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Developing Mathematical Creativity in Gifted and Talented Education

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Due to the increasingly complex challenges of the 21st century, creativity is more important than ever for today's students. Creativity is the driving force in the organizational innovation processes (Amabile & Pratt, 2016) that have become essential in modern economies and is widely recognized as a 21st-century skill that must be developed in students. In addition to its societal utility, creativity has many personal benefits. Creativity can enhance personal well-being, increase motivation (Amabile & Pratt, 2016), improve levels of enthusiasm and enjoyment (Davies et al., 2013), foster more positive attitudes toward learning (Cornejo-Araya & Kronborg, 2021), and strengthen academic engagement and achievement (Karwowski et al., 2020).

Although nurturing the creativity of all student populations is important, it is perhaps even more imperative when teaching students with gifts and talents. Creativity is a central factor in numerous models of giftedness (e.g., Renzulli, 2005; Sternberg, 2003; Subotnik et al., 2011), and researchers argue that creative development is a key outcome of gifted and talented programs (e.g., Reis & Peters, 2021). Unfortunately, creativity-supporting practices remain uncommon in gifted and talented programs. This may be due to the misunderstandings about creativity held by many teachers, including the belief that creativity does not apply to STEM subjects. Analyzing and debunking these misconceptions could help combat the inequity issues prevalent in gifted and talented education, as assessments measuring creativity are less biased than alternative identification methods (e.g., Torrance, 1971) and practices supporting mathematical creativity better accommodate diverse student populations (Kozlowski & Si, 2019).

continued on page 16

FEATURE ARTICLES

INSIDE THIS ISSUE

continued from page 1

Evidently, there is a gap between the value we ascribe to creativity and the implementation of educational practices that develop creativity. To address this discrepancy, researchers offer suggestions about how to support creativity. These include (a) allowing choice and exploration, (b) encouraging imagination, (c) specifically teaching creative thinking skills, (d) using diverse learning spaces and flexible scheduling, (e) minimizing competition and comparison, (f) providing formative feedback, (g) prompting self-reflection, (h) differentiating levels of scaffolding and challenge, (i) incorporating meaningful and authentic activities, and (j) providing opportunities for collaboration (Beghetto & Kaufman, 2014; Collard & Looney, 2014; Davies et al., 2013).

Creativity is highly relevant in STEM disciplines, predominantly through the application of creative problem-solving skills. In mathematics, specifically, creativity is necessary in situations where one "faces a mathematics problem for which there is no learned solution" (Schoevers et al., 2018, p. 242). Developing creative problem-solving skills also aligns with numerous frameworks of mathematical development, which unanimously emphasize authentic problem solving. Informed by contemporary scientific research on mathematical creativity, and lessons learned from a Javits grant project exploring the effects of differentiated, enriched mathematics curricula, this article explores three essential questions: (a) What is mathematical creativity? (b) How can we develop students' mathematical creativity? (c) How can educators improve their own ability to develop mathematical creativity?

What Is Mathematical Creativity?

Mathematical creativity involves either generating novel and appropriate solutions to mathematical problems (problem-solving) or constructing new problems that expand old problems (problem-construction). These skills are best assessed through open-ended problems with multiple possible solutions (Suherman & Vidákovich, 2022). Students may exhibit creativity in mathematics differently than in other fields, although some studies have found relationships between mathematical creativity and performance in creative domains such as writing and visual art (e.g., Han & Marvin, 2002).

Creativity involves a range of abilities, some general and some specific to a given discipline. Intelligence, divergent thinking (being able to generate many diverse ideas), convergent thinking (developing a single, optimal solution), and creative self-efficacy (believing you can be creative) are important across creative domains, including mathematics (de Vink et al., 2022; Karwowski et al., 2020). These general abilities are not sufficient, however, as they must interact with domain-specific skills throughout the creative process. In one study, mathematical knowledge was as important as divergent thinking in supporting mathematical creativity when solving open-ended problems, and mathematical achievement was an even stronger predictor of mathematical creativity than general creative abilities (Schoevers et al., 2018). In another study, divergent thinking skills, mathematical achievement, and students' interest in math were the strongest predictors of student-constructed mathematical word-problem creativity, with achievement demonstrating the strongest association (Jeon et al., 2011). Altogether, mathematical creativity involves a multiplicative blend of (a) mathematical knowledge and skills, (b) general intellectual abilities and thinking skills, and (c) personal characteristics and motivation. Mathematical creativity is an important contributor to academic achievement in mathematics and represents one avenue through which educators can appropriately challenge students with gifts and talents in mathematics.

How Can We Develop Students' Mathematical Creativity?

Mathematical creativity is best developed when students are encouraged to solve authentic problems with multiple solutions (Schoevers et al., 2018). Authentic learning involves realistic, relevant, and meaningful challenges, which results in more engaging and effective learning. Often, real-world problems do not have a single answer and divergent thinking is needed. Here is an example of how you might prompt divergent thinking: instead of asking what four plus four equals, you might ask how many different ways a cashier can make change resulting in $8.00. When developing these types of questions, it may help to consider the components of divergent thinking: fluency (generating a large number of ideas), flexibility (generating diverse ideas), originality (generating unique ideas), and elaboration (generating more developed ideas; Suherman & Vidákovich, 2022).

