers in the discipline groups, and this result is probably inaccurate.

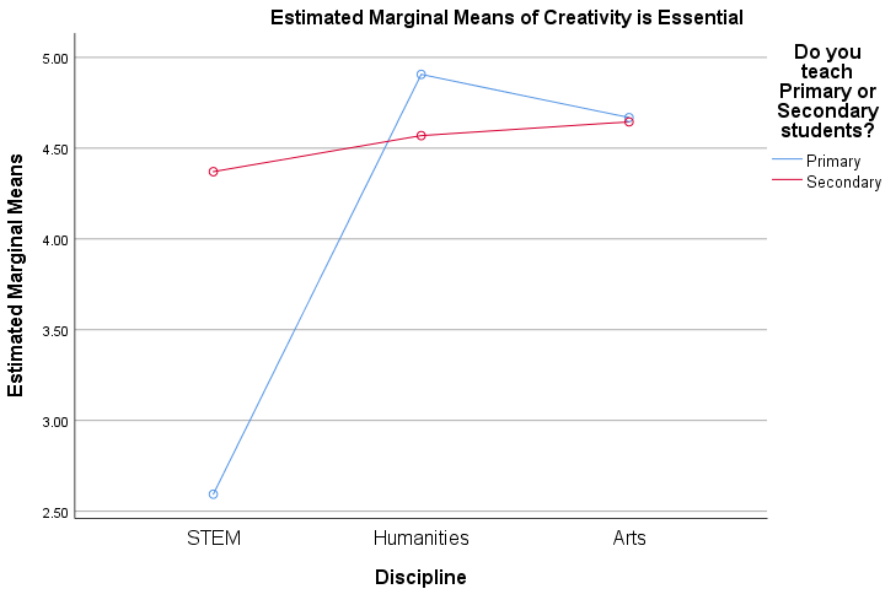


Figure 1: Interaction effect *Level* versus *Discipline* (for Factor F1)

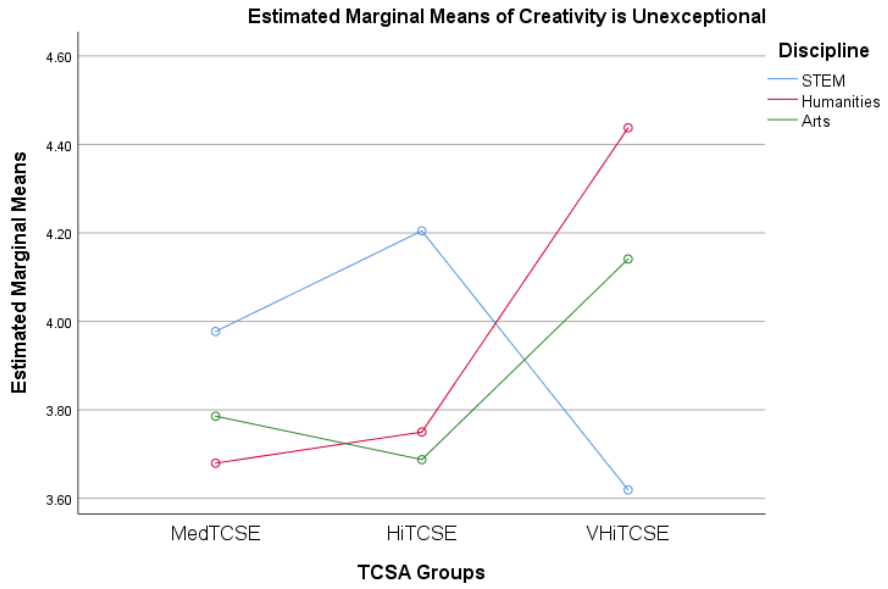


Figure 2: Interaction effect for *Discipline* versus *TCSA* (for Factor 5)

In the following sections, main effects are considered for cases where there was either no interaction effect, or, where the interaction was ordinal in nature (i.e. F1 (TCSA) and F2 (Level), in accordance with Fox, 2015 and Howell, 2010). In the latter cases, care should still

be exercised in the interpretation of main effects, as there may be an increased risk of Type I error.

Analysis of Variance – Teacher Implicit Creativity Beliefs and Gender

A one-way, between-groups analysis of variance was conducted to explore the impact of gender on levels of the five *Teacher Implicit Creativity Beliefs* subscales. Participants were divided into two groups according to their gender (Group 1: Male; Group 2: Female). There was a statistically significant difference at the $p < .001$ level in Factor 1 (*Essential*) scores: F (1, 606) = 12.367, $p = .0001$. Analysis indicated that, for Factor 1 (*Essential*) the mean score for Group 1 (Male) ($M = 4.44$; $SD = .61$) was significantly different from Group 2 (Female) ($M = 4.59$; $SD = .44$). The effect sizes, calculated using eta squared, was .02 (small) for Factor 1 (*Essential*).

These results indicate that male teachers were *significantly less likely to agree that creativity helps learning.*

Analysis of Variance – Teacher Implicit Creativity Beliefs and Discipline

A one-way, between-groups analysis of variance was conducted to explore the impact of discipline on levels of the Teacher Implicit Beliefs subscales. Participants were divided into three groups according to their discipline (Group 1 - STEM; Group 2 - Humanities; Group 3 - Arts). There was a statistically significant difference for the three discipline area groups at the $p < .001$ level in Factor 1 (*Essential*) scores: F (2, 403) = 20.65, $p = .0001$. In addition, there were statistically significant differences for the three discipline area groups at the $p < .01$ in Factor 2 (*Technical*) scores: F (2, 403) = 5.89, $p = .003$; and in Factor 3 (*Recognisable*) scores: F (2, 403) = 5.16, $p = .006$. Finally, there was a statistically significant difference for the three discipline area groups at the $p < .05$ level in Factor 4 (*Universal*) scores: F (2, 403) = 3.83, $p = .022$. The effect sizes, calculated using eta squared, were mixed and are reported below.

Post-hoc comparisons using the Bonferroni test indicated that for Factor 1 (*Essential*), the mean score for Group 1 (STEM) (*M* = 4.27; *SD* = .74) was significantly different from Group 2 (Humanities) (*M* = 4.58; *SD* = .40), and Group 3 (Arts) (M = 4.65; SD = .33), with a medium effect size (eta squared = .08). These results indicate that STEM teachers were *significantly less likely to agree that creativity helps learning* than Humanities or Arts teachers (see Figure 3).

Post-hoc comparisons using the Bonferroni test indicated that for Factor 2 (*Technical*) the mean scores for Group 1 (STEM) (*M* = 3.51; *SD* = 1.00) and Group 2 (Humanities) (*M* = 3.51; *SD* = .94) were significantly different from Group 3 (Arts) (M = 3.14; SD = .93) with a small effect size (eta squared = .03). These results indicate that Arts teachers were *significantly less likely to agree that creativity requires content knowledge* than STEM or Humanities teachers.

Post-hoc comparisons using the Bonferroni test indicated that for Factor 3 (*Recognisable*) the mean scores for Group 1 (STEM) (*M* = 3.58; *SD* = .80) were significantly different from Group 2 (Humanities) (*M* = 3.80; *SD* = .76) and Group 3 (Arts) (M = 3.78; SD = .81) with a small effect size (eta squared = .02). These results indicate that STEM teachers were *significantly less likely to agree that creativity can be tested* than Humanities or Arts teachers.

Finally, post-hoc comparisons using the Bonferroni test indicated that for Factor 4 (*Universal*) the mean scores for Group 2 (Humanities) (*M* = 3.53; *SD* = .93) were significantly different from Group 3 (Arts) (M = 3.21; SD = 1.09) with a small effect size (eta squared = .02). These results indicate that Arts teachers were *significantly less likely to agree that creativity is more than the Arts* than Humanities teachers.

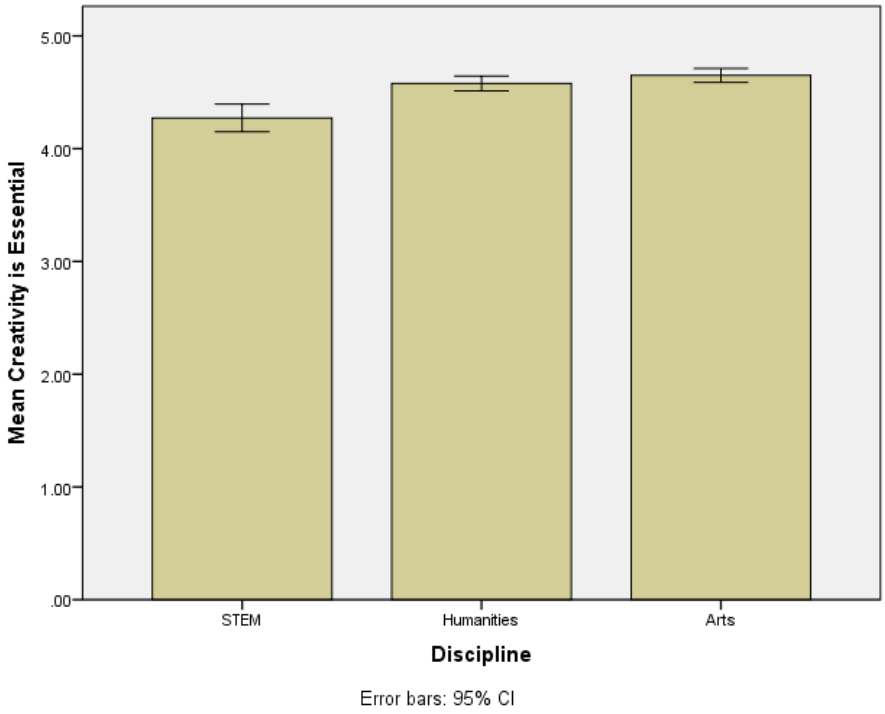


Figure 3: *Creativity is Essential* by Disciplines

Analysis of Variance – Teacher Implicit Creativity Beliefs and Level (Primary/Secondary)

A one-way, between-groups analysis of variance was conducted to explore the impact of Level on levels of the *Teacher Implicit Creativity Beliefs* subscales. Participants were divided into two groups according to their Level (Group 1: Primary; Group 2: Secondary). There were statistically significant differences for the two *level* groups at the $p < .0001$ level in Factor 2 (*Technical*) scores: F (1, 609) = 15.95, $p = .0001$, and in Factor 5 (*Unexceptional*) scores: F (1, 609) = 12.58, $p = .0001$. In addition, there was a statistically significant difference for the two *level* groups at the $p < .01$ in Factor 3 (*Recognisable*) scores: F (1, 609) = 7.31, $p = .007$. The effect sizes, calculated using eta squared, are shown below.

Post-hoc comparisons using the Bonferroni test indicated that for Factor 2 (*Technical*) the mean score for Group 1 (Primary) ($M = 3.07$; $SD = 1.00$) was significantly different from Group 2 (Secondary) ($M = 3.42$; $SD = .95$) with a small effect size (eta squared = .03). These

results indicate that Primary teachers were *significantly less likely to agree that creativity requires content knowledge* than Secondary teachers.

Further post-hoc comparisons using the Bonferroni test indicated that for Factor 3 (*Recognisable*) the mean score for Group 1 (Primary) (M = 3.54; SD = .87) was significantly different from Group 2 (Secondary) (M = 3.74; SD = .78) with a small effect size (eta squared = .01). These results indicate that Primary teachers were *significantly less likely to agree that creativity can be tested* than Secondary teachers.

Finally, post-hoc comparisons using the Bonferroni test indicated that for Factor 5 (*Unexceptional*) the mean score for Group 1 (Primary) (M = 4.16; SD = .84) was significantly different from Group 2 (Secondary) (M = 3.95; SD = .80) with a small effect size (eta squared = .01). These results indicate that Secondary teachers were *significantly less likely to agree that creative students do not have undesirable traits* than Primary teachers.

Analysis of Variance – Teacher Implicit Creativity Beliefs and TCSA Levels

A one-way, between-groups analysis of variance was conducted to explore the impact of *Teacher Creative Self-Awareness* (TCSA) on levels of the *Teacher Implicit Creativity Beliefs* subscales. Participants were divided into three groups according to TCSA levels (Group 1: Medium TCSA; Group 2: High TCSA; Group 3: Very High TCSA). There were statistically significant differences for the three TCSA groups at the $p < .0001$ level in Factor 1 (*Essential*) scores: F (2, 406) = 19.47, p = .0001, and at the level p = .001 in Factor 3 (*Recognisable*) scores: F (2, 407) = 7.47, p = .001.

Post-hoc comparisons using the Bonferroni test indicated that for Factor 1 (*Essential*) the mean score for Group 1 (Medium TCSA) (M = 4.29; SD = .66) was significantly different from Group 2 (High TCSA) (M = 4.59; SD = .46), with a medium effect size (eta squared = .04), and from Group 3 (Very High TCSA) (M = 4.66; SD = .45), with a medium effect size (eta squared = .08). These results indicate that teachers with Medium levels of creative self-

awareness (TCSA) were *significantly less likely to agree that creativity helps learning* than teachers with high to very high levels of creative self-awareness (TCSA). See Figure 4.

