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Let's do the Math… About Creativity and Mathematical Reasoning: A Correlational Study in Primary School Children

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Abstract
Mathematics, being a very ancient discipline, is usually seen as a formal subject that must be learned for school purposes, which is very far from creativity and fun. Also, mathematical skills are often considered a talent, so students are easily divided into gifted and not gifted, with a focus on speed and accuracy rather than encouraging the process of juggling between divergent and convergent thinking. In the present paper, we aimed at investigating the relationship between mathematical reasoning and different aspects of creative thinking, such as divergent and convergent creativity, aesthetic appreciation, and humor. To do so, 146 second and third graders in a primary school in Milan have been recruited and tested with mathematical and creative tasks. Correlational analyses showed significant positive relations between flexibility and originality dimensions of creativity and mathematical performance. Results are discussed by providing a theoretical framework about the relation between mathematics and creative skills.

Keywords: Creativity, Mathematics, Divergent Thinking, Convergent Thinking, Humor

1. Introduction

1.1 Notes on creativity

What is creativity? This is far from a simple question. Creativity turns out to be a multifaceted concept that cannot be defined univocally. Some claim it is a skill, those who claim it is a talent, those who claim it is a gift reserved for the few, those who claim it is an aspect of the artist, and those who think that is a sort of necessity. For example, Donald Winnicott, when studying the origin of creativity in children, claimed that: "The creative impulse is something that can be considered as a thing in itself, something that, of course, is necessary if the artist is to produce a work of art, but also as something that is present when anyone - baby, child, adolescent, adult, old - looks at anything healthily or does anything deliberately" (Winnicott, 1971).

Nonetheless, creativity can also be understood as an aspect of rational thought: not just a gift of a few geniuses, but a *forma mentis* possessed by all individuals in different ways. The first studies on creativity date back to the second half of the nineteenth century and take into account the biological-heritage aspect of talent. In the scientific debate, a shade of madness and irrationality was associated with a genius for a long time: the "*furor poeticus*." At the beginning of the twentieth century, other factors were included in the studies to move away from the idea of an abnormal cognition and assimilate creativity to an aspect of intelligence (Cinque, 2010). Indeed, creativity can support a person in understanding the surrounding environment and their own experience, thus playing a pivotal role in facing daily and extraordinary situations.

However, despite these two nuances of creativity, one being “artistic” and more related to the need for a personal expression, and the second being “cognitive” and associated with ideas production and problem-solving, it is possible to find common ground. Indeed, creativity is often used as synonymous with imagination, intuition, and curiosity, which are fundamental for both aspects of creativity. More specifically, "Creativity is the ability to transform the world through the intertwined action of sensoriality and logic, reason and imagination. [...] It is the ability to face and solve the variety of problems that mark everyday life, to discover the links between different experiences, to identify the connections between disjointed and opposing realities" (Minerva & Vinella, 2012).

1.2 Creativity and mathematics

It is important to introduce another significant distinction, that is between divergent and convergent thinking. The first is characterized by open-mindedness and the use of fantasy in an unlimited way. In contrast, the second refers to the critical capacity that translates the fantastic elements into a concrete form. Here, we are interested in including a third element in the equation, that is mathematics. Since the concept of creativity encompasses many meaningful nuances and fields of investigation and intervention, not many researchers explored in-depth the relationship between math and creativity. Being a very ancient and traditional discipline, math is frequently considered a static subject, linked to formalized teaching methods and then far from creativity and fun. These clichés tend to influence the vision of both students and teachers: the formers perceive mathematics mainly as a subject that they must learn but useless in everyday life; teachers on their side often find it difficult moving away from traditional teaching to avoid the risk to lose clarity and specificity (De Vecchi Galbiati, Folgieri, & Lucchiari, 2017). This way, the mathematical, conceptual system may not be seen as a universal solid language able to guide the students’ reasoning toward logic and problem solving, potentially valuable for daily problems as well as in future studies or for a job, but only as a set of rules and formalization to store for schooling purposes. In addition, mathematical skills are themselves often considered a talent, so students are easily divided, mostly implicitly, in gifted and not gifted, thus failing to support the math self-efficacy of the less talented since they are considered headed to poor academic performance in the field. Furthermore, math talent is usually measured by the speed and accuracy of the calculation, without considering how the student chose to get to the solution and thus the divergent and convergent aspects of thinking that are potentially related to creativity. All these factors often lead to dissipating the student’s curiosity about math and the related engagement.

