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In-service teachers' seeing mathematical creativity: Unravelling and launching mathematical creativity tasks

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Abstract

The development of mathematical creativity—typically characterized by fluency, flexibility, originality, and elaboration—has garnered growing attention within mathematics education due to its cognitive value and potential to enhance problem-solving competence. Despite this increasing interest, existing research highlights a critical gap: in-service primary school teachers often exhibit a limited understanding of mathematical creativity and face significant challenges in recognizing and assessing its manifestations in classroom settings. While prior studies have explored the influence of creativity-focused coursework on prospective teachers, investigations involving in-service educators remain sparse. Addressing this gap, the present qualitative study introduces a structured educational program designed to enhance the conceptual understanding and pedagogical practices of seven Greek in-service primary school teachers regarding mathematical creativity. The program integrates theoretical frameworks with creativity-enhancing tasks sourced from established literature, encouraging participants to analyze, solve, and adapt these tasks. Data were collected through pre- and post-program interviews and questionnaires and analyzed using thematic analysis to capture shifts in perception. The findings reveal that although participants exhibited modest enrichment in their understanding—particularly concerning the value of open-ended and non-routine tasks in fostering fluency and flexibility—they continued to struggle with promoting originality and elaboration. These results underscore the necessity for sustained, targeted professional development initiatives that support teachers in identifying and implementing strategies to nurture all dimensions of mathematical creativity. This study contributes to the field by offering empirical evidence on how thoughtfully designed programs can incrementally refine in-service teachers' perceptions and instructional approaches toward creativity in mathematics education.

Keywords: Creative Tasks, Educational Program, In-Service Teachers' Perceptions, Mathematical Creativity, Professional Development

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In contemporary educational contexts that increasingly emphasize problem-solving, innovation, and adaptability, the cultivation of students' mathematical creativity is recognized as a vital goal. Despite its importance, promoting creativity in mathematics classrooms remains a considerable challenge for educators across diverse educational systems. Although the notion of mathematical creativity is not new—having been explored by renowned mathematicians such as Hadamard (1945) and Poincaré (1910)—it has attracted renewed interest among mathematics education researchers in recent years. As Shriki (2020) notes, mathematical creativity is a complex, multifaceted construct that resists

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straightforward definition. Typically, it is characterized using the four indices of creativity proposed by Guilford (1966) and Torrance (1965): fluency, flexibility, originality, and elaboration.

The significance of fostering mathematical creativity is increasingly underscored in international research and curriculum frameworks (e.g., NCTM, 2000; Pitta-Pantazi, 2017), which highlight its role in developing students' cognitive and problem-solving capacities. However, the successful integration of creativity into classroom practice largely depends on teachers. They are responsible for selecting and implementing instructional tasks and approaches that may either promote or hinder students' creative engagement with mathematical ideas. As Even et al. (2009) observe, the question of how to prepare teachers who can nurture mathematical creativity remains underexplored.

Research on teachers' potential to foster creativity has revealed several critical issues. Studies indicate that teachers often hold misconceptions about mathematical creativity and encounter difficulties in recognizing, assessing, and supporting its development (Bolden et al., 2010; Desli & Zioga, 2015). In response, a limited number of intervention studies have sought to raise awareness and develop teachers' conceptions of mathematical creativity (e.g., Bicer et al., 2022; Levenson, 2015; Shriki, 2010). These studies have shown promising results in enhancing participants' perceptions. For instance, Shriki (2010) found that participants initially viewed mathematics as a closed domain, accessible only to experts, but later came to see it as an open field in which students could also engage creatively. However, such interventions have typically focused on prospective teachers enrolled in undergraduate or graduate education programs, whose initial motivation to develop professionally is already high. Moreover, existing studies have tended to target isolated aspects of creativity (e.g., awareness or recognition), without examining broader and more integrated perceptions, such as how creativity influences instructional task selection or classroom practice.

Consequently, there remains a critical gap in research concerning in-service primary school teachers—those who play a pivotal role in shaping students' mathematical understanding during early educational stages. This population is central to the implementation of creativity-oriented instruction, yet is often overlooked in empirical studies. Without targeted efforts to investigate and support their professional development in this area, opportunities to cultivate creativity in authentic classroom contexts may be lost.

This study seeks to address this research gap by exploring how in-service primary school teachers perceive mathematical creativity and how their conceptions and task selection criteria evolve following a targeted intervention. Specifically, the study investigates teachers' current practices related to creativity-oriented instruction (e.g., types of tasks used and frequency of implementation) and examines how their perceptions change after participation in an 18-hour professional development program focused on mathematical creativity. The intervention was designed to bridge the gap between theory and practice by engaging participants in analyzing, solving, and adapting creativity-fostering mathematical tasks. It also provided opportunities for teachers to reflect on their beliefs and consider how those beliefs influence instructional decisions.

Drawing on recent research concerning the nature of mathematical creativity, the program introduced various task types and pedagogical strategies conducive to creativity development. In addition to documenting participants' evolving perceptions, the study analyzes the tasks that teachers proposed as "creative" before and after the intervention, along with the rationales behind their choices. A thematic analysis approach is used to code and categorize the qualitative data, organizing the emerging themes into structured representations.

By examining in-service teachers' evolving conceptions of mathematical creativity and their instructional choices, this study contributes to a more comprehensive understanding of how creativity can be effectively supported in primary mathematics education. The findings aim to inform future teacher education initiatives and identify areas where further support is needed to enable teachers to foster creativity in meaningful and sustainable ways. Accordingly, a qualitative research design is adopted, aligning with the study's exploratory objectives and its focus on capturing the depth and complexity of teacher perceptions.