Further post-hoc comparisons using the Bonferroni test indicated that for Factor 3 (*Recognisable*) the mean score for Group 1 (Medium TCSA) (*M* = 3.46; *SD* = .72) was significantly different from Group 3 (Very High TCSA) (*M* = 3.82; *SD* = .89), with a medium effect size (eta squared = .04). These results indicate that teachers with Medium levels of TCSA were *significantly less likely to agree that creativity can be tested* than teachers with Very High levels of TCSA (see Figure 5).

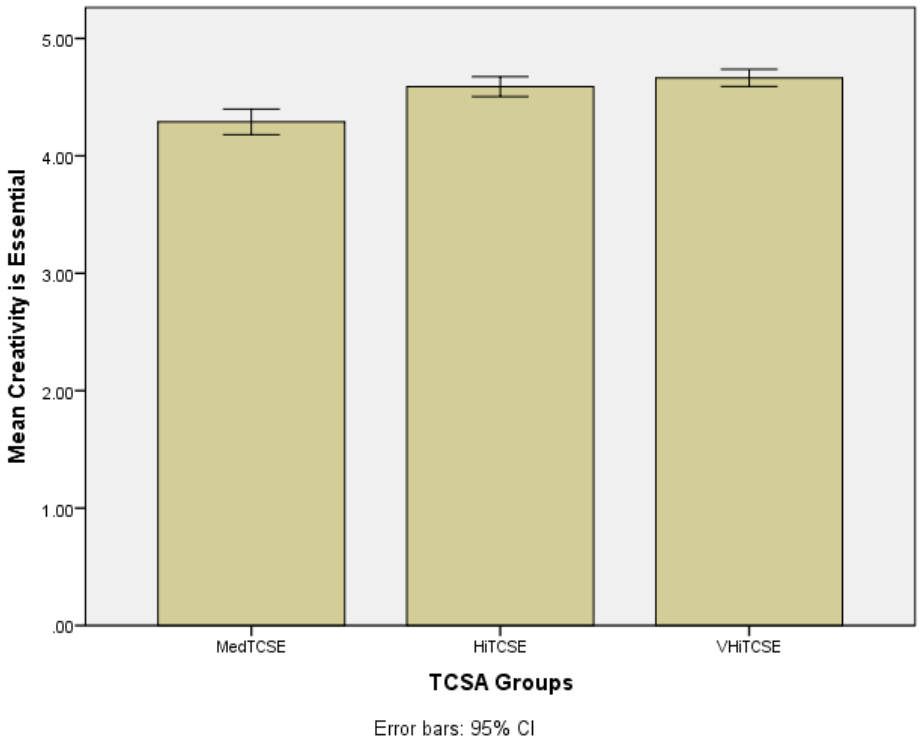


Figure 4: Creativity is Essential by Different Levels of TCSA

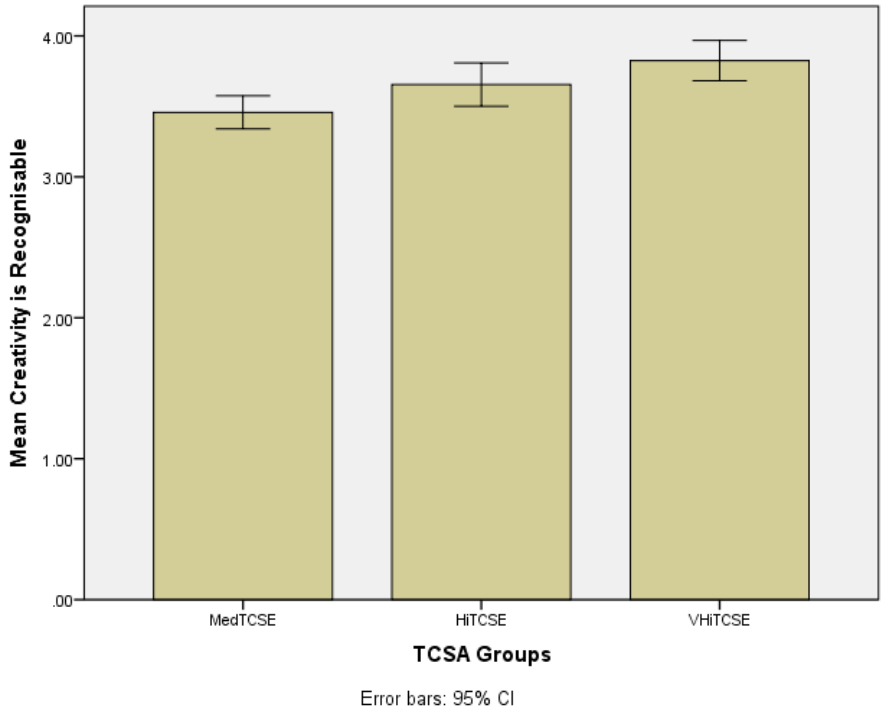


Figure 5: Creativity is Recognisable by Different Levels of TCSA

DISCUSSION

The first question addressed by this research concerns the relationship between teacher implicit beliefs and the conceptual framework known as RISE. Do teacher's implicit beliefs of creativity correspond to elements associated with *Results, Investigation, Student* and *the Environment?*

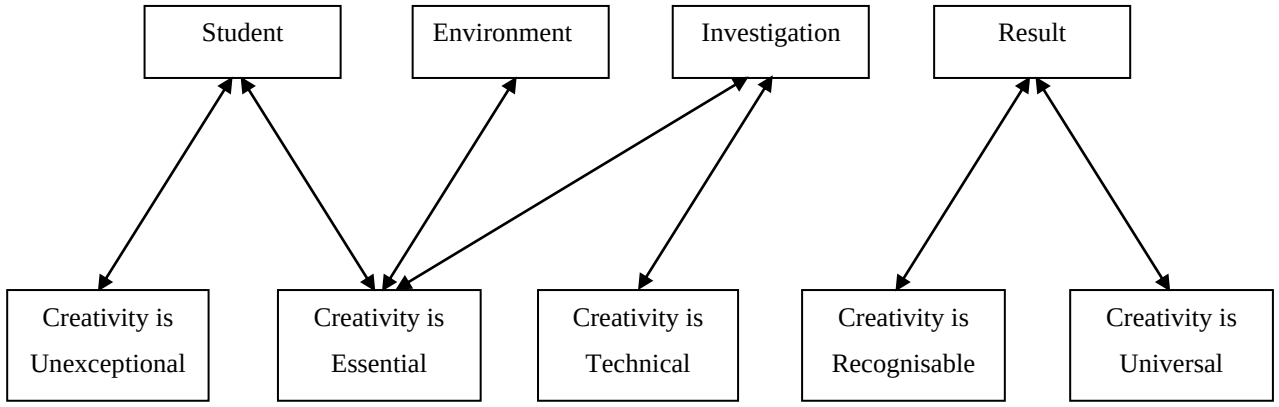


Figure 6: The RISE Framework and emergent factors

The factor analysis of the 24-item RISE Framework suggested, in fact, that teachers may interpret the underpinning 4Ps not only in a somewhat more differentiated manner (i.e. the *five* factors shown in Figure 6), but also in a more *operationalised* sense than may be conveyed by the 4Ps. For example, Rhodes's original (1961) *Person* factor typically draws attention to dimensions such as the motivation, personal properties, and feelings of the individual engaged in creativity (e.g. Cropley & Cropley, 2009; Plucker, Makel, & Qian, 2019). However, when framed as *Student*, teachers seem to associate this factor with its impact on student learning (Creativity is Essential), and its association with manifestations of student attributes, attitudes and beliefs (Creativity is Unexceptional). A more abstract, psychological concept of the creative Person becomes more concretised in the Student, through the lens of the RISE Framework. In more everyday terms, this factor analysis suggests that teachers see "student" as an expression of the fact that creative students are *not*

outliers, and *not* endowed with some special gift. Teachers see creativity as an accessible, essential and broadly applicable element of student learning.

In similar fashion, the factor analysis suggests that teachers see the role of Press not in abstract terms, as something which *can* affect creativity, but in more specific terms. Environment takes two forms in an educational context: both the more general *school* climate, and the more specific *classroom* climate, exert important influences on creativity. Creativity is essential to student learning, and the school/classroom environments have impact on that relationship.

The traditional view of Process – the core *Investigation* skills, especially divergent, associated with creativity – becomes, in this factor analysis, more operationalised as both essential to student learning (*creative students are better learners*), and as something that goes hand-in-hand with subject-specific knowledge (*better learners are more creative students*)[25]. There is a virtuous circle, or positive causal loop, involving creativity and subject knowledge. Divergent thinking, as the core process of creativity, is not simply a supplementary skill, but is absolutely central to student learning.

Finally, in this factor analysis the Result, or Product, of any creative activity moves from rather abstract notions of novelty and effectiveness – the characteristics that define a creative product – to a refutation of two common myths of creativity. Teachers see creativity as something that *can be* measured, *should be* measured, and *should be measured in every subject*, from art and music, through to science and technology. A consequence of this is that teachers need appropriate tools – rubrics, for example – to support the assessment of creativity in the things that students do.

[25] This recalls an old military adage – *good soldiers drill well, and drill makes good soldiers*.

As a result of the factor analysis, it is therefore possible to suggest not only that teachers understanding of creativity is somewhat more differentiated and operationalised than the 4Ps, but also that this understanding – their implicit beliefs – does *not* reflect some widely held myths and misconceptions. In a similar fashion to Patston et al (2018), this study suggests that teachers see creativity as not confined to the arts, not a special talent, and therefore as something teachable and assessable across the school curriculum. The benefit of presenting the questions through the more accessible language of RISE, rather than the traditional language of the 4Ps, has enabled this research to expose deeper insights into how teachers see creativity when viewed through this more domain-specific lens.

Although the factor analysis of RISE Framework items suggests that teachers hold implicit beliefs of creativity that are differentiated and nuanced, the actual scores obtained on the five teacher implicit beliefs subscales (Table 2) suggest that these implicit beliefs are not uniformly strong, nor are they the same when the sample is examined, for instance, by gender. Even as a single group, teachers' implicit beliefs most strongly reflected a belief that creativity is essential to student learning (Factor 1: $M = 4.54$, $SD = .50$), and that creativity is unexceptional (Factor 5: $M = 4.01$, $SD = .82$); there is less certainty on the remaining three factors. Teachers, as a group, *agree* that creativity is essential to learning and that it is not a special gift. However, they *tend towards agreement* on the matters of creativity being founded on discipline knowledge (Factor 2), being measurable (Factor 3), and being found across all subjects (Factor 4). This convergence is important as a foundation for teacher training and development.

Delving deeper into the strength of these implicit beliefs, possible differences by gender, level (primary versus secondary), discipline, and the teachers' self-rated levels of creative self-awareness, were explored. Only one significant interaction effect for one factor (creativity is unexceptional) emerged. Figures 2 suggests that teachers' understanding of

creativity – in the sense that creativity is/is not a special gift – differs by the teachers' own creative self-awareness. Perhaps the most interesting aspect of this result is that STEM teachers who rate themselves highly as creative teachers are the *least likely* to see creativity as unexceptional. Does this reflect lingering misconceptions about the nature of creativity? Do highly creative STEM teachers see this level of creativity as unusual for the discipline: in effect, incompatible with non-artistic disciplines? The practical consequence of this, and other specific findings, may lie in teacher training and development. If some teachers, in some disciplines, hold views of creativity that lean towards popular misconceptions, then this knowledge should be used to tailor that training.

In addition to the preceding interaction effect, a number of significant main effects were present across the five teacher implicit beliefs subscales. These are summarised in Table 3.

Table 3: ANOVA main effects and effect sizes across Teacher Implicit Creativity Beliefs

Factor	**Teacher Implicit Creativity Beliefs**	**Differences influenced by (effect size)**
1	Creativity is essential	Gender (small); Discipline (medium); TCSA (medium)
2	Creativity is technical	Discipline (small); Level (small)
3	Creativity is recognisable	Discipline (small); Level (small); TCSA (medium)
4	Creativity is universal	Discipline (small)
5	Creativity is unexceptional	Level (small); TCSA (small)

If we are seeking to embed creativity across the curriculum, these results suggest that teacher training and development should be structured with both a general component, reinforcing general beliefs about creativity across the five factors, and also a tailored component, addressing differences in implicit beliefs by gender, discipline, level and TCSA.

These findings have implications for teacher professional development. In order for professional development to have impact, it should be targeted and specific to teacher knowledge and needs. A deficit-based approach, starting with the premise that all teachers do not understand creativity but rather endorse myths and incorrect information, is both likely to meet with a negative response, and fails to reflect the disciplinary differences in implicit beliefs. On the other hand, acknowledging that there are a number of implicit beliefs in the general population *not* supported by teachers – an asset-based approach – provides a positive entry point for professional development, and, more broadly, a common language for discussing creativity in staffroom and classroom interactions. Like the findings of Kampylis, Berki and Saariluoma (2009), this study notes *inconsistency* in teacher implicit theories of creativity, however, these variations sit on a foundation that may be more compatible with theory than previously thought. Teacher education must therefore be designed to ensure that both the strengths and the weaknesses of implicit beliefs inform training, seeking to ensure that professional learning and development is includes both a general component, and a subject (or domain) specific component, across the full spectrum of subjects – and providing teachers with opportunities to develop and exercise their own creativity in their profession.