However, different scholars and researchers supported the existence of a relationship between math and creativity. For example, Haylock (1987) speaks about “mathematical creativity,” defining it as seeing new relationships and making associations between apparently unrelated ideas. Considering the other side of the coin, creativity can help a lot in the construction of mental images (Giannoli, 2012), which facilitate the acquisition of mathematical concepts. Creativity training, being focused on the process and not on the outcome, can also increase the math self-efficacy of less gifted students, enabling them to find their way of approaching the mathematical world (Regier & Savic, 2020). Finally, Creativity is also helpful for the work of the mathematician, who is called to think, invent, and often rewrite mathematical theories, starting from the reality (the facts) that surrounds him (D’Amore & Sbaragli, 2014). Hence, why shouldn’t creativity be useful for students and teachers?

1.3. Study rationale

In the present study, we aim at investigating the relationship between mathematics and different variables related to creativity. Indeed, suppose it is true that math requires the application of routines deriving from commonly known basic rules. In that case, it is also true that both mathematicians and students need to adapt already known rules to a given problem or to find new ways to approach an insolvable one. Thus, convergent and divergent thinking are equally important, and the investigation of the cognitive underpinning of these two processes requires further research.

To better investigate such a relationship, we performed correlational research in a primary school in Milan, Italy, involving second and third-grade students. The idea came from the observation that in their everyday experience, teachers report many difficulties for students to understand problems' instructions and to solve unusual problems. This often leads to impulsively tackling the assigned tasks without paying the necessary attention to analyzing the strategies potentially practical to approach the problem. This attitude seems to be linked to the activation of a routinely way of thinking that follows a typical script:

1) Attention focused on data, which are often only marginal but that are easy to detect.
2) Identification of a solution strategy also before having completed a full understanding of the problem.
3) Implementation of a solution procedure and evaluation of the results.
4) Finalizing the solution or impasse (D'Amore, 2007).

Thus, it seems that many students, when asked to face an ambiguous or complex problem, tend to follow the previous steps automatically, with poor or no awareness about what they are doing, so to reach a solution. The use of poorly reflective thinking affects the performance and the learning process, making it difficult for students to adjust previously learned strategies to new problems or develop new strategies. Furthermore, it is more difficult to learn by errors when a learner is unaware of the logical or the cognitive path that led to mistakes.

Many educational strategies can be applied to improve learners' performance in these contexts. For example, teachers may direct students' attention on a meta-level to help them set the problem in a way to be profitably approached. Students should be taught how to select the relevant information, identify previous successful strategies, understand whether or not the available strategies are applicable in the present case, formulate ideas about new possible ways of solving, and so on (Chapman, 2008; Lucchiari, 2018). However, other strategies to encourage a dynamic and balanced interaction between reflective and automatic thinking may also be used. For instance, promoting fluid and flexible thinking through creative activities may be effective. Indeed, previous studies (Alfonso-Benlliure, Meléndez, & García-Ballesteros, 2013; Antonietti & Pizzingrilli, 2009; Sala, Vanutelli, & Lucchiari, 2019) have shown that training young students through creative thinking by verbal, visual, and motor strategies may help to develop open-minded students, ready to approach constructively new as well as ambiguous mathematical problems. These results suggest that creativity training may be effective in improving cognitive flexibility. This is defined as the ability to adopt mental strategies suitable for approaching a problem and maybe readily changing to adapt to changing task demands. It allows students to adjust appropriately to the needs posed by a teacher, for example, by analyzing a problem from multiple perspectives and testing alternative solutions to a new or ill-defined problem (Diamond, 2012; McGowan et al., 2018). In math, the cognitive flexibility may play a key role by allowing students to search and find connections between problems, topics, and concepts and fostering their abilities to see a problem from multiple perspectives and analyze data in a non-standardized fashion.

A second important topic relates to the potential presence of gender differences in creativity scores and math achievements. Women report lower achievements generally, thinking about the accomplishment gained in life about to creative jobs, artistic production, or scientific fields. However, this phenomenon has been referred to as access and, subsequently, to the opportunities that men and women have been allowed to during history. Accordingly, a different view about the motivations, the financial support, and the expectations have been assigned to the two groups (Baer & Kaufman, 2008; Runco, Cramond, & Pagnani, 2010). However, despite this background, the research conducted to investigate the presence of differences in cognitive creativity and divergent thinking reported controversial results. Still, it highlighted that there is no meaningful difference in creative potential (Antonietti & Cerioli, 1991) and, when present, it is generally in favor of girls and women: "It is unlikely that a metanalysis would show a significant overall gender difference on these tests, but it should be noted that if there were to be an overall "winner" in the numbers of studies in which one gender outperformed the other, it would be women and girls over men and boys" (Baer & Kaufman, 2008). Considering the importance of the topic, we decided to include the exploration of this issue among the purposes of the present research.

