Mathematics Teachers' Beliefs and Pedagogical Approaches Regarding Creativity Within a Novel STEM Creativity Framework

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Creativity is a task-specific construct that exhibits diverse characteristics depending on the context it operates in. Currently, there is little consensus on how creativity can be defined and taught within STEM education. In this study, mathematics teachers' beliefs about STEM creativity and their pedagogical approaches to teaching creativity within a novel STEM creativity framework have been explored. Results show that mathematics teachers have a variety of beliefs and practices about creativity that can be grouped into four pedagogical themes: exposure, exploration, experimentation, and execution.

Science, Technology, Engineering, and Mathematics (STEM) education has become widespread since the beginning of the 21st century. In STEM, creativity is identified as a key skill by various educational bodies including the Organisation for Economic Co-operation and Development (OECD), and the *Australian Curriculum: Mathematics (v9.0)* (Australian Curriculum Assessment and Reporting Authority [ACARA], 2022). http://www.australiancurriculum.edu.au/Mathematics/Curriculum/F-102022) addresses critical and creative thinking as a 'general capability' that should be developed across all learning areas. Despite the popularity of STEM programs, there is a scarcity of studies that examine the teaching of creativity in STEM learning. Additionally, the lack of consensus on what STEM education is and teachers' understandings of STEM and creativity within their teaching areas present further possibilities, creating the necessity of examining the characteristics of creativity in STEM. The aim of the study reported here was to explore mathematics teachers' beliefs and pedagogical approaches regarding creativity within the parameters of a novel STEM creativity framework developed specifically to improve creativity skills in STEM education.

Literature Review

STEM education is the integrated education of science, technology, engineering, and mathematics, in order to create a multidisciplinary curriculum with various objectives. There are multiple ways to define STEM education, and little consensus exists on what STEM education is and how it should be implemented (Falloon et al., 2020). STEM education can be considered as a loosely defined domain that can include studies of individual areas, a clearly defined domain that only includes cross-disciplinary study, or even only educational projects that include all four areas that make up STEM. Similar to STEM education, creativity is also a phenomenon that has several definitions with emphasis on its various aspects. Zabelina (2018) defined creativity as an ability of "producing work that is both novel and meaningful or useful" without specifying an end product. Smith and Henriksen (2016) see creativity as "developing ideas and/or objects that are novel (original) or interesting, effective (or useful), and have a certain aesthetic sensibility as a whole". A common theme among the various definitions is that creativity is regarded as a set of skills and processes, which may include developing ideas and systems that possess certain qualities that do not necessarily translate into a tangible product.

In the Australian Curriculum (ACARA, 2022), creativity is linked with critical thinking and seen as part of the seven 'General Capabilities' needed across all learning areas. It positions creativity in a matrix that contains individual learning areas and cross-curriculum priorities that are meant to be integrated in each learning area, which includes STEM learning areas. A

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learning continuum for critical and creative thinking is in place, indicating what critical and creative thinking may look like on different levels of development from Learning Continuum Level 1 (foundation) to Level 6 (grade 10). Critical and Creative Thinking is organised into four elements; inquiring, generating, analysing, and reflecting, each of which is further divided into sub-elements that specify the skills students develop within the individual elements. The implementation of the Critical and Creative Thinking general capability in the classroom is not consistent (Skourdoumbis, 2016).

In school classrooms, opportunities for creative expression are always present, which allows for the possibility of multiple definitions of creativity existing side by side. However, it is also necessary for creativity to have domain-specific definitions. Creativity in an artistic domain is different from creativity in a scientific domain, as well as the exact creative skills that constitute what makes a musician or scientist (Sternberg, 2020), a phenomenon that is also observed in STEM. Creativity is crucial for innovation in STEM; however, despite its significance, there is no definition of creativity specific to STEM education (Stretch & Roehrig, 2021), and education policies in several countries do not feature aspects of creativity in STEM learning (Stylianidou et al., 2018). Stretch & Roehrig (2021) argued that even though young people possess mathematics and science skills, their creativity skills remain lacking. This presents a need to define what creativity looks like in STEM education and how it can be taught.