CONCLUSIONS

This study supports recent findings that teachers have a differentiated and nuanced understanding of creativity. Teachers do not appear to hold inaccurate implicit beliefs to the degree previously thought, and are open to the measurement and assessment of creativity. Generally speaking, the results of this study indicated a rejection of the notion that creativity

is synonymous only with art, music, or other related activities. Teachers also revealed that, as a group, they believe that creativity is unexceptional, recognisable, and technical. When offered the means to examine creativity through the lens of a framework (RISE), which uses language tailored to the domain of education, teachers clearly demonstrate a more open, differentiated, and nuanced view of creativity in education than has been posited in previous studies. This suggests that efforts to further embed creativity in the 21st century classroom will fall on favourable ground.

However, the findings of this study also suggest that there remains work to be done, in particular when drilling down to the level of different discipline areas, before teachers' views of creativity become highly congruent with the literature. Around the world, teachers are being asked to be more creative and to teach creative skills to their students. This study paints an optimistic picture, building on examples of where creativity already exists in the curriculum, across a range of subjects. The paper also demonstrates the importance of developing measures of creativity that are tailored to the domain of inquiry, with relevant and accessible language for the population under investigation. The findings presented in this paper suggest that the greatest opportunity for correcting any misconceptions of creativity, and speeding its appearance as a core part of school education, will be for education authorities and schools to develop the creativity of individual teachers through specific and targeted practical professional learning and development. Teachers are experts in their subjects, trained professionals who demonstrate content knowledge and pedagogic excellence every day. These findings support the hypothesis that creativity in education is not in the dark ages, rather is entering a new age of enlightenment.

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Appendix N: Journal Publication: 'What is creativity in education? A qualitative study of international curricula'

This paper was an output from a joint collaborative project involving UniSA, Geelong Grammar school and The University of Connecticut. This paper analyses eleven countries global curricula for definitions and elements of creativity. It has been submitted to The Journal of Advanced Academics as follows:

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Author Contributions

Rebecca L. Marrone: Formal Investigation of country curricula

Tim Patston: Conceptualization, Methodology, Investigation, Writing – Original Draft, Review and Editing, Supervision

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ABSTRACT

The concept of ‘Creativity’ as a desirable attribute within education is long-standing. The fields of education and Creativity have developed, and periodically intersected with, government reports, policies, commentaries and advice. Recently, an increasing number of countries have emphasized Creativity in their official curricula. This paper analyses curricula in eleven countries and asks three key questions: how is Creativity typically defined, where is it placed in the curriculum, and what concrete advice is provided for teachers? Despite widespread interest and a productive field of research in Creativity, our examination reveals little support for teachers to turn policy into practice.

Keywords: Creativity, international curricula, teaching with Creativity, teaching for Creativity

Highlights

Creativity is seen as increasingly important in education systems across the globe.

Understanding of Creativity varies across international curricula and is often inconsistent with the way it is understood in the broader field of Creativity studies.

There is little evidence of explicit support for teachers in promoting Creativity.

INTRODUCTION

The emergence of Creativity in school curricula

The launch of Sputnik I in 1957 (Steeves, Bernhardt, Burns, & Lombard, 2009) propelled the American education system into the first formal attempts to introduce Creativity into the curriculum, starting with the National Defense Education Act in 1958. This was seen as largely a matter of promoting problem solving in science, technology, engineering and Mathematics (STEM) (Herold, 1974). In the United Kingdom, interest culminated in the National Advisory Committee on Creative and Cultural Education's report (NACCCE, 1999), which broadened the STEM approach to encompass the arts and culture (in part, perhaps, because a high proportion of the committee came from the arts and arts education fields). When organisations with a global economic perspective, such as the Organisation for Economic Cooperation and Development (OECD, 2004, 2008), began to call for Creativity to be an essential part of curricula, the movement for educational change began to gather momentum. In the form of what Nordin and Sundberg (2016) referred to as a 'travelling concept', Creativity is now seen as a key competency with acceptance spread throughout global policy networks in education. Most recently, Creativity and related characteristics such as curiosity and open-mindedness have become part of 'Creating New Value', one of the three key competencies in the OECD Education 2030 project (OECD, 2018).

The journey from openly acknowledging the importance of Creativity to systematically and purposefully supporting its promotion in the classroom is a long one, however. This paper focuses on what might be regarded as the first step in this journey: school curriculum. The paper examines aspects of three basic issues: (a) how Creativity is defined in school curriculum, (b) where Creativity is placed in the curriculum, and most importantly (c) what advice for teachers who want to nurture Creativity in their students is to be found in curricula. For these purposes, a number of national curricula were systematically examined. The countries whose curricula were analyzed do not constitute a representative sample, and the paper does not contain a comparative evaluation of world curricula or a study of the reasons for the current state of affairs. Instead, it studies the way Creativity is presented in the curricula in order to gain a general idea of the support teachers receive in translating statements of in-principle approval of Creativity into practice.

Unclear issues

It has been argued that all students have the capacity to be creative (Sawyer, 2015; Vygotsky, 2004). To develop this capacity, teachers are being called upon to lead and model creative learning through creative teaching (Longshaw, 2009), but there are differing views about how to do this in actual teaching practice (Chen-Tsai, 2015). One area of confusion has resulted from lack of clarity concerning the distinction between teaching with Creativity and teaching for Creativity (Jeffrey & Craft, 2004). Ideally, both are needed; teachers should be creative in their own pedagogic methods while simultaneously enhancing the creative skills and attributes of their students (Gregerson, Snyder, & Kaufman, 2013). Cropley and Gribov (2005, p. 65) stressed the need for 'two-dimensional education', which goes beyond rote learning and fixed or propositional knowledge and encompasses the imaginative and constructive (Grigorenko et al., 2009; Sternberg, Bonney, Gabora, & Merrifield, 2012), so that students develop new ideas about how things work (Hickman, Coleman, & Greenland, 2014).

Research from a range of fields, including design (Cubukcu & Dundar, 2007), Mathematics (Altintas, 2009), business (Williams, 2001), engineering (Daly, Christian, Yilmaz, Seifert & Gonzalez, 2012), medicine (Glasziou, Ogrinc & Goodman, 2011) and education (Beghetto & Kaufman, 2016) demonstrates that Creativity can be taught, learned and developed. What is less clear, however, is exactly which knowledge, skills and attributes are involved. It has been proposed that Creativity is domain-specific (Baer, 2011) and it seems that teaching Creativity as a discrete subject can only be superficial at best. For example, the skills/knowledge set required to be creative in Mathematics is very different from what is needed in medicine or athletics (let alone creative writing). In addition, the related abilities, traits and attributes may also differ (Baer & Kaufman, 2017). That said, some core principles can nurture Creativity across most disciplines. Beghetto and Kaufman (2014, p. 6) proposed a general framework for Creativity-supporting practices:

1. Explicitly teaching for creative thinking
2. Providing opportunities for choice and discovery
3. Encouraging students' intrinsic motivation
4. Establishing a Creativity-supportive learning environment

5. Providing opportunities for students to use their imagination while learning

Barriers to creative education

There have been calls for a marriage between Creativity research and education for decades (Beghetto, 2010; Cropley, 1978, 1992; Helson, 1983) and for policy makers to reduce the barriers teachers face when translating Creativity mandates into classroom practice. There are, however, key issues that hamper understanding of how Creativity should be encouraged in education and impede effective implementation of new curricula associated with Creativity. Important among these is that many teachers are unclear about what constitutes Creativity (Aljughaiman & Mowrer-Reynolds, 2005; Fleith, 2000; Kampylis, Berki & Saariluoma, 2009; Runco, 2003). Smith and Smith (2010) note that some writers equate creative teaching with trying something new or different, whereas for others 'creative' is a label for ideas that were tried, did not work, and then discarded. Some teachers believe that Creativity is something only for gifted individuals and across a narrow range of subjects, especially the arts (Glăveanu, 2014b; Saracho, 2011; Spiel & von Korff, 2006). Many educators still view Creativity as separate from academic learning (Beghetto & Kaufman, 2007). This implies that Creativity is not perceived as a central cognitive process (Smith & Smith, 2010), but rather as a curriculum frill to be included in the teaching week wherever it can be squeezed in around the demands of literacy, numeracy and preparing for standardized testing (Beghetto, Kaufman, Baer, & Patston, 2017).

For over fifty years (Aljughaiman & Mowrer-Reynolds, 2005; Gralewski & Karwowski, 2016; Torrance, 1963; Westby & Dawson, 1995), there have been consistent findings indicating that teachers claim to support the importance of Creativity in the classroom, but do not necessarily like the personal qualities (as defined by the literature) of creative students. These qualities may include questioning authority, being nonconformist, and being impulsive, progressive or determined (Westby & Dawson, 1995); most teachers do not associate these qualities with Creativity. Low creative self-efficacy is also an obstacle for some teachers; if they do not believe that they themselves are creative, they are less likely to believe that Creativity can be developed in their students (Patston, Cropley, Marrone, & Kaufman, 2017), although research suggests that only a minority of teachers view themselves as specifically not creative (DaVia Rubenstein, Ridgley, Callan, Karami & Ehlonger, 2018). The DaVia Rubenstein et al. study found that teachers make a distinction between being

creative inside and outside the school context, and that there are many teachers who classify themselves as creative, just not in the classroom.

Recent studies however indicate that teacher attitudes and beliefs are evolving. Teachers have a more nuanced understanding of Creativity (Cropley, Patston, Kaufman & Marrone, 2019) than previously reported. They appear to be shifting in their implicit beliefs (Patston, Cropley, Marrone and Kaufman, 2017), subscribing less to myths such as the arts bias (Patston, Cropley, Marrone and Kaufman, 2018). It is not that teachers are not open to Creativity being learned, taught and assessed in classrooms, they need more concrete definitions from the education authorities and operational strategies for implementation.

Thus it appears that introducing Creativity into education represents a huge challenge for policy makers. Teachers need more than a simple instruction to make students 'more creative'. They need direction, ideas and resources. The key question is, what information is available to assist the nurturing of Creativity in the classroom? One point at which to commence the development of an answer to this question is within the documents that lay down the fundamental principles on which teaching should be based. How do national curricula help teachers to become creative educators? This issue is the primary concern of this paper.

METHODOLOGY

Definition of Creativity

Definitions of Creativity have evolved over time. Currently there is broad consensus that Creativity is not merely a cognitive process but consists of four key components. For the purposes of this paper, our starting definition was that of Plucker, Kaufman & Beghetto, (2004). This frequently cited definition posits that 'Creativity is the interaction between aptitude, process and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context' (p. 90). In other words, Creativity requires more than just thinking skills.

Selection of national curricula

Although we wished to examine a broad range of national curricula, it was logistically impossible to extend the analysis to cover the entire globe. Thus, we focused on curricula from first-world countries from Europe and the Asia Pacific region with comparable, centralized education systems and a school completion rate of over 90 percent (OECD, 2019). A further criterion for inclusion in the study was that a publicly available, comprehensive, and stable version of the curriculum was available in a downloadable version suitable for multiple reviews (Bowen, 2009). The sources to which we gained access did not represent the total sum of all curriculum documents for any specific country, but only summaries that the relevant agencies chose to make available to a wide audience. They are the distillations of curriculum contents that the systems in question chose to post publicly. It is, however, logical to assume that these agencies emphasized what they regarded as important, thus providing a proxy for the Creativity climate of their curriculum.

In addition, we incorporated a separate, already completed analysis of the Hungarian curriculum (Bereczki, 2015). In order to gain some idea of possible region-specific aspects of curriculum we also analyzed the Middle Years program of the International Baccalaureate (IB), currently taught in 108 countries (IBO, 2014). The final result of this procedure was that we analyzed curricula from Australia, England, Estonia, Finland, Hong Kong, Hungary, Iceland, Ireland, New Zealand, Scotland, and South Korea, plus the IB. Our sample thus extended the geographical range of earlier studies such as Heilmann and Korte (2010) and Cachia, Ferrari, Ala-Mutka and Punie (2010). In qualitative studies, basic themes (which Cropley (2019) calls ‘concepts’) usually stabilize after the analysis of around 10-12 cases. As a result, this group of national curricula was large enough to satisfy what Cropley (p. 32) referred to as the ‘pragmatic criterion’ of ‘usefulness’.

Data analysis

Our aim was to identify the general approach of the curricula to Creativity, not to carry out, for example, an exact differential analysis of between-country or within-country differences. For example, no analysis was made of difference across grade-levels or subject areas, although as far as possible we analyzed documents for similar grade levels and similar subject areas. In an extended discussion of qualitative research methods, Cropley (2019) emphasized the value of starting qualitative analyses with a pilot study, which provides preliminary insights into the object of study, rather than adopting a tabula-rasa approach. In

this study we started by examining the Australian Curriculum (ACARA, 2014) in order to develop an initial conceptual orientation for the analyses of national curricula. For example, the ACARA document offers an initial working definition of Creativity: 'Creativity involves students learning to generate and apply new ideas in specific contexts, seeing existing situations in a new way, identifying alternative explanations, and seeing or making new links that generate a positive outcome' (ACARA, 2014). This curriculum, however, used the terms 'critical thinking', 'creative thinking', and 'Creativity' interchangeably and inconsistently across the learning areas, indicating that closer examination is needed.