About mathematical skills, a study was conducted in Italy (Tomasetto, 2013) which showed how gender stereotypes influence this tendency to consider children more inclined to mathematics than girls and the consequent choice of girls to move towards the humanities. These data suggest that the topic needs further studies.

Summing up, the aims of this study were a) to verify the relationship between mathematics, creativity skills, aesthetic appreciation, and humor; b) to explore the presence of significant differences according to gender to both mathematical skills and creativity. To do so, 155 children of a primary school in Milan have been tested for different aspects of cognitive creativity and mathematical competencies. We hypothesized that, according to the discussed literature, girls could be more creative in creative tasks. Also, we expected that students with higher cognitive flexibility, as measured by tests on divergent thinking and other creative dimensions, would also show higher mathematical abilities.

2. Materials and methods

2.1 Participants

The sample consisted of 6 classes of the same primary school, including 155 students, 76 boys, and 79 girls. 80 of them were second-grade students, while 75 were third-grade students. The Italian primary school system starts at 6 years of age (1st grade) and lasts for five years. The average number of students in the classes was 25.83 (S.D = 1.33).

After administering the tasks, 9 students were excluded for subsequent analyses because of incomplete data. Thus, the final sample included 146 students, 68 boys, and 78 girls. 72 second graders and 74 were third graders. The school council approved the study and communicated it to the children's parents, who signed the informed consent. The study was evaluated and approved by the local ethical board.

2.2 Assessment

Both mathematical and creative tests were presented as games that required imagination and engagement. They were composed of two parts: the first one involved logical-mathematical exercises and lasted about 25 minutes, while the second consisted of divergent-thinking exercises lasting 15 minutes. The total duration of the test was about 40 minutes. The level of difficulties of the proposed tasks was adjusted to the grade of students.

2.2.1 Mathematical assessment

The logical-mathematical test consisted of 5 exercises for the second and 6 for the third graders. The exercises were taken from the INVALSI tests, which are written tests carried out by Italian students with the purpose to assess the levels of learning of some basic skills in Italian, Mathematics, and English at certain critical moments in the school curriculum. Based on the results of the INVALSI tests, indications are provided to the classes and the schools about the average skill level achieved in a given subject. Every exercise was presented in a paper-and-pencil format. Children were first explained the exercise; then there was a set time to do it. The start of a new exercise was not free: instead, it was scheduled on a general timesheet not to give any advantage to anyone (see Table 1 for details).

Table 1: The Math exercises proposed to 2nd and 3rd graders.

Pre-test	**Second-graders**	**Third-graders**
	EX. 1: Link digits to the correct faces of a dice.	EX. 1: Circle the even numbers in red and the odd numbers in green and write an example of odd numbers.
	EX. 2: Write the previous and the following numbers in the correct boxes.	EX. 2: Complete incomplete words and find which semantic category they belong to.
	EX. 3: Identify which additions are right or wrong.	EX. 3: Insert given numbers within a story in a logical order.

	EX. 4: Within pairs of numbers written in different sizes (congruent/ incongruent) circle the higher.	EX. 4: Identify which multiplications are right or wrong.
	EX. 5: Identify geometric shapes: how many triangles/rectangles… are there in the complex figure? Which is the total?	EX. 5: Real-life problem-solving: Which character cannot buy a newspaper with the owned money and why?
		EX. 6: Complete the calculation: Starting from the number in the first square, follow the arrows (backward/forward) and get to the correct number.

2.2.2 Creative assessment

The creativity assessment was divided into three tests. For second graders, the tests included:

- Incomplete figures: this task was taken from the Abbreviated Torrance Tests (ATTA, Goff, 2002), in which two incomplete drawings are presented. The instruction is to complete them by using imagination. The test is usually targeted at adult samples. We selected it since it allows a more accurate assessment of creative skills thanks to a broader number of creative indices (see 2.4.1).
- Parallel lines: this task was taken from the Torrance Test of Creative Thinking (TTCT, Torrance, 1998). We selected six pairs of lines from which the child is asked to create any type of object.
- VAST Test: we selected five pairs of black and white figures from the Visual Aesthetic Sensitivity Test (VAST: Götz, 1985). The child has to choose the figure that, according to him/her, and following the standards of aesthetic value, is the most balanced among the pairs. We chose this task since it detects an aspect of creativity more related to the artistic aesthetic.