Mathematical Creativity and Creative Tasks

Mathematical creativity is widely recognized as a multifaceted and complex construct that remains difficult to define with precision (Shriki, 2020). In an effort to challenge the outdated perception that creativity is the exclusive domain of eminent mathematicians, Sriraman (2008) emphasizes that students, too, can exhibit creativity in mathematics. He defines mathematical creativity as "the process that results in unusual and insightful solutions to a given problem, irrespective of the level" (p. 15). Building on this view, Sriraman et al. (2011) highlight originality and novelty as central components of mathematical creativity, clarifying that what is considered novel need only be new to the individual making the discovery, rather than to the broader mathematical community.

Earlier conceptualizations, such as Krutetskii's (1976; as cited in Sriraman, 2008), describe mathematical creativity as the capacity for abstract thinking and generalization within mathematical contexts. This perspective continues to be endorsed by contemporary researchers (e.g., Hershkovitz et al., 2009; Lev-Zamir & Leikin, 2011). Flexibility has also been emphasized as a key component of creativity, particularly in relation to overcoming cognitive fixations and breaking free from stereotypical problem-solving approaches (Haylock, 1997; Levenson, 2011). Leikin and Elgrably (2022), among others, underscore that mathematical creativity involves generating multiple solutions to a given problem and employing diverse strategies in the problem-solving process. Synthesizing various definitions, Kwon et al. (2006) propose a twofold conceptualization of mathematical creativity: "the creation of new knowledge" and "flexible problem-solving abilities" (p. 52). Similarly, Levenson (2022, p. 470) frames mathematical creativity as "a disposition that promotes the ability to generate several solutions and solution paths, to change directions of focus, and to produce novel and original solutions."

Drawing on these perspectives, the present study adopts a working definition of mathematical creativity in school settings as the exploration and discovery of multiple or original solutions to mathematical tasks, demonstrating flexibility in problem-solving, making generalizations, and/or constructing new (personally novel) mathematical knowledge.

To describe and assess mathematical creativity, researchers frequently rely on the four indices of creativity proposed by Guilford (1966) and Torrance (1965), which have become foundational in creativity research: (a) fluency, referring to the number of responses or solutions to a task; (b) flexibility, involving the use of varied strategies or approaches; (c) originality, defined by the novelty or rarity of responses; and (d) elaboration, reflecting the depth, detail, or generalizability of a response. These indices serve as key criteria in evaluating both students' mathematical creativity and the potential of instructional tasks to foster creative thinking (e.g., Levenson et al., 2018; Lev-Zamir & Leikin, 2011).

Teachers play a pivotal role in nurturing mathematical creativity. As Levenson (2011) asserts, teachers not only act as content experts but also shape the classroom environment in ways that influence students' willingness to explore diverse and novel mathematical ideas. A supportive classroom atmosphere—where students are encouraged to propose multiple solutions, challenge ideas, and engage in constructive discourse without fear of criticism—is essential for the development of creative thinking. Importantly, teachers select the mathematical tasks that students engage with and determine how those tasks are discussed. Thus, the selection of tasks that have the potential to foster creativity—referred to here as creative tasks—is a crucial instructional decision (Hershkovitz et al., 2009).

Given that creative tasks are intended to cultivate students' mathematical creativity, their effectiveness is often evaluated through the lens of the four creativity indices (e.g., Hershkovitz et al., 2009; Levenson et al., 2018). Although researchers have associated various task types with different dimensions of creativity, these associations have not been systematically mapped. A clearer understanding of how specific task characteristics align with particular creativity components—such as fluency, flexibility, originality, and elaboration—would provide teachers with actionable frameworks for designing and implementing activities that foster creative mathematical thinking.

In this study, we address this gap by categorizing creative tasks identified in the literature based on their alignment with different dimensions of mathematical creativity. Notably, a single task may support multiple creativity dimensions, reflecting the inherently multifaceted nature of creativity. For example, open-ended tasks—which permit multiple valid outcomes—promote fluency and originality by encouraging students to explore a wide range of solution paths (Kwon et al., 2006). Tasks that overcome fixations cultivate flexibility by requiring solvers to depart from algorithmic or stereotypical approaches (Haylock, 1997). Non-routine problems, which lack straightforward solution strategies, also support flexibility by compelling students to experiment with diverse strategies (Yeo, 2009). Ill-structured problems, often modeled on real-life contexts, do not yield single correct answers and thus enhance fluency and flexibility by inviting multiple perspectives (Jonassen, 1997). Tasks involving pattern recognition and generalization develop elaboration through abstract reasoning and the extension of mathematical structures (Lev-Zamir & Leikin, 2011; Sheffield, 2013). The "What-if…" strategy—which involves altering or extending existing problems—can stimulate all four creativity dimensions by fostering exploration and innovation (Silver, 1997; Zioga & Desli, 2023). As Klein and Leikin (2020) point out, such tasks are often absent from standard textbooks, requiring teachers to creatively reformulate closed problems into more open and exploratory formats. Lastly, problem posing by students—as emphasized by Silver (1997)—engages students in authentic mathematical activity, fostering flexible thinking and promoting both cognitive and affective benefits. Tasks that lead to the discovery of personally novel mathematical ideas reflect one of the core pillars of creativity: the construction of new knowledge (Kwon et al., 2006).