The ACARA curriculum also implies that creative outcomes are important: 'Creative thinking involves students learning to generate and apply new ideas in specific contexts… This includes combining parts to form something original, sifting and refining ideas to discover possibilities, constructing theories and objects' (ACARA, 2014, p.1). There was little information, however, about actual products (in the sense of our working definition of Creativity), so that statements about creative outcomes were overwhelmingly generic learning outcomes rather than domain specific. Thus, a second exploratory theme emerged (see Cropley, 2019 for a discussion of 'emergent' topics) — not, however, from educational theory but from the pilot study. To give a third example, the ACARA document suggests that activities should be 'challenging', 'engaging', 'inquiry based', and so forth (ACARA, 2014), but there is little information in the document concerning what such activities would look like in the individual learning areas and at different year levels.

Subsequently, we undertook a document analysis (Bowen, 2009; Mayring, 2000) of the national curricula in our study. This followed a deductive analytic strategy to code statements in individual curricula against our three research questions:

1. How is Creativity defined?

2. Where is Creativity placed in the curriculum?

3. Is there concrete advice for teachers about nurturing Creativity in their students?

The document analysis involved a form of objective hermeneutics (McCaffrey, Raffin-Bouchal, & Moules, 2012). Coding was done by identifying statements in each curriculum which referred unmistakably to one of the themes just listed. As is typical of objective hermeneutics, each curriculum document was coded by a coding team of three

education researchers. A set of rules was developed for deciding how to code statements, followed by a discussion of each curriculum document among the coders. As is common in such studies, a number of themes emerged that went beyond the initial three research questions listed above. In light of these, we took the opportunity to revisit curricula. With new insights into the problem, we coded their contents a second time, using the 'emergent' ideas as a framework. Thus, the analysis was an iterative and reflective process. It involved an initial examination then a more thorough reading, followed by discussion of emerging patterns and organization of the information into categories generated by the research questions (Fereday, & Muir-Cochrane, 2006). It is also worth noting that this was an exploratory analysis designed to elicit common threads and themes. We were aware that curriculum documentation serves different purposes in different countries and may be interpreted differently by educators at different stages and levels (Heilmann and Korte, 2010). Our focus, however, was on the place, purpose, and practice of Creativity.

RESULTS

Table 1 contains a synthesis of the understanding of Creativity expressed in the curricula; not all ideas were expressed in every curriculum, but the general picture summarized in the table emerged.

Table 1. Aspects of Creativity emphasized in curricula

Aspect	Content of the aspect
Definition	Problem finding, solution finding, transcending accepted ideas and norms, creating valuable new ideas
Source	Innate, learned
Processes (Cognition)	Imagining, exploring, investigating, critical thinking, problem identification, abstract thinking, making connections, generating ideas, evaluating ideas,
Personal Properties	Playfulness, curiosity, openness to experience, imaginativeness, self-confidence, self-expression, autonomy
Motivation	Challenge, excitement
Product	New ideas

Classroom Activities	Role play, creative writing, artistic expression, application of educational technology

Initially, we looked for definitions of Creativity and how these might align with our working definition, (Plucker, Kaufman & Beghetto, (2004) Thus, we were looking for references to process, product, individual properties, and acknowledgement of the importance of the social context, basically the '4 Ps' of Creativity. What was striking is that the curricula included in the analysis concentrated on only two of these: Person and Process. A third P (P for 'Press', i.e. the classroom environment) was also referred to, although in a general and superficial way (e.g. 'role play', 'artistic expression'). Also notable is that the references to Process were largely confined to stereotypically 'creative' processes such as imagining, exploring, or making connections. There was little explicit linking of Creativity with processes such as acquisition of information or accurate retrieval of existing knowledge, despite the fact that this link has been receiving increased attention in the last 15 years (e.g. Paulus, Coursey, & Kenworthy, 2018). The traditional fourth P (Product) was mentioned only in vague, general terms (e.g. new ideas), which means that a topic that is often dear to teachers' hearts — assessment — was given little attention.

DISCUSSION

As Beghetto (2010) noted, "a creative mandate from external policy makers will do little to help long-standing barriers in the classroom" (p. 449) without additional information such as targeted professional development, additional support documents and explicit assessment guidelines. Such information was largely lacking.

Personal properties: It is evident from the literature that personal qualities and attributes play a key role in the development of creative skills and capacities (Gralewski & Karwowski, 2016; Sternberg & Lubart, 1995). These include curiosity and interest, which are related to motivation (Hennessey, 2015a), and imagination (Beghetto & Kaufman, 2014; Jung, Flores & Hunter, 2016). Students are more likely to develop creative skills if they are motivated (Hennessey, 2015b), open to new experiences (Feist, 1998; Baer & Li, 2006; Li et al., 2015), willing to take intellectual risks (Oral, 2008), and are tolerant of ambiguity (Zenasni, Besancon & Lubart, 2008). The attributes of the learner were an important feature of

curricula. However, discussions in the documents had more the sense of "this is what the learner brings" rather than "this is what schooling might help the learner to acquire" accompanied by discussion of ways in which this acquisition might be facilitated. The concept of a range of levels of creativity such as Big-C versus mini-c was absent, and there was little explicit information about how creativity-facilitating attributes might be recognized and developed. Thus, creativity was seen as something that is already present in children (or not), and there was an implication that it is reserved for the gifted.

Process: The steps in the process of emergence of a creative product are also of great importance. As Cropley and Cropley (2015) showed, starting from Wallas (1926) these steps are conceptualized in various ways by different authors. They include problem identification (Reiter-Palmon & Robinson, 2009; Vernon, Hocking & Tyler, 2016), idea generation (Osborn, 1957; Gilson & Litchfield, 2017), looking at problems from multiple perspectives (Kalyuga, Renkl, & Paas, 2010), establishing new or unexpected connections (Csikszentmihalyi, 1996; Perry-Smith, 2006; Chan, Peletz & Shunn, 2012), suggesting alternative solutions (Ritter & Mostert, 2016), and looking at multiple possibilities before deciding on a final outcome (iteration: Amabile & Muller, 2008; Kaufman & Sternberg, 2010). Finally, "validated" ideas are selected for implementation (Vernon, Hocking & Tyler, 2016). This process should also have some kind of end point, outcome or product. This may be a tangible physical object, an idea or series of ideas, or a new process (Kozbelt, Beghetto & Runco, 2010; Said-Metwaly, Kyndt, & Van den Noortgate, 2017). It must be novel and in some way useful to its creator or creators (Sternberg & Lubart, 1999) and also measurable (Cropley & Cropley, 2015). However, there was almost no reference to creative outcomes in the curricula.

The learning environment: It has been known for some time (Amabile et al., 1996; Jindal-Snape, Davies, Collier, Howe, Digby & Hay, 2013) that creativity can be enhanced or inhibited in an appropriate learning environment which has both physical (Dul, Ceylan & Jaspers, 2011; Dul & Ceylan, 2014) and psychological (Garces, Pocinho, Jesus & Viscu, 2016; Runco & Pagnani, 2011) supportive elements. However, perhaps the most striking aspect of the analysis of curriculum documents is that the critical component of environment was scarcely mentioned. In fact, the documents reveal little systematic attempt to identify a holistic supportive framework for creativity based on the considerable literature available in

the field of creativity. Given the current shift towards benchmarking of international academic standards (Valverde, 2000), this is surprising. It is in some ways understandable that there is a focus in these definitions on creative individuals, their aptitudes and personal properties, and the creative process. However, the area in curricula about which the least amount of information was found was concrete advice for teachers about actual creativity-related practices for nurturing creativity in students.

It is true that there were numerous mentions of creative products/outcomes, but few mentions of the types of practices and activities that could support these outcomes. While there were references that corresponded with the five general practices suggested by Beghetto and Kaufman (2014), as noted above, their appearance was sporadic. Similarly, explicit mention of "providing opportunities for choice and discovery" were also very thin on the ground. Thus, there was strikingly little explicit advice that focused on how teachers might include creativity-supporting practices in their area of expertise, and an overall lack of evidence of understanding at the policy level of a need for this advice.

In fact, such guidelines exist: Examples include the "Creativity-Fostering Teacher Behavior Index" CFTIndex) (Soh 2018), through which teachers can carry out self-assessment of the learning environment they generate in their classroom, the "Phase-Related System for the Analysis of Process (PSAP) (e.g. Cropley, 2019), through which they can assess the relative strength of development of phases such as those mentioned above (e.g., generating ideas, suggesting alternative solutions, or validating solutions) and the Creative Solutions Diagnosis Scale (Cropley & Cropley, 2016) through which both teachers and students can assess their own solutions. Failure to provide such guidance raises the risk that the myths and implicit beliefs relating to issues like the nature of creativity, the qualities of creative students (as articulated earlier), or the properties of creative products will dominate thinking: If teachers believe that creativity resides only in particular subjects, that they as teachers are not creative in the classroom, and that creative qualities in students are undesirable, then it will be very difficult for creative practices to be developed in educational settings.

Recommendations

In order for teachers to effectively introduce new curricula, with both explicit and implied modifications to existing pedagogies, a number of pre-conditions need to be put in place. Teachers need to understand what their national education body means by the term "creativity," and they need to accept that teaching with and for creativity is possible in all subject areas. If new curricula are introduced, teachers need to be familiar with what they should do to promote it and how to ascertain the degree of success of their efforts. Teachers need to be offered substantial professional learning opportunities in order to become skilled in this new pedagogic paradigm. They also need to be aware of their own beliefs, and asked to challenge them. However, achieving these is dependent on the system recognising what is needed. At this point it appears that at least some education systems may make mandates, they have a long way to go in terms of delivering effective guidelines on educating teachers about creativity and creative education.

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Appendix A

Summary of references to ‘Creativity’ in individual school curricula

Country	**Defined**	
1. Australia	Yes	Critical and Creative Thinking is one of seven General Capabilities which are assumed to be embedded into the learning areas. “Creativity involves students learning to generate and apply new ideas in specific contexts, seeing existing situations in a new way, identifying alternative explanations, and seeing or making new links that generate a positive outcome” (ACARA, 2014, p. 1).
2. England	No	One of the overarching aims of the curriculum is to “help engender an appreciation of human creativity and achievement” (Department of Education, 2014, p. 5). Design & Technology refers to critical thinking and imagination.
3. Estonia	No	No clear definition. “Creativity” used 22 times in general curriculum document. Emphasis on “providing an environment in which creativity is fostered” (Republic of Estonia Ministry of Education and Research, 2014, p. 5) and to provide methods that foster creativity (for example role-play, creative writing, and artistic self-expression). More emphasis than other curricula on

		creative thinking and creative work, but not a great deal about "creativity" as per our definition.
4. Finland	No	Creativity is one of the "underlying values" and there is an emphasis on the activities that support creative outcomes. Creativity is linked with imagination, self-expression and playfulness.
5. Hong Kong	No	No clear definition. "Creativity" used 19 times in general curriculum document. Emphasis in learning area documents (i.e. maths, science and social sciences documents). Shifts focus between "self–expression" definition and "abstract thinking" conceptions. Focus on Four Key Tasks, creativity being part of Project Learning and Problem Management (Primary 1–6) and Thinking Skills (Secondary). NB: Use of the language and concepts associated with the research literature in various learning areas.
6. Hungary	No	No clear definition. "Creativity" as a term is mentioned nine times in the section on competences (Bereczki, 2014). "There are several areas of development which form part of all competences that are to be established in all subject areas. They include critical thinking, creativity, initiative, problem solving, cooperation, risk

		assessment, decision-making, emotion management, social skills and tolerance. (HNCC, 2012, p. 2)
7. Iceland	Yes	"Creativity" is one of six fundamental pillars of education. These pillars form the basis of the curriculum guidelines. "Creation involves forming tasks and communicating them, to make something, make something new or different from what the individual knows or has done before; Creation is to invent, enjoy, encourage curiosity and interest, engage the imagination and play with possibilities; Creativity is to sense what lies ahead and carry it out; Creativity is based on curiosity, challenge, excitement and search; Grappling the problem and finding a solution" (Ministry of Education, Science and Culture with Subjects, 2014, p. 22).
8. Ireland	Yes	Via the Department of Culture, Heritage and the Gaeltacht (2016) in *Creative Ireland 2017-2022*, which defines creativity as "a set of innate abilities and learned skills: the capacity of individuals and organisations to transcend accepted ideas and norms and by drawing on imagination to create new ideas that bring additional value to human activity" (p. 11). The Department of

		Education and Skills is a key partner in this government arts policy. Key skill of "Being creative" in Junior Cycle Education is defined as "imagining, exploring options and alternatives, implementing ideas and taking action, learning creatively, stimulating creativity using digital technology" (p. 13).
9. New Zealand	No	The curriculum "takes at its starting point a vision of our young people as lifelong learners who are confident and creative, connected, and actively involved" (Ministry of Education, 2017, p. 4). Most of the references came from the introductory values statements, and from The Arts learning areas.
10. Scotland	Yes	Definition comes from a government paper, *What is creativity?*, representing three ministerial portfolios. "Creativity" defined as "the capacity to generate ideas that have value to the individual, to look at familiar things with a fresh eye, to examine problems with an open mind, make connections, learn from mistakes and use the imagination to explore new possibilities. Ultimately creativity is the ability to make the world anew, to shape the future and enrich the here and now" (The Scottish Government, 2013, p. 9).