Concerning third graders, the task included:

- Incomplete figures: same as for second graders but, in this case, children were also required to write a title down for each figure.
- VAST Test: same as for second graders but, in this case, children were also required to write a title down for each selected figure.
- Cartoon: this task was designed by the authors to assess children's sense of humor, considered one of the components of creativity (Gundry, Kickul, & Prather, 1994). Indeed, they were required to complete the dialogues of a scene.

2.3 Scoring

The dependent variables were derived as follows:

2.4.1 Second graders' performance

The mathematical performance was assessed by calculating the sum of the correct answers, and then the percentage of accuracy (Math). For what concerns creativity, 4 different scorings have been calculated for Incomplete Figures (from now on: IF) by using the standard scoring system (Manual of the Adult Torrance Test; Goff, 2002). They included fluidity, originality, elaboration, and what we called IF-Plus, which included the sum of nine indices that may or may not be present in the given answer. They included opening, unusual perspective, sense of motion/sound, image richness, articulation in the story's description, a combination of two or more figures, internal view, representation of feelings or emotions, and the presence of fantastic elements. Moreover, an overall index (from here on IF_tot) was calculated as the sum of all sub-scores of the IF test.

To evaluate the Parallel lines test, four criteria have been assessed according to the standard procedure as described by the manual (Sprini & Tomasello, 1989). They included: fluidity, flexibility, originality, and elaboration. In addition, an overall index (from here on Lines-tot) was calculated as the sum of the previous indices. Also, for the

VAST test, we calculated the number of correct answers. Finally, a total creativity index (CI) was computed as the sum of IF_tot, Lines_tot, and VAST.

2.4.2 Third graders' performance

In the third classes' tests, the same procedure was applied to math performance (Math), Incomplete Figures, and VAST. In this last case, an extra score was evaluated, that is, the originality of the title given to the figure. The score ranged from 0 to 3 and relied upon the frequency of each given answer based on the list of all responses by the students. Finally, an overall index (hereinafter Vast_Tot) was calculated as the sum of the two criteria identified (correctness and title originality). Concerning the cartoon, two criteria were identified: the context, i.e., whether the answer was given was correctly placed in the context represented by the image, and originality. The scores ranged from 0 to 2 and were assigned based on the frequency of the given answers. The most common solutions received 0 points, less common answers received 1 point, while the funniest and unique answers received 2 points. An overall index was then calculated (from here on Cartoon_Tot) as the sum of the two previous criteria. Finally, the creativity index (CI) was calculated as the sum of IF_tot, VAST_tot, and Cartoon_tot

3. Results

Two sets of analyses were performed on the dataset. A) The first was meant to explore relationships between mathematical performance and the different subcomponents of creative thinking. B) The second one aimed to explore the presence of differences between girls and boys for creative and mathematical skills.

A) Pearson's correlations have been run on the dataset, including Math, Lines (fluidity, originality, flexibility, elaboration, Tot), Cartoon (context, title originality, tot), Vast (hits, title originality, tot), FI (fluidity, originality, elaboration, plus, tot).

The analyses performed showed some significant positive correlations between the mathematical performance (Math) and the lines test taken by second graders about flexibility scores ($r=0.25$; $p=0.032$), originality ($r=0.33$; $p=0.005$), as well as total score ($r=0.25$; $p=0.031$). (see fig 1a, b, c).