Teachers' Perceptions of Mathematical Creativity

Teachers' perceptions of mathematical creativity play a pivotal role in shaping classroom environments that either support or inhibit students' opportunities to engage in creative mathematical thinking (Levenson, 2011). When teachers adopt a narrow view of creativity—such as equating it solely with creating a fun or enjoyable atmosphere—they may inadvertently constrain students' opportunities by limiting the selection of mathematical tasks, discouraging the exploration of multiple solution strategies, and dismissing responses that deviate from conventional norms. In contrast, teachers who hold a more comprehensive understanding of creativity are more likely to value students' diverse responses and to implement open-ended, creativity-enhancing instructional activities (Koslowski et al., 2019).

However, the literature suggests that teachers' conceptions of mathematical creativity are often ambiguous. Both international studies (e.g., Bolden et al., 2010) and national studies in Greece (Desli & Zioga, 2015; Zioga & Desli, 2019b) report that teachers struggle to recognize and nurture mathematical creativity. These challenges often stem from a limited understanding that centers more on generating student interest or enjoyment than on fostering the cognitive and affective processes associated with creative mathematical engagement.

In a study conducted in the United States, Aljughaiman and Mowrer-Reynolds (2005) found that while 81% of in-service primary school teachers believed creativity could be cultivated in schools, many of them viewed creativity development as an extracurricular or supplementary aspect of the curriculum—one that contributes to amusement rather than to meaningful mathematical learning. Similarly, Bereczki and Kárpáti (2018), in their systematic review of the literature on teachers' beliefs about creativity, proposed a conceptual framework that synthesizes these beliefs. They found that many teachers equated creativity primarily with originality, often overlooking other dimensions such as flexibility and elaboration.

Further insights come from Levenson's (2013) study, which involved Israeli graduate students pursuing master's degrees in mathematics education. These participants, comprising both primary and secondary school teachers, associated mathematical creativity with flexibility and originality. When asked to select creativity-promoting tasks, they preferred those that encouraged non-algorithmic thinking and multiple solution strategies. The same participants also acknowledged the importance of students' intrinsic motivation and affective engagement.

In the Greek context, where research on mathematical creativity remains limited, Desli and Zioga (2015) found notable differences between prospective and in-service primary school teachers' conceptions. Prospective teachers emphasized stimulating students' interest and promoting cooperative learning, whereas in-service teachers were more focused on traditional, textbook-oriented problem posing, reflecting a narrower pedagogical approach.

Teachers' perceptions of creative students and creative teaching further illuminate these dynamics. Leikin et al. (2013), in an international survey of secondary school mathematics teachers, reported that participants associated student creativity with the ability to formulate conjectures, recognize mathematical patterns, think independently, and employ multiple problem-solving strategies (i.e., flexibility). In terms of teacher creativity, participants identified characteristics such as enthusiasm for mathematics, encouragement of student initiative, and the integration of mathematics with art and science. Notably, participants from India emphasized the importance of incorporating real-life contexts into mathematical instruction.

Similarly, Lev-Zamir and Leikin (2011) found that teachers viewed creative educators as those who exhibit both mathematical and pedagogical flexibility—such as the ability to adapt or redesign mathematical tasks—and originality, such as generating tasks beyond the textbook. Craft (1997) also observed that creative educators are characterized by their willingness to take instructional risks and adapt their teaching plans to accommodate students' evolving needs.

Teachers' perceptions of creative pedagogy—defined as teaching that actively promotes students' opportunities to be creative—have been synthesized by Bereczki and Kárpáti (2018). Their review highlighted key pedagogical priorities, including fostering divergent thinking, supporting active learning, cultivating inclusive classroom environments, and promoting collaboration and positive interpersonal relationships.

Previous Educational Programs regarding Mathematical Creativity

Although relatively few studies have investigated the implementation of educational programs specifically designed to foster teachers' understanding of mathematical creativity, existing research has yielded promising results. For example, Shriki (2010) designed an undergraduate course for prospective secondary school mathematics teachers in Israel with the goal of deepening their understanding of mathematical creativity. This six-week course—part of the participants' first Methods course—aimed to provide "new insights into the meaning and complexities of mathematical creativity" (Shriki, 2010, p. 163), focusing particularly on its nature and processes. During the course, participants were encouraged to engage in authentic mathematical activity by "working like real mathematicians"—for instance, inventing geometric concepts and exploring their properties. Most chose to collaborate in pairs. The findings revealed that the course enhanced participants' awareness of mathematical creativity. Prior to the course, they tended to emphasize the final product and viewed mathematics as a closed domain accessible only to professionals. After completing the course, however, participants placed greater value on the creative process itself (e.g., asking questions, posing problems, and exploring ideas), as well as affective dimensions such as motivation, excitement, and curiosity. They came to see mathematics as an open field in which students could generate new insights and original contributions.

Similarly, Levenson (2015) examined how an in-service secondary school mathematics teacher's perceptions of mathematical creativity evolved through participation in a semester-long graduate course in Israel. The 14-session course introduced participants to diverse perspectives on mathematical creativity and addressed both theoretical and practical issues related to its development in all students. In alignment with Shriki's (2010) approach, the course engaged participants in collaborative activities involving creative problem-solving and the invention of new geometric concepts. Additionally, participants were asked—at the beginning, middle, and end of the course—to identify and justify tasks they believed could foster mathematical creativity. Levenson found that the course positively influenced the participant's conceptions. Initially, she associated creativity exclusively with gifted students. By the end of the course, however, she understood creativity more broadly, aligning it with the constructs of fluency, flexibility, and originality, and recognizing its relevance for learners of all levels.