Encouraging your students to develop many diverse, unique, and detailed solutions is important, but you must also recognize convergent thinking's role. In addition to generating novel ideas, creativity involves analyzing, evaluating, and refining those ideas (Sowden et al., 2015). In one study, grade five students' performance in multiple-solution tasks was highest among students with high levels of both divergent and convergent thinking skills (de Vink et al., 2022). Lessons developed in the *Thinking Like Mathematicians: Challenging All Grade 3 Students* project emphasized whole-class discussions highlighting students' mathematical thinking, and these discussions provided opportunities to develop convergent thinking skills. For example, you might prompt students to first share the different tools or strategies they used to solve a problem and then evaluate their relative effectiveness. Importantly, avoid assuming students are familiar with divergent and convergent thinking strategies; creativity is best supported when creative thinking skills are explicitly taught (Beghetto & Kaufman, 2014).

Problem construction, or problem posing, is another important aspect of the creative process, and it includes defining problems, establishing goals, identifying constraints, and gathering information relevant to the problem (Mumford et al., 1991). In many classrooms, mathematical problems are clearly defined; students with pre-

requisite mathematical knowledge and abilities will readily understand what is being asked and what procedures are needed to arrive at a predetermined solution. Creative problem solving is not typically this straightforward, however, and students might need to determine exactly what the problem is and how it could be solved. To develop problem-constructing skills, Lewis and Colonnese (2021) suggest using "Three-Act Tasks" in which students are guided through the following stages: (a) analyze an ill-defined problem and develop a question that can be solved, (b) determine what mathematical strategies will lead to appropriate solutions, and (c) compare the effectiveness of the different pathways and solutions. Such exercises have been shown to increase fluency and flexibility in students' creative mathematical thinking. Importantly, problems must be open-ended; potential solutions, and even the problems themselves, should be free to vary.

How Can Educators Improve Their Own Ability to Develop Mathematical Creativity?

Research has outlined strategies that can develop teachers' capacity to nurture students' mathematical creativity. For example, learning environments better support creativity when teachers have opportunities to take risks, develop their own creativity, collaborate with other educators, and receive feedback aimed at improving practice (Collard & Looney, 2014). Davies et al. (2013) highlighted the importance of implementing less prescriptive learning activities, emphasizing long-term growth in creative thinking skills, modeling creativity, and ongoing reflection on one's practice. Other researchers suggest making creative thinking a central lesson objective (Tran et al., 2017), adapting pre-existing lessons (rather than starting from scratch) to better foster mathematical creativity (González & Deal, 2019), and, when working with students with varied readiness levels, differentiating lessons to provide appropriate levels of challenge for all students (Gubbins et al., 2013). For other resources, you might also consider exploring *Creativity and Education's* (2022) website. The following recommendations summarize the strategies outlined in this diverse research:

1 **Build connections with other professionals.** Find opportunities, either in-person or online, to gain support, collaborate, share ideas, and receive feedback on your practice. You can find many accessible groups on platforms such as Twitter and Edmodo.

2 **Be flexible and take risks.** Creative learning activities involve unknown outcomes, which can be simultaneously freeing and uncomfortable. Recognize uncertainty as an integral aspect of the creative process and leverage it to accommodate diverse students. For further reading, *Creative Development: Transforming Education Through Design Thinking, Innovation, and Invention* (Kelly, 2016) outlines the importance of unknown outcomes and other factors important to students' creative development.

3 **Develop and model your own creativity.** Students might not immediately understand what it means to think creatively in mathematics and could feel vulnerable doing so. Reflecting on your own creativity can provide valuable insight into your students' experiences. As you design or adapt lessons, observe how you determine goals; generate, select, and explore ideas; make associations; and evaluate your work. You might then incorporate these creative thinking skills when you model your mathematical thinking to students.

4 **Prioritize the creative process.** Although creativity has beneficial outcomes, it is not merely a means to an end; the creative process is a meaningful end itself. Because creative thinking skills take time to develop, consider highlighting growth in students' thinking as they learn how to apply mathematical creativity to different problems. An online search for "metacognitive rubrics" could offer many ideas regarding how to prompt students to reflect on their thinking.

Conclusion

Developing creative thinking abilities is important to building transferable 21st-century skills that will help in many areas of students' lives. Creative problem solving in mathematics is one domain in which these increasingly essential abilities can be developed, and implementing the strategies highlighted here will support your students in realizing their unique creative potential. Throughout our work on the *Teaching Like Mathematicians: Challenging All Grade 3 Students* project, we have identified ways in which teachers can develop their understanding of mathematical creativity and how to nurture it. We are confident that by following these suggestions, you can too. **THP**

References

A Pdf of the References cited in this article can be found on the THP webpage on www.nagc.org

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