11. South Korea	Yes/no	Something of a definition is provided: “one who shows creativity with new thinking and challenges based on basic capabilities” (Minister of Education, Science and Technology, 2009, p. 1). One of the five aims of the curriculum is “to facilitate student autonomy and creativity” (p. 3).

Appendix O: Journal Publication: 'The development of mathematical creativity across high school: Increasing, decreasing, or both

This paper was an output from a 2-year joint collaborative project involving UniSA, Geelong Grammar school and The University of Connecticut. This paper examines a total of 649 Australian secondary school students and explores changes in student mathematical creativity within and across grade levels. It was published in Thinking Skills and Creativity as follows:

Tubb, A. L., Cropley, D. H., Marrone, R. L., Patston, T., & Kaufman, J. C. (2020). The development of mathematical creativity across high school: Increasing, decreasing, or both? *Thinking Skills and Creativity, 35*, 100634. ://doi.org/10.1016/j.tsc.2020.100634

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ABSTRACT

The advent of the Fourth Industrial Revolution (Industry 4.0) and a broader digital transformation of society is driving both a renewed focus on Science, Technology, Engineering and Mathematics (STEM) education as well as a recognition that creativity is a prerequisite for employment in the 21st century. Together, these elements are the catalyst for a key question: *what is the impact of school education, in its broadest sense, on the development of STEM-based creativity in children*? To shed greater light on this question, this study focuses on mathematical creativity in children across grades six-12, at a large Australian school. The study reported in this paper found that although mathematical creativity increases from year to year, there is a significant within-year decline in creativity. This paper explores possible explanations for this decline, suggesting that it is driven by a combination of environmental, personal, and process-related factors present in the context of school education. The study sheds light on the relationship between the development of mathematical creativity in high school students, and the factors that may impede this development.

Keywords: Creativity, mathematics, STEM, Industry 4.0, developmental models

INTRODUCTION

The Fourth Industrial Revolution (or *Industry 4.0*[26]) – the integration of data analytics, artificial intelligence and automation – is now an established paradigm, informing a broader process of the *digital transformation* of society (see Gilchrist, 2016), impacting not only businesses and organisations, but also education. Digital transformation therefore drives a conversation about the *Future of Work*. What skills/competencies will individuals need in order to thrive in a world of artificial intelligence and digitalisation?

Bruner (1962) forecast the impact of this transformation almost sixty years ago, recognising that *creativity* would be the key differentiator between human and artificial intelligence. The World Economic Forum (WEF, 2016), among others, has reached a similar conclusion. In compiling a list of key 21st century *skills*[27], in an era of digital transformation, the WEF has identified creativity and complex problem solving among the most important abilities needed in the 21st century. When coupled with the strongly technological nature of the Fourth Industrial Revolution, it becomes clear that the development of a domain-specific ability to find creative solutions to *STEM-based problems* is of paramount importance for educational institutions. However, even as creativity becomes recognised as a *pre-requisite* for school education (Corazza, 2017), one key question must be posed. *What is the impact of school education, in its broadest sense, on the development of creativity, particularly in STEM subjects such as mathematics?*

Creativity in Education

Creativity has been framed in educational terms since the beginning of the modern creativity era, across many different disciplines (see, for example, Beghetto & Kaufman, 2017). Guilford's (1950) presidential address to the American Psychological Association stressed the importance of creativity in *vocational and educational practices* (p. 444), while Guilford (1959) underscored the necessity, in modern education, of developing *all facets* of intellect,

[26] The terms *Fourth Industrial Revolution*, and *Industry 4.0*, have been in common use since the concept was launched by the German government in 2011.

[27] "Skill" may not adequately capture the complex, multifaceted nature of creativity. See, for example, Cropley (2019), which explores the nature of creativity as a broader *competency*.

including creativity. Over the subsequent 60-70 years, creativity has been defined as the result of a complex interaction of cognitive abilities, personal qualities, and environmental factors leading to novel and effective outcomes (the so-called 4Ps framework defined in Rhodes, 1961). This framework has been applied to STEM disciplines such as engineering (e.g. Cropley, 2015; Cropley, Cropley, & Sandwith, 2017), and mathematics (e.g. Sak, et al., 2017; Leikin & Pitta-Pantazi, 2013). Set in this context, creativity should therefore be understood not as a skill to be *trained* into individuals, but as a competency – a system of skills, abilities, attitudes and knowledge – that must form part of an individual's *education*.

Although creativity in education has been studied extensively, from a variety of perspectives (see Beghetto, 2019; Cropley, 2001; Mullen, 2019) there remain significant gaps in the creativity literature regarding the relationship between school education (in the broad sense of factors such as pedagogy, environment, and classroom practices) and the development of creativity, particularly in STEM-based areas. The first omission in the literature is the relative lack of clarity and consensus (summarised by Chang et. al, 2017) surrounding how creativity, in general, develops in children. This is a domain-general question of developmental trends in creativity, usually operationalised as divergent thinking (i.e. the ability to produce many, varied responses to a stimulus). The second gap centres on a specific lack of clarity surrounding the domain-specific development of *STEM-based* – specifically mathematical – creativity in children.

There is an acknowledged lack of consensus on the definition of mathematical creativity (see Haavold, 2018, p.2); however, a common convention based on Haylock (1987) is to operationalise mathematical creativity as *the ability for divergent production within mathematical situations* (Haavold, 2018, p.2).

Developmental Trends in Divergent Thinking in Children

Studies of developmental trends in divergent thinking[28] in school children, such as Russ, Robins, and Christiano (1999), frequently report an apparent lack of change over time. More

[28] Divergent Thinking (production) is typically assessed (see Plucker, Makel and Qian, 2019) by analysing responses to verbal (i.e. written) or figural (i.e. picture) prompts, across the categories of ideational *fluency* (the

recently, Runco and Acar (2019) reviewed several studies on divergent thinking in children. They noted that Kleibeuker, De Dreu and Crone (2013) found no differences in fluency and flexibility between children in age groups 12-13 and 15-16, albeit in a small sample (N=98). Wallace and Russ (2015), in similar fashion, studied a small group of girls in the age range 9-14 and suggested that divergent thinking skills are relatively stable over time. Similarly, an older, larger study (Iscoe & Pierce-Jones, 1964) found no age-related differences in fluency or flexibility among children in the age range five-nine years.

In contrast, Memmert (2011) found statistically significant increases in figural creativity across three age groups (7, 10 and 13) albeit in a small study (of just over 100 participants). Similarly, Charles and Runco (2001) found statistically significant changes to verbal creativity scores across three grade levels (3, 4 and 5), with scores generally peaking in the grade 4 participants. Claxton, Pannells and Rhoads (2005), in a small, longitudinal study, also found a statistically significant change in figural creativity (elaboration) examining students as they progressed from grade 4, through 6 and up to grade 9.

Not only is there uncertainty regarding the developmental trajectory of creativity in children in general, but the studies considered so far, in addition to being frequently of limited scope (a narrow range of ages) and sample size (Lau & Cheung, 2010), generally are cross-sectional in design, and only explore creativity *between* grade levels (and therefore ages). There is therefore an implicit assumption that the effect of any grade level/age, and the schooling that accompanies this, is *uniform* within that time period. Therefore, two questions remain unanswered: (a) is there any change in creativity *within* grade levels/ages, and; (b) what happens to creativity in the domain-specific area of mathematics?

Developmental Trends in Mathematical Creativity in Children

Haavold (2018) looked specifically at mathematical creativity, comparing students in grades eight and eleven. He found evidence that the older students (grade eleven) were more creative

number of responses), *flexibility* (the number of different categories of responses), *elaboration* (the extent to which responses are developed and extended within categories) and *originality* (the uniqueness of responses).

on a mathematics task (noting, however, a significant interaction between age and mathematical achievement).

Bahar and Maker (2011) examined the relationship between mathematical creativity and mathematical ability in 78 first to fourth grade students. Their analysis supported fluency, flexibility, elaboration, and originality as significant predictors of mathematical achievement. The study found that both mathematical creativity and mathematical achievement increased across grade levels, however, correlations by grade level showed that mean scores for fluency were low at grade one, higher at grade two, low again at grade three, and high again at grade four. Bahar and Maker (2011) suggested that these correlational *slumps* may be due to the impact of teachers who use 'traditional methods', or, they may be because students who participated in the study were drawn from low Socio-Economic Status (SES) communities.

Sak and Maker (2006) observed 841 first to fifth grade students from four schools, suggesting that domain knowledge was progressively associated with fluency, originality, flexibility and elaboration, from lower to upper grades, while age was associated with domain knowledge only in lower grades. Further analysis indicated that *years of schooling* significantly contributed to students' creativity, even after domain knowledge was partialled out. Students displayed peaks and slumps as a function of age and domain knowledge, but not as a function of grade. Similarly, Kattou et. al. (2013) found a link between mathematical ability and mathematical creativity in 359 fourth, fifth and sixth grade students, though the researchers did not examine how creativity differed across grade levels.

Each of the above studies examining the relationship between grade level and mathematical creativity employed a cross-sectional design. This limits the ability of the analysis to draw conclusions about differences in the age-groups/grade levels, due to the fact that each may have been influenced by different environmental factors. In addition, cross-sectional designs limit the ability to compute correlations between the different age-groups/grade levels.

In light of these mathematics-focused studies, we return to an earlier question: *What is the impact of school education, in its broadest sense, on the development of STEM-based creativity in children*? Four questions emerge from the preceding discussion: (a) In the specific domain of mathematics, in any given grade level, what is the association between

knowledge and creativity? (b) How does the relationship between knowledge and creativity in mathematics change across the school careers of children? (c) How does the relationship between grade level/age and creativity in mathematics change over the school careers of children? (d) How does mathematical creativity change *within* different grade levels/ages?

To explore these questions four hypotheses were tested in this study:

- Hypothesis 1 – There will be a general, positive relationship between student mathematical creativity and mathematics Grade Point Average (GPA) in each grade level;
- Hypothesis 2 – High mathematics GPA, regardless of grade, will be associated with higher levels of mathematical creativity;
- Hypothesis 3 – Student mathematical creativity will increase between groups with increasing grade level;
- Hypothesis 4 – Student mathematical creativity will increase within groups *during* each grade level.

METHODOLOGY

Participants and Procedures

A total of 649 (368 male; 279 female; two not specified) students from a private, fee-paying school in Australia commenced this study in March 2016. A cohort-sequential design (Leedy & Ormrod, 2013) was employed in order to explore both between-groups (i.e. cross-sectional) differences in creativity between grade levels, as well as within-subjects (i.e. longitudinal, developmental) trends in creativity within single grade levels. There were 52 (35 male; 17 female) participants from grade six (approx. age 11); 130 (77 male; 52 female) from grade eight[29] (approx. age 13); 233 (129 male; 101 female) from grade nine (approx. age 14), and; 34 (127 male; 105 female) from grade ten (approx. age 15). In the final stage of the project (June 2018), an additional, new group of 235 (117 male; 98 female) grade nine students also joined the study. Although participant numbers fluctuated during the study due

[29] In the present study, in the state of Victoria, Australia, "High School" commences with grade seven.

to competing curriculum requirements and other scheduling factors, 896 (433 male; 355 female; 108 not specified) participants took part in the final stage of the study in June 2018, with 82 in grade eight; 235 in grade nine; 191 in grade ten; 189 in grade eleven, and; 199 in grade 12[30].

Measures

The participants in this study completed a test of mathematical creativity based on Baer (1991) at up to five different time points across the period March 2016 to June 2018. The prompts, similar to typical figural and verbal divergent production tasks, are designed as open-ended questions seeking a broad range of novel responses to simple mathematical tasks. The *mathematical creativity* test was presented as follows[31]:

- Time 2 (March 2016) – What is the most creative way you can use what you know in mathematics to write some mathematics questions or equations where the answer is "8" (for example, "4 x 2", or "10 – 2" are not very creative answers). You have three minutes to write down your ideas. Be as creative as you can!
- Time 3 (June 2016) – The same introduction was used, but the problem now focused on the answer, "13"
- Time 4 (September, 2016) – The same introduction was used, but the problem now focused on the answer, "-5"
- Time 5 (November, 2016) – The same introduction was used, but the problem now focused on the answer, "1/3"
- Time 6 (June, 2018) – The same introduction was used, but the problem now focused on the answer, "3.66"

While mathematical creativity is widely operationalised in terms of divergent production (and therefore the criteria of *fluency*, *flexibility*, *originality* and *elaboration*), in

[30] The Australian school year runs from February to December. Students coded as grade six in 2016 were therefore in that grade level for the entire period of 2016 and were in grade eight in 2018.