Bicer et al. (2022) also developed a course for prospective primary school teachers in the United States, which focused on instructional strategies for promoting students' mathematical creativity. The course emphasized both problem-solving and problem-posing, and participants were trained to adapt routine textbook exercises into tasks that could support creative thinking. Their results showed significant improvements in participants' mathematical creativity, as measured by fluency, flexibility, and originality scores. Moreover, participants reported more positive attitudes toward creative tasks than those in a control group.

Despite these promising findings, existing studies have largely targeted pre-service teachers—individuals still undergoing professional preparation, whose beliefs about mathematics education are not yet fully formed. These participants may also have been more motivated to demonstrate growth, particularly when their development was explicitly evaluated. Consequently, it remains uncertain whether similar outcomes would occur among in-service teachers not subject to performance-based assessment during interventions. This represents an important gap in the literature.

Moreover, most previous studies (e.g., Shriki, 2010; Levenson, 2015) focused on secondary school mathematics teachers who typically possess strong content knowledge due to their academic background in mathematics departments. In contrast, primary school teachers often have more limited formal training in mathematics. As Levenson (2013) suggests, this distinction warrants further investigation—particularly whether primary and secondary school teachers attend to different task characteristics and cognitive demands when aiming to promote mathematical creativity.

These gaps highlight the need for further empirical research exploring in-service primary school teachers' conceptions of mathematical creativity and their approaches to fostering it through instructional practices. The present study seeks to address these issues by focusing specifically on experienced teachers working in public primary schools. We aim to capture a realistic and detailed picture of their evolving perceptions through a structured intervention. In designing our study, we drew inspiration from the content and structure of prior programs, particularly those developed by Shriki (2010) and Levenson (2015). We found Levenson's use of task selection and justification as a means to reveal participants' conceptions of creativity especially valuable, and we have incorporated a similar strategy in our research design.

The Current Study

In view of the long-standing appreciation of mathematical creativity in both research studies and curricula—an appreciation that, however, is still insufficiently reflected in school practice—the current study aims to investigate in-service primary school teachers' perceptions of mathematical creativity, the tasks that promote it, and how it can be cultivated in the classroom. Furthermore, the study examines how these perceptions evolve after the teachers participate in an educational program focused on mathematical creativity. The following research questions guided the study:

1. How do primary school teachers perceive mathematical creativity and creative tasks?
2. To what extent do their perceptions and ability to select creative tasks change following participation in a professional learning program focused on communicating a research-informed perspective of creativity in mathematics?

This study contributes to the literature in several ways. First, it provides a foundation for the design of teacher education programs related to creativity in mathematics. Second, it systematically investigates in-service primary school teachers' perceptions of mathematical creativity using two research tools: interviews and questionnaires. Third, it identifies areas in which participants require further support to effectively foster mathematical creativity in their students.

METHODS

This study was conducted in Greece, where educational courses on mathematical creativity have not yet been organized for in-service teachers by the Ministry of Education. Additionally, the concept of mathematical creativity has only recently been introduced to undergraduate courses in pedagogical departments, albeit very sparsely. Furthermore, in mathematics textbooks (which are currently being rewritten), there is a lack of tasks that promote creativity development. As a result, participants in the study confirmed that they had no prior knowledge of mathematical creativity before participating in the program.

Participants

Prior to beginning the study, the necessary ethical permissions were obtained, and an ethics certificate authorizing the research was issued by the Ministry of Education. Subsequently, invitations were extended to primary schools in Northern Greece, inviting teachers to voluntarily participate in an educational program focused on mathematical creativity. The decision to include in-service primary school teachers aligns with the study's aim of investigating the perceptions and task-selection criteria of educators with real classroom experience. Seven in-service primary school teachers accepted the invitation and took part in the study. They all work in state primary schools in Greece and represent a wide range of primary school teachers in terms of age, years of experience, postgraduate education, and the Grades they teach. More specifically, as seen in Table 1, four are male, and three are female. Their teaching experience varies between 8 and 30 years, with an average of 21 years of experience, whereas their age varies between 32 and 55 years, with an average of 45,6 years. One participant holds a master's degree in language education, another participant holds a master's degree in mathematics education, and a third participant is a Ph.D. candidate in Mathematics Education. The rest do not have any postgraduate studies. At the time of the study, two of the participants teach Grade 1, three of them teach Grade 4, and two teach Grade 5. Their participation in the study is voluntary and anonymous, and the names assigned to them for the present paper are pseudonyms.

Table 1. The participants' background

Participant (Pseudonym)	Gender	Age	Years of Experience	Postgraduate Studies	Grade
Jason	M	43	18	Mathematics Education	4
Andrew	M	55	30	-	5
Nicole	F	48	23	-	1
Helen	F	32	8	Language Education	4
Peter	M	41	15	Mathematics Education	4
Georgia	F	47	22	-	1
Paul	M	53	28	-	5

The Program

The educational program covered a period of six weeks and was conducted by the first author of the present study. It was concluded in six weekly meetings, which lasted three hours each. We opted to conduct the program over six meetings, following the approach of Shriki (2010), as we determined this duration to be adequate for achieving the program's objectives without overloading participants' schedules. The meetings were held in quiet and adequate spaces in a Greek University Department of Primary Education's own premises during the afternoon after the participants had completed their teaching obligations. All the participants were present in all six meetings, which was a mandatory prerequisite for their participation in the study.