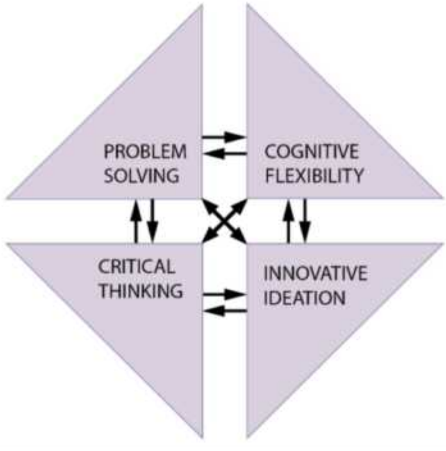
This paper reports part of a doctorate study on teachers' beliefs and pedagogical approaches regarding creativity in STEM education. The researcher draws on the literature to draft a STEM creativity framework. Acknowledging that some definitions of creativity may look different within the parameters of STEM education, this paper reports preliminary findings on the framework in understanding mathematics teachers' beliefs and pedagogical approaches regarding creativity.

A Novel Framework for STEM Creativity

In this study, a STEM creativity framework containing four specific elements is proposed, which, as a cluster, provides a working definition of STEM creativity: problem solving, critical thinking, innovative ideation, and cognitive flexibility (Figure 1); each element is drawn from aspects of creativity identified in the literature. The four elements are designed to be in interaction with each other in a STEM learning program and not to be implemented individually in a siloed style; all elements need to be present in a program in order for the framework to be implemented effectively. The framework was designed in light of existing creativity frameworks, current literature, the critical and creative general capability of the Australian curriculum, and the experiential learning theory.

Figure 1

STEM Creativity Framework



Problem solving is considered an essential element of STEM creativity; the positive impact of problem solving in STEM disciplines on student creativity and development of enquiry skills is acknowledged on policies and a survey of STEM instructors' perspectives across numerous European nations (Stylianidou et al., 2018. The contribution of problem solving to creativity in STEM education can also be linked to the requirement of integrating information from multiple sources during the problem-solving process (Wu & Koutstaal, 2020).

Various definitions have been proposed for critical thinking. Scriven and Paul (1987) defined critical thinking as a process of conceptualisation, application, analysis, synthesis, and evaluation of information. Critical thinking is a core educational goal whose importance has been widely acknowledged, specifically in STEM learning environments. The importance of critical thinking in creativity, have been examined by several scholars to date; some researchers recommended the integration of critical thinking and creativity, while others considered them as distinct processes (Wechsler et al., 2018).

Ideation is a key component of creativity and generating ideas is an indispensable process in STEM contexts (Hite et al., 2016) and hence, a significant aspect of STEM education is equipping students to be able to respond to problems. Ideation processes entail various aspects including the number of ideas that are generated, their variety and level of detail, and the originality of the ideas, that is, the level of innovation (Nijstad et al., 2010), all of which could have implications in the development of learning materials that target ideation skills. In this draft framework ideation is required to be innovative; in the process of ideation, many people refer to existing knowledge and concepts, and tend to favour generating accessible ideas; hence, it is important to distinguish between innovative and easily accessible ideation.

Cognitive flexibility is defined by Spiro (1988) as the ability of a person to restructure and adapt their knowledge in various ways in response to changing requirements or situations, which is a crucial ability specifically in STEM learning environments. Similarly, according to Nijstad et al. (2010), cognitive flexibility is "the ease with which people can switch to a different approach or consider a different perspective" (p. 42). Multiple studies found a positive relationship between creativity and cognitive flexibility. Therefore, it can be suggested that cognitive flexibility is a fundamental aspect of creativity and that it is present in the process of generating creative alternatives to problems.

Method

Potential participants who had experience teaching mathematics and at least one additional STEM discipline were invited to participate in a semi-structured interview. Participants, selected via snowball sampling, consisted of ten teachers; the majority of whom completed a qualification beyond initial teacher training. The ages of the participants ranged from 31 to 71. The participants' teaching experience ranged from 4 to 30+ years; the majority were experienced educators with over 20 years of teaching practice, and all participants taught student cohorts of every secondary grade. In line with the recruitment criterion, all participants had experience teaching one or more STEM disciplines in addition to mathematics: four participants taught mathematics and science, two mathematics, technology, and engineering, and a further two taught mathematics, science, and technology. Two participants taught all STEM disciplines.