[31] Note that "Time 1" was designated for the collection of baseline data unrelated to this study.

this study three independent judges (high school teachers, with experience in teaching mathematics) used the Consensual Assessment Technique (CAT; Amabile, 1982; Kaufman, Plucker, & Baer, 2008), in which judges with sufficient expertise in the relevant domain assign ratings of the creativity of all products produced by a particular sample. Past research has shown very high inter-rater agreement (Kaufman & Baer, 2012) and evidence of validity (Amabile, 1996). High school teachers have consistently been shown to be appropriate choices to rate student creativity (Baer, Kaufman, & Riggs, 2009; Kaufman, Baer, Cropley, Reiter-Palmon, & Sinnett, 2013).

The CAT methodology was chosen for this study in order to address concerns over the construct and convergent validity of common creativity tests and procedures (see Hennessy, Amabile, & Mueller, 1999). Judges in the current study assessed the creativity of the students' responses on a scale of 1 to 6, where 1 = *not at all creative* and 6 = *most creative*. Inter-rater reliability was calculated for each time period and the judge's scores and ranged from .726 to .781. The mean inter-rater reliability for these measures (based on all raters over all time periods) was .754. In addition to the mathematical creativity measure, the school provided each student's *Mathematics GPA* score. This is a measure, ranging from 1 to 10, of each student's grade point average at the end of 2016 (November), and the end of second term (June) in 2018. GPAs at the school are assigned by individual teachers to individual students for the subject in question. They are not scaled.

To reduce the risks of Type I (false positive) errors, this study set significance levels for all statistical tests at $p = .05$. Although a number of statistical tests have been conducted in this study, potentially increasing the risk of Type I errors, the within-subjects trend results (i.e. Hypothesis 4) should be seen as four independent analyses (the four different grade levels) conducted in parallel. Comparisons are made only on a single variable in each of the independent grade levels, therefore reducing the apparent *multiple comparisons* that normally increase the risk of Type I error.

RESULTS

Both graphical and numerical assessments of skewness and kurtosis indicated that the data were normally distributed, and therefore suitable for parametric analysis. Table 2 lists basic

descriptive statistics for student Mathematics GPA data, while Table 3 lists descriptive statistics for student mathematical creativity data.

Table 2. Descriptive statistics: Mathematics GPA

Variable	Grade	*N*	*Mean*	*Std. Dev.*	*Min*	*Max*
Mathematics GPA 2016	6	-	-	-	-	-
	8	130	6.53	1.94	2	10
	9	233	5.64	1.75	1	10
	10	234	6.68	1.79	3	10
Mathematics GPA 2018	8	82	6.78	1.77	3	10
	9	235	6.20	2.03	1	10
	10	191	5.93	2.09	1	10
	11	189	6.63	2.22	1	10
	12	199	6.82	2.02	1	10

Table 3. Descriptive statistics: Mathematical creativity

Variable	Grade	*N*	*Mean*	*Std. Dev.*	*Min*	*Max*
Mathematical creativity 2016	6	52	1.92	0.43	1	3.0
	8	121	1.84	0.57	1	3.5
	9	218	2.06	0.69	1	4.2
	10	230	2.23	0.77	1	4.6
Mathematical creativity 2018	8	-	-	-	-	-
	9	212	2.22	0.85	1	4.5
	10	126	2.30	0.84	1	4.7
	11	122	2.45	0.92	1	4.7
	12	109	2.59	1.05	1	5.2

Note that not all students completed all measures in all time periods. For example, grade six students in 2016 completed the mathematical creativity test, but did not receive mathematics GPA scores, while grade eight students in 2018 have a mathematics GPA score but did not complete the mathematical creativity test.

To test the within-subjects relationship between mathematical creativity and mathematics GPA (H1), Pearson product-moment correlations coefficients were calculated for each grade level represented in the data. Table 4 shows moderate yet significant positive correlations for each grade (whenever both variables were available) in both 2016 and 2018. Higher levels of mathematics GPA are associated with higher levels of mathematical creativity in each of grades eight to eleven (grade 12 was not significant). Hypothesis 1 is therefore largely supported.

Table 4. Pearson correlations: Mathematical creativity and Mathematics GPA

Year	**Grade**	***r*(N)**	***p***
2016	6	-	-
	8	$r(120) = 0.27$	$p = 0.00$
	9	$r(218) = 0.24$	$p = 0.00$
	10	$r(226) = 0.30$	$p = 0.00$
2018	8	-	-
	9	$r(211) = 0.45$	$p = 0.00$
	10	$r(126) = 0.30$	$p = 0.00$
	11	$r(116) = 0.22$	$p = 0.02$
	12	$r(96) = 0.17$	$p = 0.10$

Two-Way, Between-Groups Analysis of Variance (2016 Data)

To explore the impact of mathematics achievement and grade level on levels of mathematical creativity (Hypotheses 2 and 3), a two-way, between-groups analysis of variance was conducted on the student data for 2016. This seeks to replicate the results of Haavold (2018), who explored the influence of grade level on student mathematical creativity, after controlling for mathematical achievement. The sample of 597 participants in the present

study was divided into three groups on the basis of Mathematics GPA (Group 1: *Low*, [GPA range 1-5; N = 188]; Group 2: *Medium*, [GPA range 5.5-6.5: N = 181]; Group 3: *High*, [GPA range 7-10: N = 228]), and three grade levels (eight, nine, and ten). This partitioning of students was performed in order to create three roughly equal groups, allowing Mathematics GPA to act as one of the categorical, independent variables necessary (in addition to grade level) for a two-way, between-groups analysis. The dependent variable was the students' average mathematical creativity score for 2016 (see Table 3).

The results of the ANOVA are presented in Table 5. The interaction effect between mathematics GPA and grade level was *not* statistically significant, F (4, 555) = .08, p = .95. There was a statistically significant main effect for mathematics GPA, F (2, 555) = 15.67, p = 0.000, η^2= 0.05 (medium), and a statistically significant main effect for grade Level, F (2, 555) = 11.06, p = 0.000, η^2= 0.04 (small-medium).

Table 5: Two-way Analysis of Variance for Mean Mathematical Creativity (2016)

Variable	**Sum of Squares**	***df***	***Mean square***	***F(x,y)***	***p* (two-tailed)**	η^2
Mathematics GPA	14.41	2	7.21	15.67	0.00	0.05
Grade level (2016)	10.17	2	5.09	11.06	0.00	0.04
Grade Level (2016) * Mathematics GPA	0.34	4	0.08	0.18	0.95	0.00

η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988)

Post-hoc comparisons using the Tukey HSD test indicated that the mean mathematical creativity score for Group 3 (High mathematics GPA; M = 2.29, SD = 0.72) was significantly different from Group 1 (Low mathematics GPA; M = 1.90; SD = 0.70) and Group 2 (Medium mathematics GPA; M = 2.00, SD = 0.63). However, the mean mathematical creativity score for Group 1 was not significantly different from the mean mathematical creativity score for Group 2. These results indicate that students with *low* and *medium* mathematics GPA had significantly lower mathematical creativity than students with a *high* mathematics GPA. For students tested in 2016, hypothesis 2 is therefore supported.

Similarly, post-hoc comparisons using the Tukey HSD test indicated that the mean mathematical creativity score for Group 1 (grade 8; M = 1.84, SD = 0.57), was significantly different from Group 2 (grade 9; M = 2.06; SD = 0.69), and Group 3 (grade 10; M = 2.23; SD = 0.77). Similarly, the mean mathematical creativity score for Group 2 was significantly different from Group 3. These results indicate that students in grade eight had significantly lower mathematical creativity than students in grade nine, who had significantly lower mathematical creativity than student in grade ten. Hypothesis 3 (for the 2016 data) is supported.

Two-Way, Between-Groups Analysis of Variance (2018 Data)

A further two-way, between-groups analysis of variance was conducted for the data obtained for 2018. Here, the sample of 968[32] participants was again divided into three groups on the basis of mathematics GPA (Group 1: *Low*, [GPA range 1-4; N = 178]; Group 2: *Medium*, [GPA range 5-7.5; N = 466]; Group 3: *High*, [GPA range 8-10; N = 324]), and four grade levels (nine, ten, eleven, and 12). The dependent variable was the students' mathematical creativity score for 2018 (see Table 3).

The results of this ANOVA are presented in Table 6. The interaction effect between mathematics GPA and grade Level was once again *not* statistically significant, F (6, 537) = 1.54, p = .16, η^2= 0.02. There was, however, a statistically significant main effect for mathematics GPA, F (2, 537) = 18.09, p = 0.000, η^2= 0.06 (medium), but *no* statistically significant main effect for grade level, F (3, 537) = 1.81, p = 0.14, η^2= 0.01 (therefore failing to support hypothesis 3 for 2018 data).

Table 6: Two-way Analysis of Variance for Mean Mathematical Creativity (2018)

Variable	**Sum of Squares**	***df***	***Mean square***	***F(x,y)***	***p* (two-tailed)**	η^2
Mathematics GPA	26.87	2	13.43	18.09	0.00	0.06
Grade level (2018)	4.03	3	1.34	1.81	0.14	0.01

[32] This figure includes 72 who did not report a grade level.

Grade Level (2018) * Mathematics GPA	6.88	6	1.15	1.54	0.16	0.02

η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988)

Post-hoc comparisons using the Tukey HSD test indicated that the mean mathematical creativity score for Group 1 (Low mathematics GPA; *M* = 1.96; *SD* = 0.78) was significantly different from Group 2 (Medium mathematics GPA; *M* = 2.27, *SD* = 0.86) and Group 3 (High mathematics GPA; *M* = 2.68, *SD* = 0.92). Similarly, the mean mathematical creativity score for Group 2 was significantly different from the mean mathematical creativity score for Group 3. These results indicate that for the sample of students in 2018, those with *low* mathematics GPA had significantly lower mathematical creativity than students with a *medium* mathematics GPA, and that students with *medium* mathematics GPA had significantly lower mathematical creativity than students with a *high* mathematics GPA. Hypothesis 2, for students tested in 2018, was therefore supported.

Within-Subjects Analysis: Grade Levels and Mathematical Creativity

In order to explore *within-subjects* differences in mathematical creativity across the duration of this study (i.e. developmental trends within each grade level/cohort over the time periods spanning March 2016 through to June 2018, or Hypothesis 4), a series of one-way, within-subjects analyses of variance would normally be conducted. However, because not all students in each grade level completed all of the tests of mathematical creativity during this period, the analysis was confined to a series of paired-samples t-tests, conducted for various pairs of time periods, for each year level. Table 7 summarises the mean mathematical creativity scores across the time periods T2 – T6.

Table 7: 2016 Mathematical Creativity scores by time period

Period	**Grade**	***N***	***Mean***	***Std. Dev.***	***Min***	***Max***
Time 2	6	24	2.09	0.80	1	4
March	8	-	-	-	-	-
2016						
	9	-	-	-	-	-
	10	189	2.55	1.05	1	5.8

Time 3	6	42	1.94	0.48	1.25	3.5
June 2016	8	58	2.07	0.73	1	5
	9	189	2.14	0.77	1	4.5
	10	148	2.21	0.82	1	5.7
Time 4	6	40	1.99	0.61	1	3.8
Sept 2016	8	80	1.95	0.61	1	3.5
	9	164	1.98	0.71	1	4.2
	10	130	2.17	0.84	1	4.4
Time 5	6	38	1.87	0.57	1	3.8
Nov 2016	8	98	1.74	0.65	1	3.4
	9	-	-	-	-	-
	10	134	1.87	0.80	1	4.7
Time 6						
June 2018	8	-	-	-	-	-
	9	212	2.22	0.85	1	4.5
	10	126	2.30	0.84	1	4.7
	11	122	2.45	0.92	1	4.7
	12	109	2.59	1.05	1	5.2

Grade 6 Mathematical Creativity

The results of paired-samples t-tests for the available time periods for grade six are shown in Table 8. This cohort was not assessed in 2018, therefore the longitudinal trend analysis is limited to 2016 only.

Table 8: Mathematical Creativity Paired t-tests – grade six (2016)

	Time 2 *(March 2016)*	Time 3 *(June 2016)*	Time 4 *(Sept 2016)*	Time 5 *(Nov 2016)*

Time 2	---			
Time 3	$t(20) = -0.73$	---		
	$\eta^2 = 0.03$			
Time 4	$t(20) = -1.21$	$t(30) = 0.41$	---	
	$\eta^2 = 0.07$	$\eta^2 = 0.006$		
Time 5	$t(14) = -0.96$	$t(31) = -0.19$	$t(27) = -1.04$	---
	$\eta^2 = 0.07$	$\eta^2 = 0.001$	$\eta^2 = 0.04$	

Notes: Table reports t-statistics for the relevant paired t-tests. * denotes $p \leq 0.05$
η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988)

The results indicate (Figure 2) a modest, but non-significant decline in mathematical creativity scores for grade 6 students across the four time periods comprising the school year 2016. Hypothesis 4, for students in grade six (2016), is not supported.