The program was mainly inspired by Shriki's (2010) and Levenson's (2015) educational courses but differentiated in certain aspects. Unlike Shriki's (2010) course, which focused primarily on prospective secondary teachers' engagement in mathematical investigations, or Levenson's (2015) course, which addressed creativity across preschool to secondary education, our program specifically targeted primary education. It focused on how particular task characteristics foster specific aspects of creativity. Its primary purpose was to enhance the participants' knowledge of mathematical creativity so that, in due course, they would be more able to recognize and assess mathematical creativity and choose tasks that offer opportunities for students' creativity development. More specifically, the program's objective was twofold. First, it aimed to strengthen the theoretical background of the participants on different aspects of creativity: definitions of mathematical creativity, Torrance's creativity indices, the characteristics of creative students and creative teachers, and the importance of the teacher's role in providing suitable situations and stimuli for creativity development in the classroom. Second, it also had a more practical purpose: to reinforce teachers' awareness of the characteristics of creative mathematical tasks and improve participants' ability to evaluate, choose, modify, extend, and create tasks that promote students' mathematical creativity. Teachers' evolving knowledge and perceptions of mathematical creativity were examined using pre- and post-intervention interviews and questionnaires. Although classroom implementation was not observed in this study, the program was designed to bridge theory and practice by encouraging teachers to critically examine and select tasks they could feasibly implement in their own classrooms. Approximately 45 minutes (not consecutive) were allocated to lecturing during each meeting. The participants were also encouraged to engage actively in individual work and in whole-class discussions during the meetings, express their views, discuss and debate the program's content, and solve and alter mathematical tasks. The tasks were carefully selected to progressively enhance participants' understanding of mathematical creativity and to support their ability to identify and adapt creativity-promoting tasks. Each session was designed to align with one or more creativity traits—such as fluency, flexibility, originality, and elaboration—and to foster reflective dialogue. The analytical description of the weekly meetings is presented below. A concise overview of the meetings is presented in Table 2.

Table 2. Overview of the meetings

Meetings	Focus of the Session	Tasks Used	Teachers' Reflections
1st	Concept clarification (e.g., mathematical creativity, creative student, creative teacher, Torrance's creativity indices), the teacher's role in creativity development.	-	Initially, teachers were uncertain about the potential for developing mathematical creativity in the classroom. After discussing research findings, they became optimistic.
2nd	Fostering fluency, originality, and divergent thinking.	Open-ended tasks.	Teachers solved open-ended tasks, finding as many solutions as possible. They participated eagerly.
3rd	Fostering flexible, non-algorithmic, non-stereotypical thinking.	Problems that overcome fixations, non-routine problems.	Teachers were encouraged to find different strategies to solve problems. They participated eagerly.
4th	Creativity within real-life situations. Fostering elaboration, abstract thinking, generalizations in the mathematical contexts.	Ill-structured problems, tasks with patterns and/or generalizations.	Teachers solved tasks. Some were reluctant whether primary school should emphasize abstract thinking.
5th	Extending previously solved problems, encouraging students' problem-posing, fostering creativity to generate new knowledge.	Various tasks extended using the "What-if…" strategy, tasks that lead to new knowledge.	Teachers highlighted the need for students to pose problems that stem from their interests and the importance of teachers' role in creativity development.
6th	Modifying tasks to promote mathematical creativity. "Opening up" closed tasks.	Traditional algorithmic tasks that were discussed and modified.	Teachers hesitated to participate actively. They explained why the tasks were not prone to fostering creativity but faced difficulties in "opening" them up.

The First Week (Concept Clarification)

During the first meeting, the participants were introduced to different theoretical aspects of creativity retrieved from the literature review. A variety of questions were addressed to the participants, for example, "What is creativity?", "What is mathematical creativity?", "Is there a difference between them?", "Which personality traits describe a person who is creative in mathematics?", "Can mathematical creativity be cultivated in school?", "Who is a creative student, and who is a creative teacher in mathematics?". A discussion unraveled among the participants and the first author in order to allow them to express their perceptions concerning the abovementioned concepts. Then, the consensus among researchers (e.g., Leikin, 2009; Silver, 1997) that mathematical creativity can be developed in the classroom through proper guidance was highlighted.

Subsequently, some representative definitions of mathematical creativity were presented to the participants. Emphasis was given to those who include the concepts of flexibility, non-algorithmic way of thinking, the creation of new knowledge, abstract thinking, the ability to generalize in the mathematical context, and the ability to solve an old problem in a new way. Then, Torrance's creativity indices and their application in mathematics as a tool for evaluating and developing creativity were examined. The importance of incorporating interdisciplinary problems in mathematics education was also discussed. Finally, research findings were highlighted regarding the teacher's crucial role in students' creativity development (Kandemir et al., 2019). Apart from implementing creativity-fostering tasks (Levenson, 2015), particular emphasis was given to the potential "fallibility" (Ervynck, 2002, p.52) of creative ideas and the importance of cultivating a safe environment for students to express their ideas (Kozlowski & Si, 2019).

The Second Week (Open-ended Problems)

The second and following meetings were dedicated to creative tasks. The creative tasks were organized into eight categories (presented in section "Mathematical Creativity and Creative Tasks") to facilitate the program's needs. The first category was *open-ended problems* (Kwon et al., 2006). Their numerous advantages were discussed, e.g., their potential to encourage divergent thinking and students' ability to discover many (fluency) and original (originality) solutions.

In addition, participants had the opportunity to solve various open-ended problems and attempted to find as many solutions as possible. The participants' engagement with problem-solving served two purposes: firstly, they became better accustomed on a theoretical and practical level. Secondly, the fact that they were encouraged to explore different solutions potentially would lead them to implement this process in their teaching to reinforce their students' fluency. Most teachers were eager to participate and search for different outcomes to the problems.