Interviews lasted approximately 30–45 minutes; the interview questions ranged from introductory questions that seek to elicit information regarding teachers' attitudes and pedagogical approaches to creativity in STEM education to questions that aim to understand teachers' opinions on how to deliver the four STEM creativity skills. Interviews were transcribed using an online transcription tool and the transcripts were available to participants to review or edit their responses until the time interview data analysis commences. NVivo version 10 was used to code the qualitative interview data thematically. Data was coded according to categories. When data was recorded into NVivo, all interview participants were assigned a generic identifier and number.

Results

An evident difference between the participants' understanding of creativity is the distinction between participants with technology and/or engineering teaching experience (coded TE) and participants with science teaching experience (coded SI). Teachers with engineering and technology teaching experience had a more concrete and results-based approach to teaching creativity, whereas teachers with science experience did not consider a tangible end result or product as a requirement of creativity. This approach could be linked to the nature of the individual disciplines as well as the educational backgrounds of the respondents. The views of the two participants who had experience teaching all four STEM learning areas also aligned primarily with the participants with technology and/or engineering teaching experience. This distinction was evident in all responses to all questions.

For all TE respondents, a practical aspect is an essential element of what creativity is, and the creative process is meant to culminate in an end result in the form of a physical object or another product. This suggests that creativity on a purely theoretical level is not of the same level of sophistication, and a creative act can only be considered creative if it serves a purpose. Furthermore, according to TE teachers, creativity appears to be a tool to arrive at a better solution or response. Overall, TE teachers attributed many factors to what constitutes creativity that largely aligned with each other, and all of them stated specific criteria that required for a task or tasks to be considered creative. This contrasts with the views of SI teachers, who had a more open and fluid understanding of what creativity means and did not necessarily link it to the production of a visible product or end result. All SI respondents viewed the simple act of thinking in a different way or adapting a different approach when looking at things as creative acts. SI teachers viewed creativity as a general skill beneficial for the holistic development of a student, or a certain approach to academic and non-academic aspects of life, and indicated that creativity is personal; even if a creative act is insignificant in comparison to many other creative acts, it is still creativity for the specific student who undertook the creative act. Nevertheless, all SI teachers stated that while creativity in the mathematics and science domains do not require a product, there should still be a benefit for a student to undertake an act of creativity.

All respondents mentioned the importance of possessing base knowledge to practise creativity, and specified that in order to practise creativity, students need to acquire a knowledge and skill base, highlighting the task-specific nature of creativity. The process of teaching creativity commences with the introduction of new knowledge, skills, and perspectives to students. Base knowledge can be acquired through various methods such as direct teacher instruction and exposing students to examples of relevant projects. Respondents also identified potential barriers to students acquiring base knowledge and skills, including lack of teacher knowledge and technological literacy, availability of equipment in schools, and curricular limitations. Another significant factor that was identified in the interviewees' responses was creating an environment for creativity to be enabled and supported. This factor was elaborated by every respondent in largely aligning but individual ways. Pedagogical methods to achieve the right environment for creativity practice included collaborative work, peer feedback, and discussions in whole-class and small group settings, as well as developing open-ended learning experiences and assessment items that would allow learners to express and develop their creativity. Additionally, all respondents stated that creating a 'safe space' is essential via encouraging students to share their thoughts and perspectives, and ensuring every learner's voice is heard.

Pedagogical practices on how to teach creativity did not differ significantly across the two groups. All respondents stated that creativity can be taught, even though the techniques they used to teach creativity differed according to their teaching areas. One of the practices mentioned by all respondents was an experimental approach to learning, and the importance of students coming up with multiple options, approaches, looking from different perspectives, and trying out new things as factors in expressing and developing creativity. Approaches of trial and error, learning through making mistakes to develop new possibilities and ideas, and intellectual risk-taking are some of the factors in developing creativity in students. Experimental learning should also be supported through open-ended tasks and assessment items that give learners enough scope to try different possibilities, as mentioned by several respondents in both teaching domains. However, respondents also noted that scaffolding in both learning and assessment is also necessary to maintain the exploration in the right direction and ensure learning goals are met.