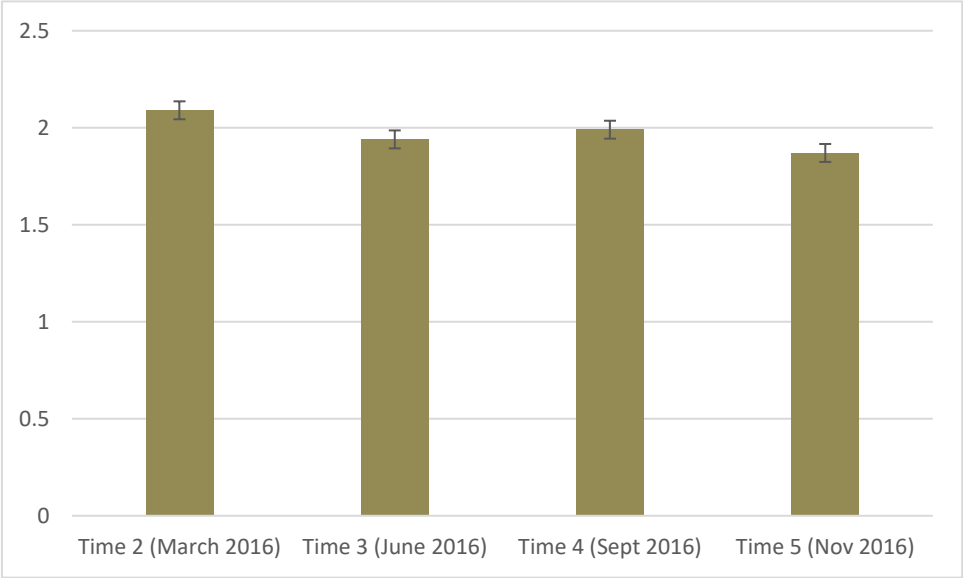


Figure 2: Average Mathematical Creativity scores – Grade six (2016)

Grade 8 Mathematical Creativity

The results of paired-samples t-tests for grade eight are shown in Table 9. The mathematical creativity of this cohort was assessed three times in 2016, and once in 2018.

Table 9: Mathematical Creativity Paired t-tests – Grade eight (2016)/Grade ten (2018)

	Time 2 *(March 2016)*	Time 3 *(June 2016)*	Time 4 *(Sept 2016)*	Time 5 *(Nov 2016)*	Time 6 *(June 2018)*
Time 2	---				
Time 3	---	---			
Time 4	---	$t(34) = -0.31$ $\eta^2 = 0.003$	---		
Time 5	---	$t(45) = -1.93$ $\eta^2 = 0.08$	$t(62) = -2.45$* $\eta^2 = 0.09$	---	
Time 6	---	$t(35) = 2.87$* $\eta^2 = 0.19$	$t(53) = 4.41$* $\eta^2 = 0.27$	$t(55) = 4.84$* $\eta^2 = 0.30$	---

Notes:

Table reports t-statistics for the relevant paired t-tests. * denotes $p \leq 0.05$

η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988)

For students who were in grade eight in 2016, and who progressed to grade ten in 2018 (Table 9: Figure 3), there were statistically significant *declines* in mathematical creativity between periods T4 and T5 (in 2016) as well as significant *increases* between periods T3 (2016) and T6 (2018); T4 (2016) and T6 (2018), and; T5 (2016) and T6 (2018), see Figure 3. Hypothesis 4 (grade eight, 2016) is not supported.

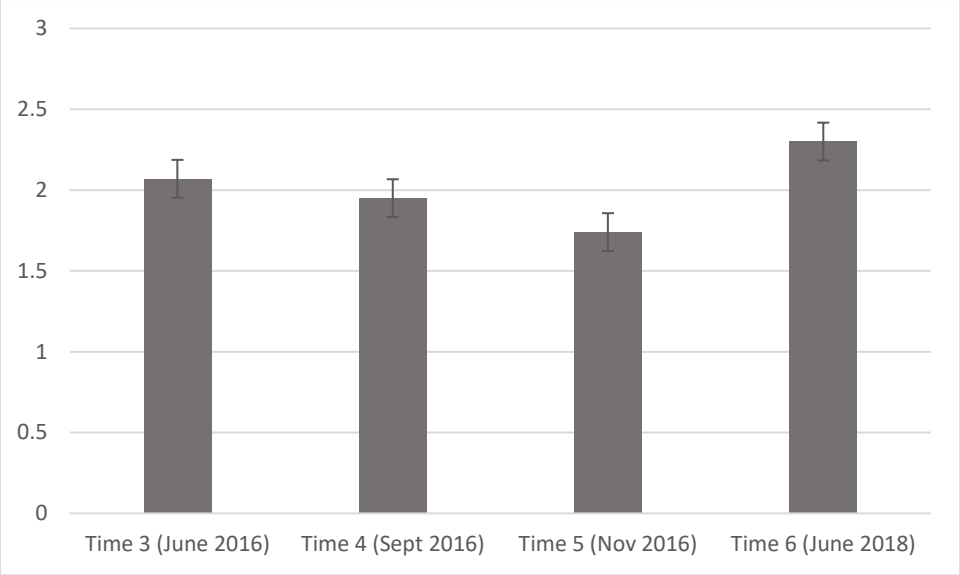


Figure 3: Average Mathematical Creativity Scores – Grade eight (2016)/Grade ten (2018)

Grade 9 Mathematical Creativity

The results of paired-samples t-tests for the available time periods for grade nine are shown in Table 10. The mathematical creativity of this cohort was assessed two times in 2016, and once in 2018.

Table 10: Mathematical Creativity Paired t-tests – Grade nine (2016)/Grade eleven (2018)

	Time 2 *(March 2016)*	Time 3 *(June 2016)*	Time 4 *(Sept 2016)*	Time 5 *(Nov 2016)*	Time 6 *(June 2018)*
Time 2	---				
Time 3	---	---			
Time 4	---	$t(134) = -2.20$* $\eta^2 = 0.03$	---		
Time 5	---	---	---	---	
Time 6	---	$t(89) = 1.95$	$t(75) = 2.88$*	---	---

	$\eta^2 = 0.04$	$\eta^2 = 0.10$

Notes:

Table reports t-statistics for the relevant paired t-tests. * denotes $p \leq 0.05$

η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988)

For students who were in grade nine in 2016, and who progressed to grade eleven in 2018 (Table 10: Figure 4), there was a statistically significant decline in mathematical creativity between periods T3 and T4 (in 2016) as well as a significant increase between periods T3 (2016) and T6 (2018). Hypothesis 4 (grade nine, 2016) is again not supported.

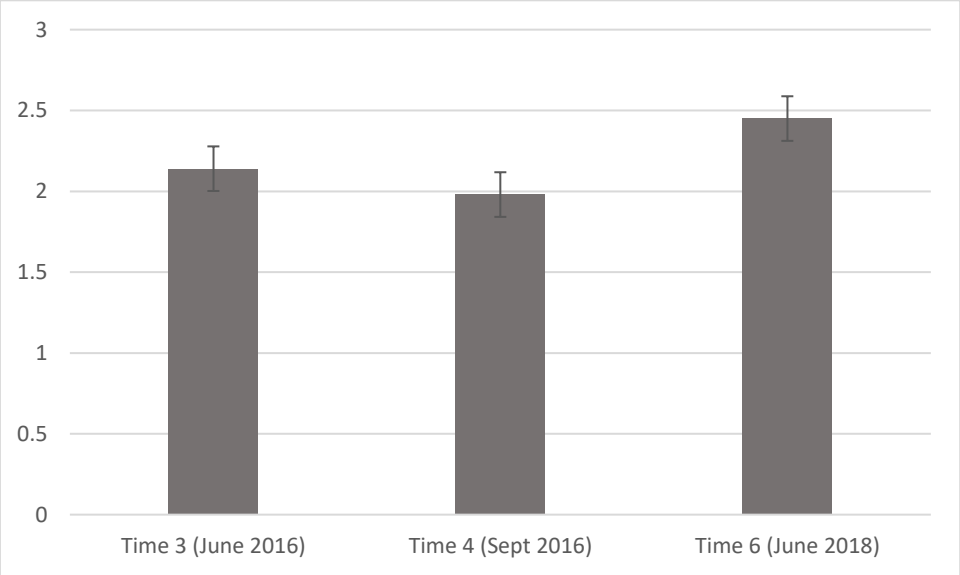


Figure 4: Average Mathematical Creativity Scores – Grade nine (2016)/Grade eleven (2018)

Grade 10 Mathematical Creativity

The results of paired-samples t-tests for grade ten are shown in Table 11. The mathematical creativity of this cohort was assessed four times in 2016, and once in 2018.

Table 11: Mathematical Creativity Paired t-tests – Grade ten (2016)/Grade 12 (2018)

	Time 2 *(March 2016)*	Time 3 *(June 2016)*	Time 4 *(Sept 2016)*	Time 5 *(Nov 2016)*	Time 6 *(June 2018)*
Time 2	---				

Time 3	$t(119) = -4.45^*$ $\eta^2 = 0.14$	---			
Time 4	$t(111) = -3.96^*$ $\eta^2 = 0.12$	$t(90) = -0.14$ $\eta^2 = 0.00$	---		
Time 5	$t(114) = -6.25^*$ $\eta^2 = 0.26$	$t(94) = -3.72^*$ $\eta^2 = 0.13$	$t(86) = -3.20^*$ $\eta^2 = 0.11$	---	
Time 6	$t(87) = -0.19$ $\eta^2 = 0.00$	$t(72) = 2.50^*$ $\eta^2 = 0.08$	$t(65) = 3.13^*$ $\eta^2 = 0.13$	$t(71) = 7.56^*$ $\eta^2 = 0.45$	---

Notes:

1. Table reports t-statistics for the relevant paired t-tests. * denotes $p \leq 0.05$
2. η^2 effect size: .01 = small; .06 = medium; .14 = large (Cohen, 1988)

For students who were in grade ten in 2016 and progressed to grade 12 in 2018 (Table 11), there were statistically significant *declines* in mathematical creativity between multiple time periods in 2016, as well as significant *increases* between periods T3, T4 and T5 (2016) and T6 (2018) see Figure 5. Hypothesis 4 (grade ten, 2016) is again not supported.

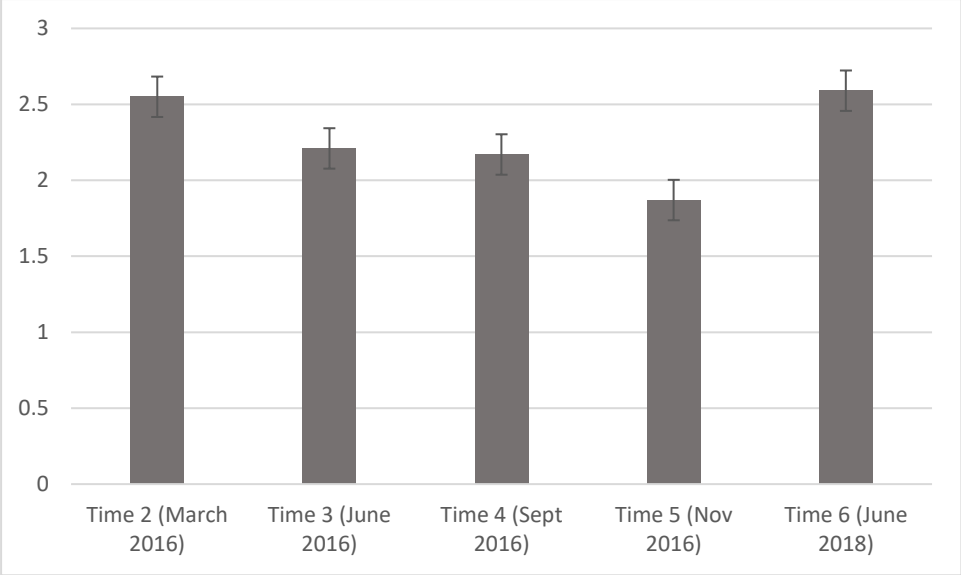


Figure 5: Average Mathematical Creativity Scores – Grade ten (2016)/Grade 12 (2018)

DISCUSSION

Notwithstanding a number of studies conducted on various aspects of the developmental trajectory of creativity, there remains considerable uncertainty about the nature and development of creativity in school-aged children (Chang et. al., 2017; Kim & Pierce, 2013). This extends to the developmental trajectory of mathematical creativity (Haavold, 2018). With an increasing focus on STEM subjects in the wake of the Fourth Industrial Revolution, and in the context of a broader digital transformation, it is important to understand the impact of school education on STEM-based creativity.

In this study, we asked the overarching research question what is the impact of school education, in its broadest sense (e.g. pedagogy, environment, classroom practices), on the development of STEM-based creativity in children? We sought to explore this by looking more specifically at mathematical creativity and aspects of school education, including subject knowledge, and developmental factors both within and between different grade levels. Drawing on the known associations between creativity and domain knowledge generally (e.g. Kaufman, Glăveanu, & Baer, 2017), in STEM (e.g. Cropley & Kaufman, 2019), and in mathematics (e.g. Sak et al, 2017), we hypothesised that, in any given grade level, we would find a positive relationship between a student's mathematical ability (as represented by their mathematics GPA), and their mathematical creativity. This hypothesis (H1) was largely supported by our data (only grade 12 did not reach significance). In simple

terms, for all grades but 12, the better that students are at mathematics, the greater their ability to express creativity in mathematics. This suggests a broadly positive relationship between the students' school education and their mathematical creativity.