The Third Week (Problems that Overcome Fixations, Non-routine Problems)

During the third meeting, the participants were engaged mainly with problems that cultivate a flexible, non-algorithmic, non-stereotypical way of thinking. Initially, participants worked with tasks that develop the ability to "*overcome fixations"* (Haylock, 1987, p. 64). More specifically, the distinction between *algorithmic* and *content-universe fixation* was made clear, incorporating Haylock's (1997, p. 69-70) examples. Additional tasks, taken from the school mathematics textbooks, were also used and modified to allow for the development of non-algorithmic thinking.

Then, the category of *non-routine* problems (Yeo, 2009) was introduced to the participants, who were encouraged to think flexibly and find different strategies to solve some of those problems.

Furthermore, the need for students to discuss and explain their strategies in the classroom was emphasized.

The Fourth Week (Ill-structured Problems, Patterns, Generalizations)

At the beginning of the fourth meeting, the discussion turned to *ill-structured problems* (Jonassen, 1997), their connection to real-life situations, and their potential to encourage fluency, flexibility, and, consequently, creativity. Then, the focus narrowed down to tasks that develop an abstract way of thinking and involve *patterns* or encourage students to make *generalizations* in the mathematical context (Hershkovitz et al., 2009). Again, the participants had the time to solve such tasks and discuss their potential to cultivate students' mathematical creativity by developing the fourth index of creativity, i.e., elaboration (Lev-Zamir & Leikin, 2011). Problems retrieved from mathematical contests, the field of number theory, and the research literature (e.g., Boaler, 1998; Sheffield, 2015) were employed.

The Fifth Week (the "What-if…" Strategy, Problem-posing, Creation of New Knowledge)

This meeting began with a discussion regarding the extension of previously solved problems in ways that cultivate students' mathematical creativity. Then, the "What-if…" strategy was introduced, and numerous examples utilizing this strategy were presented. In addition, the participants were encouraged to extend or reformulate various tasks or pose new ones employing the "What-if…" strategy. Also, to expand on that, students' problem-posing as a creative act was discussed. Silver's (1997) suggestion that students should have the opportunity to pose problems that derive from their interests or their wish to explore a hypothesis further was endorsed.

Lastly, a key dimension of creativity leads to new knowledge. Examples of mathematical activities that instruct students to discover new (for them) knowledge were used (for example, the ones described in Lev-Zamir & Leikin, 2011, p. 24). Sriraman et al.'s (2011) view regarding the similarities between the original work of professional mathematicians and students who discover insightful and unusual solutions, or solve an old problem in a new way, was highlighted. The participants emphasized the importance of teachers' role as facilitators to this end.

The Sixth Week (Task Modification)

Numerous mathematical tasks were presented to the participants during the sixth and last meeting. Most were conventional, algorithmic tasks taken from the school mathematics textbooks. The participants were asked to comment on these tasks and explain if, in their opinion, they foster creativity and why. Then, they were encouraged to modify each task to offer more opportunities for creativity development. This approach is consistent with Klein and Leikin's (2020) suggestion that teachers should be encouraged to pose open-ended tasks and tasks that can be solved using multiple strategies, by reformulating closed textbook tasks. However, at this point in the program, teachers hesitated to participate actively. Although they elaborated on why the tasks were not prone to fostering creativity, they faced difficulties in "opening" tasks, transforming them into creativity-promoting ones. In most cases, they eventually modified the tasks to have more than one answer only after solid encouragement from the researcher. This difficulty could be attributed to a lack of experience or time limitations. However, as explained later, the time limitation factor was anticipated and considered when designing the research tools.

Research Design and Tools

This study employed methodological triangulation to enhance the validity and reliability of the findings. By collecting data through interviews and open-ended questionnaires, methodological triangulation allowed for a more comprehensive understanding of teachers' perceptions and task selection regarding mathematical creativity. As Bryman (2016) and Mabry (2008) explain, using multiple data collection methods can strengthen the integrity of a study, particularly in qualitative research. More specifically, the study was concluded in two phases. During the first phase, conducted before the educational program, the participants completed a questionnaire regarding creativity-promoting tasks. Furthermore, each participant was interviewed concerning their perceptions of mathematical creativity. The study's second phase took place approximately two months after the completion of the program. Again, the participants completed the questionnaire and were interviewed. The research tools were precisely the same as in the first phase, allowing space for the evolution of participants' perceptions to become apparent.

The Questionnaire

The purpose of the questionnaire (see Appendix A) was to encourage participants to express freely their perceptions regarding the types of tasks that promote students' mathematical creativity and highlight the reasons for the potential of these tasks. In other words, the questionnaire aimed to investigate whether the participants identified creative tasks and what characteristics they attributed to those tasks. To this end, using "open" questions was preferred so that participants could answer as they wished. It consisted of the following questions: a) Choose a task that, in your opinion, promotes students' mathematical creativity, b) State the source of it, and c) Explain why you believe that this task promotes mathematical creativity. The questionnaire was adapted from Levenson (2013), who originally developed it to explore teachers' perceptions of tasks that promote mathematical creativity. The items were translated into Greek, with minor adjustments made to improve clarity. The adaptation process included an expert review by two university researchers specializing in mathematics education and qualitative research methods.

During the study's first phase, the questionnaire was administered to the participants approximately two months before the program's initiation. It was returned to the first author three weeks later. During the second phase, it was administered approximately two months after the completion of the program and was returned within the next three weeks. Participants filled in the questionnaire without any time limitation, in their own time, and without the presence of the authors. This deliberate decision aimed at enabling participants to search for tasks from different sources. The completion of the questionnaire was not anonymous: the authors knew which participant completed which questionnaire to gain a broader understanding of their perceptions in combination with their interviews.