Respondents from both the TE and SI groups stated that contextualisation and application of learning is an essential pedagogical approach to teach creativity in STEM learning areas. This took multiple forms; however, in all cases, entailed some manner of connection between the newly acquired knowledge and skills and an aim that is to be responded to; an application area for the contextualisation of the new knowledge and skills. The implementation of this approach depended on individual learning areas, ranging from practical, hands-on tasks and assessment items in technology and engineering, student-created and guided experiments in science, and solving hypothetical problems in mathematics. All SI respondents also stated that creating scope for students to express themselves is important in the application of learning.

Each participant had unique responses regarding the four elements of STEM creativity, which suggests that despite their experiences throughout STEM learning areas, the exact definition of the elements and how they can be taught effectively may look different in each discipline. It was also noted that all participants referred, directly and indirectly, to all elements of the STEM creativity framework when they spoke about creativity even at the earlier stages of the interviews, before targeted questions about the elements of STEM creativity were directed to them. Furthermore, the respondents made individual connections between the four elements in many cases. These observations may signify that the participants teach the four elements, separately and concurrently, even when they do not do it consciously. A summary of the participants' beliefs and pedagogical approaches regarding each element is presented below.

Problem solving: All TE teachers had a clear outlook on what problem solving is and stated that problem solving is responding to a need or a situation. Conversely, SI respondents had a broader perspective on what problem solving can mean in mathematics and science. One respondent made a direct link to creativity and stated that problem solving occurs when there is a question that requires creativity, and another respondent noted that "pure creativity" comes into play when there is no precedent of a solution that would respond to a problem. In terms of pedagogical approaches, two TE and two SI respondents identified brainstorming and ideation tasks as precursors of problem-solving tasks, indicating a process of skill-building, and argued that problem solving as a creative practice is a skill that is learned and developed over time with practice, which allows learners to refer to prior learning as they build a skillset. Three TE respondents noted that teaching problem solving effectively entails giving students unguided, or minimally guided, challenges. Additionally, two SI respondents noted that teaching problem solving also requires the teacher to formulate the 'right' kind of problems.

Critical thinking: As opposed to problem solving, SI teachers elaborated on critical thinking more than TE teachers, and all participants offered distinct responses. One SI respondent stated that critical thinking is "a deeper level of problem solving" and added that it involves looking further into the question and using different approaches. Another stated that critical thinking means not taking anything at face value, and added that when learners receive new information, they should scrutinise its meanings beyond the surface. TE respondents' definitions of critical thinking entailed the analysis of the feasibility and producibility of an idea or product. In terms of pedagogical approaches, the respondents aligned critical thinking most closely with tasks that require students to explore new knowledge and skills. Two TE teachers stated that in technology education, critical thinking can be taught through evaluation and testing tasks, where learners examine their own designs according to set criteria. all SI respondents stated that discussions are essential to initiating and improving critical thinking.

Innovative ideation: Most TE participants defined ideation as developing multiple possible solutions to a problem or situation. As opposed to TE domain teachers, SI teachers approached ideation on a more abstract level and not necessarily as a process undertaken to directly respond to a problem or need. One respondent with experience every STEM learning area stated that ideation does not only involve generating options, but also comparing them to each other in order to produce the most optimum final option. Respondents identified brainstorming activities as effective idea generation processes, and recommended brainstorming to take place in groups to enable students to be inspired by each other. The majority of respondents across the two groups specified the need for a safe space for ideation to be practised in a group setting. However, each respondent had a different insight into how it can be taught best. Three TE respondents stated that learners should be offered a scaffold to engage with ideation, and two SI respondents highlighted the benefit for students considering other students' perspectives as an effective learning technique.

Cognitive flexibility: Most respondents were unaware of the term cognitive flexibility; however, they all referred to the individual elements of what constitutes it when asked about their understanding of and pedagogical approaches to creativity in previous questions. Out of all respondents, only one (TE) identified an explicit teaching of cognitive flexibility in the curriculum in the form of students developing 'contingency plans' for their projects, which indicated an underrepresentation of cognitive flexibility in the curriculum. TE respondents approached the teaching of cognitive flexibility in everyday life or hypothetical scenarios, and a further TE respondent argued that cognitive flexibility can only be acquired through practice. Three SI respondents interpreted the practice of scientific cognitive flexibility as learners using knowledge to make changes to their understanding of a theory or apply knowledge in a different way. A further SI respondent stated that this practice extends beyond science, and knowledge acquired in different subjects can also be used.