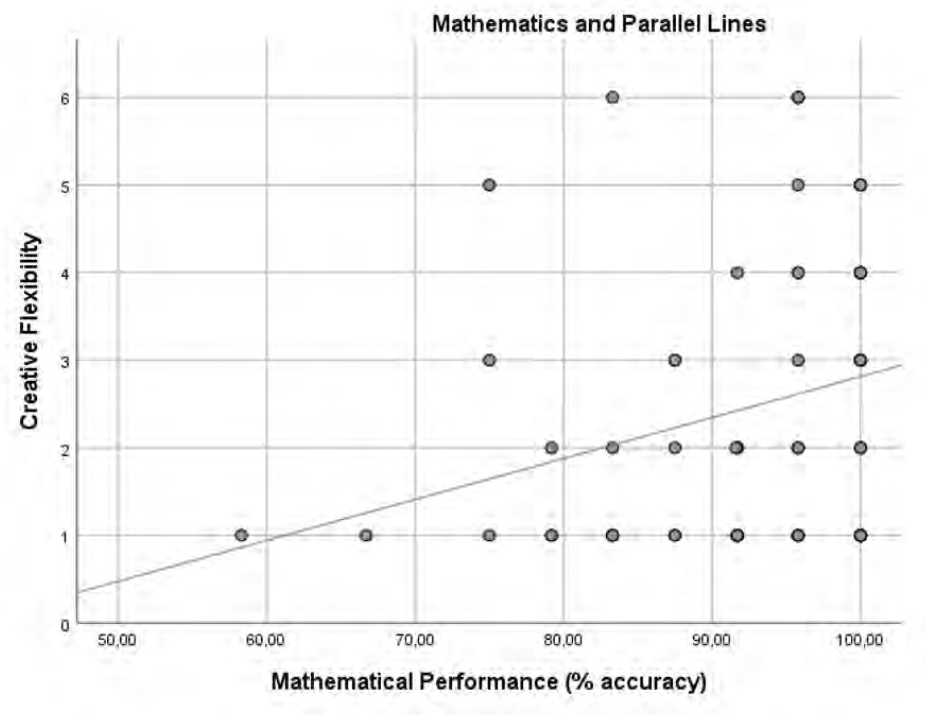

Figure 1a: Significant positive correlation between Mathematical Performance and Creative Flexibility at the Parallel Lines Test.

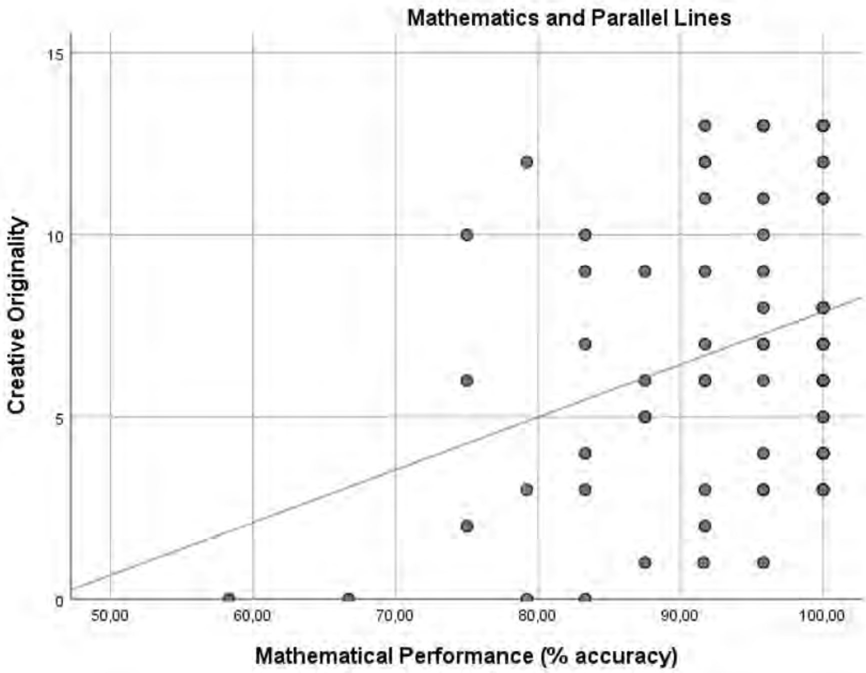

Figure 1b: Significant positive correlation between Mathematical Performance and Creative Originality at the Parallel Lines Test.