The Interview

The interview (see Appendix B) aimed to investigate participants' perceptions of mathematical creativity, as well as the changes these perceptions underwent after the program, regarding three main axes: a) general creativity and mathematical creativity (e.g., "Who, in your opinion, is a creative person?", "Who is creative in mathematics?"), b) the procedures that foster mathematical creativity in the classroom (e.g., "What can a teacher do to promote students' mathematical creativity?"), and c) employing creative tasks in teaching mathematics (e.g., "Which tasks have the potential to promote students' mathematical creativity?"). The interview questions were developed based on themes from the literature and the aims of the intervention. To ensure content validity, the questions were reviewed by two experts on the field. To ensure clarity, they were piloted with one teacher who was not involved in the main study. Reliability was supported through researcher reflection and memo-writing during transcription and coding (Corbin & Strauss, 2015). A semi-structured interview format was chosen to allow for flexibility while maintaining focus on key topics. As Bryman (2016) explains, semi-structured interviews offer the interviewees great freedom to reply and allow room for clarification and in-depth discussion. Since the study's objective is to investigate participants' sincere perceptions, all questions were open, encouraging participants to explain and elaborate on their opinions.

Each participant was interviewed twice. The first interview took place approximately one month before the program's initiation and the second three months after the end of the program. This three-month intercession potentially gave participants enough time to reflect on the concepts and ideas discussed during the program and (hopefully) adopt them in their teaching practice. The interviews took place in a quiet room in each participant's working environment. Each interview had a duration of approximately 30 minutes, was recorded, and subsequently transcribed.

Data Analysis

Data gathered from the interviews and questionnaires were analyzed using thematic analysis. According to Clarke and Braun (2014), thematic analysis is a widely used, helpful, and flexible method for recognizing, analyzing, and reporting patterns (or, in other words, themes) within qualitative data. Initially, the participants' interviews were transcribed and, along with their responses in the questionnaires, were carefully examined to identify excerpts that provided answers to the research questions. Then, following the process proposed and thoroughly described by Clarke and Braun (2014), the data gathered was analyzed based on relevant fragments to generate initial codes. Participants' coded responses were independently graded by two researchers, resulting in a high inter-rater reliability (Cohen's Kappa coefficient of .84). In cases where the researchers' codes did not align, they engaged in discussion and reviewed the data until a consensus was reached. The coding process involved both deductive coding, based on predefined categories from Bereczki and Kárpáti's (2018) framework, and inductive coding to capture emergent patterns specific to mathematical creativity. Then, the codes were arranged and sorted into semantic categories that serve as a sort of organizing theme for the results. Subsequently, through further analysis, the themes were reviewed, refined, and, where necessary, combined or separated. Finally, clear definitions and labels were assigned to each theme. The final themes are presented in Table 3.

Table 3. Categories and themes derived from the data analysis

Categories	Themes
Nature of mathematical creativity	Context of reference
	Distribution
	Malleability
	Enablers
Creative students	Actions
	Way of thinking
	Personal traits
Creative teachers	Teaching styles
	Personal traits
Creative pedagogy	Creativity-fostering strategies
	Classroom environment
Creative tasks	Content of creative tasks
	Structural characteristics of creative tasks
	Students' task posing

As previously mentioned, the themes were partially based on the conceptual framework proposed by Bereczki and Kárpáti (2018) regarding teachers' beliefs about creativity. Hence, a combination of deductive and inductive approaches was used, which, per Proudfoot (2023), integrates the strengths of both methods. Deductively, the pre-ordinate categories within Bereczki and Kárpáti's (2018) framework served as our initial guide, as their systematic review meticulously synthesized recent research findings on teachers' conceptions of creativity. Additionally, we extracted new themes from the data through an inductive approach to encapsulate our participants' perceptions and surpass the fact that Bereczki and Kárpáti's (2018) framework refers to general creativity rather than specifically mathematical creativity. The combination of deductive analysis (guided by established frameworks) and inductive analysis (allowing new themes to emerge) provided a comprehensive understanding of teachers' perceptions of mathematical creativity before and after the intervention.

RESULTS AND DISCUSSION

Consistent with the semantic categories identified in the data analysis, the findings are analyzed from five perspectives: the nature of mathematical creativity, creative students and teachers, creative pedagogy, and creative tasks.

The Nature of Mathematical Creativity

When participants attempt to define mathematical creativity, they describe how it can be expressed. As seen in Table 4, before the program, they associate it mainly with flexibility[1] or, in other words, approaching a problem in different ways. For example, Nicole states that "*The person who does not get stuck in a single way of thinking, who looks for many different ways and solutions, who is willing to examine a situation again from the beginning, is a person who is creative in mathematics*." Only two participants connect creativity to originality, while none mentioned fluency. One possible way to explain the absence of fluency in Table 4 is participants' limited prior experience with multiple-solution tasks, which may have provided few opportunities to observe and recognize fluency as a component of creativity. After the program, they emphasize flexibility and originality slightly more than before. For instance, Peter explains, "*Mathematical creativity relates to originality, the ability some people have to think differently than the majority.*" This came as a surprise; we expected unanimous references from participants to fluency, flexibility, and originality, given the significant emphasis placed on Torrance's indices of creativity during the program and the numerous tasks that were solved and modified in this direction. The fact that participants continued to largely overlook fluency when describing creativity may suggest that they perceive fluency as a preliminary or less significant feature compared to novelty or flexibility. Additionally, it may indicate that they have not fully differentiated between fluency and flexibility.