We then examined the relationship between mathematical ability (GPA) and mathematical creativity more closely, hypothesising (H2) that students grouped by low, medium, and high mathematics GPA would show a corresponding increasing ability in mathematical creativity. Students with high mathematics GPAs, in other words, would be the most mathematically creative. This hypothesis was also supported by our data, across all grade levels in both 2016 and 2018. Together, these results are broadly consistent with Haavold (2018). Although the results are significant, and support domain-specific models of creativity (see Kaufman, Glăveanu, & Baer, 2017), they do not shed much light on the question of developmental trajectories of creativity.

To see if the positive relationship between mathematical creativity and mathematical ability extended to a more general age/grade level relationship (i.e., H3: do older, more experienced students have higher mathematical creativity?), we also examined our data by grade level, finding a positive relationship for the 2016 data (grades six to 10), but no relationship for 2018 data (grades nine to 12). Although there was no interaction effect between mathematics GPA and grade level for either the 2016 or the 2018 data, this result lends weight to the developmental notion that some of a student's ability to express mathematical creativity may result more generally from their cognitive maturity (as opposed to their greater mathematical knowledge) in line with Piaget's stages of cognitive development (e.g. Piaget & Inhelder, 1969). Furthermore, while this relationship is positive, and significant, in the first three years of high school (grade 8-10), the relationship appears to diminish in the latter stages of high school (still increasing, but not achieving significance – see Table 3). In other words, for children up to about age 15/16 (grade 10), both age and GPA play a positive role in their mathematical creativity. Beyond age 15/16, however, grade level (and therefore age) does not play a significant role in students' mathematical creativity. This might suggest that school education, in a broad sense, has a positive impact on mathematical creativity up to about age 15/16, but is neutral beyond that.

These results contrast to more general studies of developmental trends in divergent thinking. Torrance's (1968) seminal paper proposed that the development of creativity is a

non-linear process, with "slumps" at various ages. More recent studies, for example Camp, (1994); Krampen, Freilinger, and Wilmes, (1988); Smith and Carlsson, (1990), also report developmental slumps, while Kim (2011) found declines in elements (fluency and originality) of divergent thinking, especially in high school. A recent analysis of developmental trends in creativity (Barbot, Lubart, & Besançon, 2016), describes "peaks, slumps and bumps".

Cropley (2001) explained these non-linear developmental patterns by echoing the work of Piaget and Inhelder (1969), proposing that slumps and surges in children's creativity may be driven both by how much school a child has completed (in other words, the *environment*) and by age-related cognitive changes (e.g. changes from *preoperational* to *operational* thought, or from *egocentric* to *socio-centric* thinking). Barbot, Lubart, and Besançon (2016) propose an "optimal fit" model which supports the idea of a highly individual and somewhat fluid developmental trajectory. These models acknowledge that creativity is domain-specific, that it requires a developing level of both attitudes and skills, and that creativity changes over time. In other words, creativity develops along a highly individualised pathway, reiterating Vygotsky (2004) and Sawyer (2003). Most recently, Chang et. al. (2017) suggested that a particular driver of the developmental patterns observed in empirical studies may be the *transitions* that students experience in their education. For example, moving from elementary school to high school, and even from junior to senior high school, may affect creativity as much as changes in age and cognitive development (p. 114).

In the findings for the between-groups tests (H2 and H3), it is also important to consider the limitations of the cross-sectional design used for this part of the study. We cannot rule that out differences across grade levels may be due to differences in the life experiences and education of the students in each group.

The final test in this study (H4), and one intended to explore a perceived gap in research on developmental trends in creativity, was to examine mathematical creativity *within different grade levels*. In other words, the longitudinal, developmental trends of creativity in specific cohorts. While the preceding tests suggest a generally positive relationship between grade level (and therefore school education) and mathematical creativity, an important aim of this study was to form a more differentiated picture of mathematical creativity *within* the course of any given school year/grade level.

We hypothesised that the within-year effect of school education on mathematical creativity would be no different to the between-years relationships. If mathematical creativity increases across high school, then we would assume that it increases steadily within each grade level, as well as from one grade to the next. The data, comprising a longitudinal study of four cohorts of students, suggests a rather different story. Only in grade six (2016) did the data *not show* a statistically significant *decrease* in mathematical creativity within the grade level. Even then, for the grade six data, scores decreased from T2 (March) to T5 (November), albeit not significantly. For grades eight, nine, and ten (2016), however, mathematical creativity declined in every time period throughout the year. In multiple instances these declines are statistically significant within the grade level. The most compelling of these is the result for grade ten (2016), for which only one interval out of six did not show a statistically significant decline in creativity.

Also of interest in these results is the fact that, for the transitions from the end of grades eight, nine, ten (November 2016) to the middle of grades ten, eleven, 12 (June 2018), the recovery of mathematical creativity scores was positive and statistically significant. Furthermore, the change from the mid-point of grades eight, nine, ten (June 2016) to the mid-point of grades ten, eleven, 12 (June 2018) was positive (and significant) for grade eight and ten.

This latter set of (within-year) results *did not support* our hypothesis that student mathematical creativity will increase *during* each grade level but suggests a very interesting phenomenon. Within the grade levels studied, mathematical creativity scores decline as the school year progresses, before recovering one-and-a-half to two years later. We expect the observed recovery, based on support for our hypothesis that age/grade level and mathematics GPA are positively related year-on-year, however there are worrying questions embedded in these results. First, why is student mathematical creativity declining within grade levels? Second, is the students' mathematical creativity being dragged down *across* different grade levels by this phenomenon? In other words, if the within-grade decline was not present, would student mathematical creativity be *even higher* as they progress through their high school careers? Is their mathematical creativity being adversely affected by something that occurs *within* each school year, and which is a function of where, when or how students are

educated? Are studies of between-years creativity in school-age children masking some within-year effect?

A key consideration is, of course, why this within-year decline may be occurring. Rhodes' (1961) 4Ps can be used to examine possible reasons, above and beyond any specific testing fatigue that might be present. In terms of the *Person* (the students' personal properties, motivation, and affect) the within-year decline in mathematical creativity may be explained by decreased student enthusiasm and, depending on the teacher and school, potentially self-efficacy, and openness over the course of a school year. These, in turn, may be manifestations of a more general fatigue, both physical and cognitive, that accumulates over the course of the school year (and possibly also fatigue in relation to the tests of creativity that were administered). In terms of the *Process* – especially, divergent thinking – the within-year decline may be explained by a general shift over the school year towards convergent thinking as end-of-year assessments draw closer. This may reflect an interaction with *Press* (Environment), and with changes in *Process* driven by an environment which is increasingly propelled by the need to achieve good results in traditional forms of summative assessment (for the school in question, at least 50% of student grades are determined by end-of-year assessments). In other words, at the start of any given school year, there may be less pressure and focus on end of year results, and therefore more scope for a more creativity-favouring environment that fosters divergent thinking. This also suggests that the role of creativity-facilitating aspects of teacher classroom behaviour (e.g. Soh, 2018; Cropley, 2018) may be both critical, and may change unfavourably as the school year progresses.

The final element that may help to explain the within-year decline in mathematical creativity is *Product*. A general shift across the school year from a more open, relaxed environment to a more demanding, results-oriented environment would likely foster a shift from divergent thinking to convergent thinking. This, in turn, might be expected to impact on the outcomes students produce, with the early stages of the year leading to more creative outcomes (i.e., with greater scope for novelty), but the latter stages favouring more convergent (and therefore potentially less original) outcomes. This is one of the reasons the Consensual Assessment Technique (CAT; Amabile, 1982) was used in this study. Returning to the original research question, our data suggest that, when viewed through a *within-year*

lens, where, when and how children are educated may have an unexpected negative impact on mathematical creativity.

Of course, there are limitations in the present study that may also help to explain the results obtained. Perhaps chief among these is the potential impact of individual classroom environments. Even within a grade level, the data represented in this study come from more than one classroom/teacher. Many variables fall outside what can be reasonably controlled in a study of this type. An additional, potential limitation of this research centres on the characteristics of the school where the study was undertaken. The school in question is, for example, a fee-paying, private school. Socio-demographic factors such as these may therefore contribute to the impact of the hypothesised *Process* drivers detailed above. Not only would it be ideal to replicate these findings in a different type of school, but it would also be important to determine if it is possible to extrapolate to other countries and – especially – other cultures. Finally, the within-year declines may also be an artefact of the *complexity* of the mathematical problem presented at each time period, and even the time limit imposed on test. It is possible, for example, that stimulus at Time 2 ("8") is mathematically more complex than the stimulus at Time 4 ("-5"). This explanation is somewhat offset by the fact that if we compare scores in June 2016 (Time 3, stimulus "13") and June 2018 (Time 6, stimulus "3.66") for students in grades nine and 10 (i.e. comparing students of the same ability, at the same time point in the school year) we find that creativity scores *increased* in both cases, despite a possible increase in the complexity of the stimulus (see Table 7). Nevertheless, the complexity of the maths task used at each time period, and the possible impact on creativity, warrants further research.

Even given these considerations, the data present a compelling picture, both confirming between-groups expectations for mathematical creativity yet also suggesting ample scope to address personal, procedural, and environmental factors that may impede the development of mathematical (and indeed other forms of) creativity in schools.

In terms of developmental trajectories of mathematical creativity, the evidence in this study suggests a year-on-year statistically significant increase up to grade ten, with a likely increase beyond that. This is broadly consistent with the existing general, developmental models of creativity discussed earlier. This seems to be driven by increased mathematical ability and, to some degree, increased maturity. All of this, however, is set against within-

year declines, leading to a saw-tooth pattern of mathematical creativity growth that is akin to a cycle of "two steps forward, one step back." It might be said, therefore, that increases in student mathematical creativity in high school occur both *because of* the school environment and *in spite of* the school environment!

CONCLUSIONS

This study supports a positive relationship between mathematical ability and mathematical creativity, for students across grades six through to 12, consistent with expectations. The study further suggests, somewhat contrary to other findings, that mathematical creativity is positively associated with age. However, the study also presents a surprising pattern of *within-grade declines* in mathematical creativity over the course of the school year. These declines may be driven by a combination of the accumulation of physical and cognitive fatigue, with consequences for self-efficacy and enthusiasm, as well as the interaction between the general educational environment, cognitive processes and outcomes. Further investigation is certainly warranted.

The implications for the development of [mathematical] creativity in schools are important, especially in an era of digital transformation which has seen the rise of creativity and problem solving as key 21st century skills/competencies. Perhaps chief among these is the fact that schools wishing to develop the creativity of their students must consciously manage the interaction of person, process, product, and environment for both students and teachers. It may not be enough simply to develop skills in divergent thinking, and it may be insufficient merely to foster self-efficacy, motivation, and curiosity. Unless these facets of creativity are developed and deployed in a favourable school environment, the gains in some areas may be wiped out by the losses in others.

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Appendix P: Database search for key terms used in literature

Database	Key words	Results
A+ Education. All databases selected	Math/s/mathematics/math/s/anxiety Creativity Teachers/teachers attitudes STEM Anxiety Gender/sex	895- 74 abstracts read 25 considered appropriate
EBSCOHOST All databases selected	Creative/creativity Attitude change Teacher/s	165 responses Added the word 'creativity intervention' = 1 response
EBSCOHOST All databases selected	Math/s/mathematics/math/s/anxiety Attitude change Teacher/s creativity	524 responses – searched within for 'creativity intervention' = 5 responses
Education database/ ProQuest central All databases selected	Math/s/mathematics/math/s/anxiety Gender/sex Creativity	344 results- search within (attitudes) = 263 results. Titles scanned read 10 abstracts and 3 were selected
ProQuest Dissertations & Theses Global All databases selected	Math/s/mathematics/math/s/anxiety Creativity intervention Teachers/teachers attitudes Gender/sex	7 results with all key words in the abstract
PubMed All databases selected	Math/s/mathematics/math/s/anxiety Creativity	15 responses = 1 relevant

	Gender/sex	
PubMed All databases selected	Math/s/mathematics/math/s/anxiety Creativity Gender/sex	20 responses = 4 relevant
Google scholar	Math/s/mathematics/math/s/anxiety Creativity Teachers/teachers attitudes STEM Anxiety Gender/sex	Scanned for relevance.

A systematic database search was conducted on the 8th of April 2017 using the EBSCOHOST database and selecting all databases within.

Key words included Mathematics AND attitude change AND teachers. 824 responses were returned. Creativity was added to the search resulting in 5 responses. No date limit was set initially because attitude change research dates for 50 years as does creativity.

It was decided to eliminate ‘creativity’. Instead the researcher read through the 824 Abstracts and broadened the readings to include other STEM based articles. A key point was addressing teacher attitude change and looking for ‘creative interventions’ despite them being explicitly stated. Further to this initial search subsequent searches in 2017, 2018 and 2019 on the abovementioned databases were conducted.