All participants interpreted the interactions between the elements of the STEM creativity framework in different ways. Half of the participants indicated a certain structure, linear or cyclical, to how the elements of STEM creativity would be implemented in a unit of study, which can involve one or two elements at a time. Four participants stated that the elements can occur simultaneously and without a particular linear or cyclical order throughout the implementation of a unit of study. Out of the four elements, problem-solving emerged as the element that was the most prioritised; half of the respondents indicated that they would initiate the implementation of the elements of STEM creativity with problem solving, which could be a consideration in their pedagogical approaches.

Discussion

The pedagogical approaches and practices stated by the respondents are categorised into four themes based on interview results: *exposure, exploration, experimentation, and execution*. These themes represent the overall categories of pedagogical beliefs and practices teachers expressed, with various methods and techniques to implement them. They were identified and defined through participants' responses to the interview questions. The names of all themes except for 'execution' have been used multiple times by all participants. The execution theme was named based on the participants' use of words such as 'application' and 'putting into practice' of the newly acquired skills and knowledge within a STEM learning program.

Exposure: This initial phase entails direct instruction from the teacher in various forms and is the base knowledge phase that the respondents referred to. According to the respondents' opinions, this phase is mostly teacher guided. However, in some cases, it can be scaffolded by a teacher, but the knowledge-finding and sharing can be undertaken by the learners.

Exploration: This phase is when learners begin to internalise newly acquired knowledge and skills, make connections with prior learning, and apply critical thinking and elaborate on the new knowledge and skills. It entails student-centred knowledge finding, exchange of knowledge, discussions, and other collaborative tasks that allow the learners to digest the knowledge and skills but not 'make' anything or produce new knowledge.

Experimentation: This phase is the precursor of execution and is inspired by the exposure and exploration phases. It involves brainstorming and ideation tasks, and often takes the form of learners coming up with their own problem-solving methods or experiments. In this phase, learners begin to use the newly acquired knowledge, skills, perspectives in some shape or form that may be the same or different from what they received in the exposure and exploration stages.

Execution: This phase takes the forms of contextualisation, connecting the newly acquired knowledge and skills to real life or a hypothetical scenario, and/or producing a tangible or intangible application of creativity, creating an end result, a final product, or solving a problem.

While it was observed that half of the participants in the TE group preferred to implement these themes in a rather rigid order of exposure, exploration, experimentation, and execution, they are nevertheless movable pedagogical themes that can be applied without a certain iterative, linear, or cyclical order. Most teachers identified that even when a certain structure is present in a project, students very often go back to a previous phase to fill gaps in knowledge, skills, or complete additional tasks. Furthermore, when a theme was identified in a response, another theme was often also mentioned, or one theme was implemented with the support of one or more other themes, which suggests that the four pedagogical themes are commonly applied in conjunction with each other, and in some cases, cannot be applied without the concurrent implementation of another theme. The validation of the framework was determined via the observation that all participants mentioned every element of the framework organically without being prompted and before the questions that identify and target the individual elements of the framework. However, since the participants' classroom practices were not observed, it was not possible to ascertain how they implemented the elements of the framework.

Concluding Remarks

In this study, a novel framework for STEM creativity has been designed and discussed. The researcher's primary objective was to explore mathematics teachers' beliefs and pedagogical approaches regarding creativity within the parameters of the framework. The findings indicate that mathematics teachers believe creativity is a learned skill and interpret creativity and the elements of the STEM Creativity Framework through a range of perspectives and four pedagogical themes: exposure, exploration, experimentation, and execution. Further research on the topic is needed to observe the teachers in their classroom practice in order to identify and examine consistencies and discrepancies between interview and observation data. Additionally, classroom observations could potentially lead to further amendments to the STEM Creativity Framework. The results of this study may inform future research regarding the instruction of creativity skills in STEM education and the design and development of future STEM creativity programs. The delivery of creativity skills within a framework designed specifically for STEM education that can operate within curricular boundaries can also lead to improvements in student outcomes and future STEM careers.

Acknowledgements

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