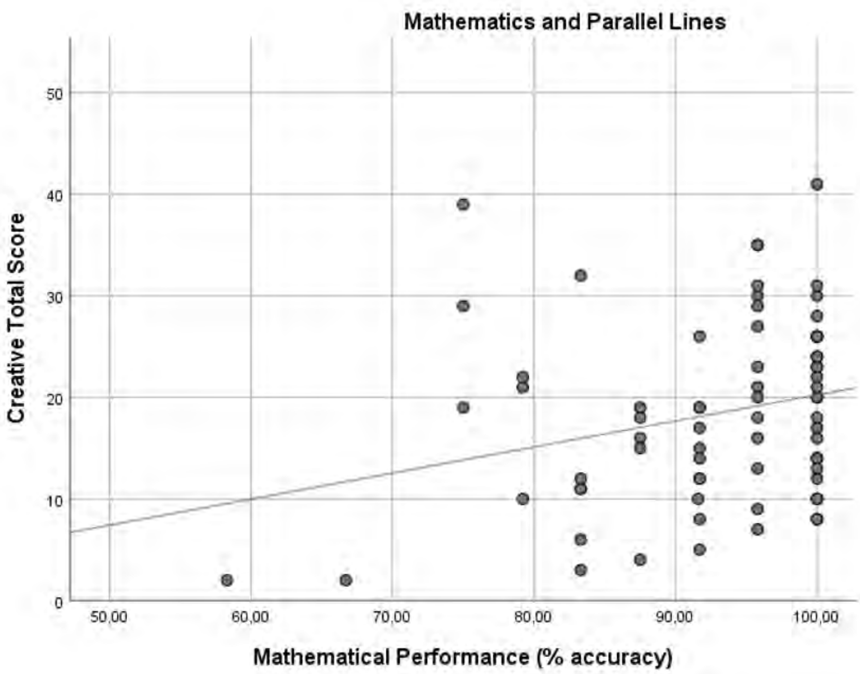

Figure 1c: Significant positive correlation between Mathematical Performance and the Creative Total Score.

B) To assess the presence of differences between boys and girls, five t-tests were performed, four for the creative variables (Lines-Tot, Cartoon-Tot, Vast-Tot, CI) and one for the mathematical performance, using gender as an independent factor. The analyses did not reveal any significant results.

4. Discussion and conclusions

The correlations found between mathematical performance and creativity are particularly interesting especially analyzing the related sub-components. In fact, not creativity in general seems to be associated with mathematical skills, but some of its specific dimensions, particularly cognitive flexibility, and originality. At the same time, fluency and elaboration showed poor correlations. This finding is significant since the ability to solve mathematical problems is more naturally related to the ability to navigate the problem space through a systematic attempt to find connections between concepts and categories, which implies a cognition free from categorical constraints. Conversely, less efficient math students generally show a sort of cognitive rigidity that maintains their attention on a given solution procedure, thus impeding approaching a mathematical problem fully and openly (Gersten, Jordan, & Flojo, 2005; Musna & Juandi, 2020). Many low-skilled math students tend to rely on solutions and algorithms that have already been acquired, tested, and consolidated, showing difficulty tackling new or ambiguous problems that instead require flexibility and inventiveness. Even originality follows this reasoning because a good student should be able to produce and test novel solving strategies, even if never seen, going out of her comfort zone.

Moreover, the definition of mathematical creativity takes into account these two aspects, emphasizing the importance of flexibility and originality instead of generativity (Pehkonen, 1997; Sriraman, 2004), which leads the student to trial and error processes that are often not very effective and frustrating. Finally, elaboration is scarcely considered in mathematical creativity since this dimension can be more relevant for an expert mathematician who needs to focus also on details and the elegance of the procedure and demonstrations (Yaftian, 2015). However, students generally do not require such an elaboration, having little relevance for elementary school students. Probably, for higher grade students, the role of elaboration and even fluency may be more relevant than we observed, even though also in higher education contexts, most problems seem to derive from a lack of flexibility (Stad, Van Heijningen, Wiedl, & Resing, 2018).

Concerning our hypothesis about gender differences, we could not confirm it since our data did not reveal significant differences between boys and girls in creativity and math scorings. Our results support those hypotheses and evidence that link the gender differences reported by some studies more on social contexts as well as the studies setting than on actual gender-related differences (Tomasetto, 2013).

In conclusion, our data confirm the existence of a significant relationship between creativity, considered here as a general property of the students' mind, and the performance at a specific school field such as mathematics. Since the core characteristic of creative thinking is cognitive flexibility, it seems plausible to hypothesize that the found relationships between such different domains may be explained by the role played by flexibility in many school domains. Furthermore, our results suggest that creativity training, though not specifically focused on a specific field, might improve students' performance in various disciplines (Lucchiari, Sala, & Vanutelli, 2019). In particular, we suggest that many elementary students who show difficulties in math may benefit from creativity training (Bicer, 2021).

Such training should be only partially focused on the so-called mathematical creativity. A more general creativity pathway should support the development of a fluid and flexible cognition potentially helpful in boosting the development and the consolidation of mathematical skills, more than a focused intervention. However, in higher-level students, specific training could be provided to support specific skills and the production of elaborated algorithms and elegant solving strategies (Schoevers, Kroesbergen, & Kattou, 2020).

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