Regarding the distribution of mathematical creativity in the students' population, prior to the program, only two participants express the opinion that all students can be creative in mathematics. Furthermore, the concern that younger students cannot be creative in mathematics is raised by Georgia, who teaches Grade 1. After the program, three participants state with certainty that all students can indeed be creative in mathematics. This finding was surprising to us, as we expected that, in line with Shriki (2010), participants would view mathematics as an open domain where every student can be creative. However, one possible explanation is that they attribute specific characteristics to creative students, such as curiosity, self-confidence, and a flexible way of thinking (see Table 5). Furthermore, Georgia reconsiders her previous statement and expresses the belief that younger students, especially, can be creative in mathematics.

[1] The participants were seven in total but could provide more than one answer each.

One significant shift in participants' perceptions relates to the malleability of creativity. Before the program, participants seem pessimistic, as many consider it hard to cultivate mathematical creativity in the classroom due to time limitations and pressure to implement the school curriculum. As Georgia explains, "*(To cultivate students' creativity) you have to disregard the instructions of the curriculum because it has time restrictions.*" Andrew even states that, at present, creativity is being suppressed in school settings. After the program, however, participants appear to be much more optimistic, as most are confident that mathematical creativity can be cultivated at school. The discussions during the intervention, along with the plethora of creative tasks presented and solved, likely contributed to participants realizing that fostering creativity is not as demanding or time-consuming as they had previously assumed.

Table 4. Teachers' perceptions of the nature of mathematical creativity before and after their participation in the program

Perceptions of the Nature of Mathematical Creativity	Number of Participants	
	Before the Program	After the Program
Context of reference		
Flexibility	5	6
Originality, novelty	2	4
Ability to solve problems easily	2	2
Use of mathematical thinking in everyday life	2	1
Understanding of mathematical concepts	-	1
Imagination	-	1
Distribution		
All students can be creative in mathematics	2	3
Younger students cannot be creative in mathematics	1	-
Mostly younger students can be creative in mathematics	-	1
Malleability		
It can be cultivated in school	2	5
At present, it is being suppressed	1	-
Its cultivation is difficult due to circumstances	3	1
It can be cultivated or suppressed	1	1
Its cultivation lies in the responsibility of the teachers	2	2
Enablers		
Education	6	7
Family environment	2	2
Intrinsic motivation	1	1
Personality	1	-
Connecting mathematical concepts with real-life	1	1

Creative Students in Mathematics

Attempting to describe students who are creative in mathematics, the participants mention various actions, personal traits, and ways of thinking that characterize creative students and are summarized in Table 5. Before and after the program, most participants believe creative students' actions are mainly characterized by flexibility and fluency. More specifically, they explain that creative students search for different solution strategies and for many different solutions or answers to given problems.

According to participants, students who are creative in mathematics are mainly characterized by a flexible way of thinking. Prior and following the program, for example, they attribute to mathematically creative students a flexible, non-algorithmic, and non-stereotypical way of thinking. Participants also refer to the personal traits that characterize creative students in mathematics. Before and after the program, they believe that a creative student's personality is deeply distinguished by curiosity or, in other words, willingness to explore. Nicole elaborates on the significance of curiosity: "*Curiosity may often have a negative meaning, but students who are curious and motivated, who feel the need to explore the world around them, are creative students*." Participants also emphasize self-confidence or boldness (for students to express their ideas), intrinsic motivation, and imagination. The fact that participants place great importance on students' self-confidence and willingness to explore aligns with findings from other research. These characteristics are associated with students taking risks and initiative, which have also been highlighted in other studies (e.g., Aljughaiman & Mowrer-Reynolds, 2005). According to the systematic review by Bereczki and Kárpáti (2018), there are significant differences in how teachers worldwide perceive creative students. As they explain, teachers tend to overemphasize certain features of creative students (e.g., imagination, self-confidence), while neglecting other important traits (e.g., divergent and critical thinking).

Table 5. Teachers' perceptions of creative students, before and after their participation in the program

Perceptions of Creative Students	Number of Participants	
	Before the Program	After the Program
Actions		
Search for different solution strategies	4	5
Search for many different solutions	3	3
Search for new and innovative solutions (novelty)	1	2
Expand problems	1	2
Express new ideas (novelty)	1	1
Pose questions	1	1
Way of thinking		
Flexible	4	4
Non-algorithmic	4	4
Non-stereotypical	2	4
Critical	1	2
Divergent	1	1
Abstract	-	1
Personal traits		
Curiosity, willingness to explore	4	4
Self-confidence, boldness	4	4
Intrinsic motivation	3	3
Imagination	2	2
Hard work	2	1
Strong mathematical background	1	2
Taking initiative, independence	1	2

The identification of curiosity, confidence, intrinsic motivation, and imagination as features of creative students has important implications for mathematics teaching. Teachers who recognize these traits as elements of creativity may be more inclined to cultivate them in the classroom—for example, by encouraging students to ask questions, highlighting multiple solution strategies, and fostering an environment where exploration is welcomed and mistakes are not penalized. Conversely, the limited emphasis on imagination and divergent thinking likely reflects a curricular focus on algorithmic and computational approaches rather than on creativity and open-ended exploration. Teachers may be reluctant to associate imagination and divergent thinking with mathematical practice due to a lack of exposure to instructional resources and pedagogical frameworks that support these connections. This suggests a need for professional development programs that validate these creativity aspects in teachers' perceptions.

Creative Teachers in Mathematics

In an effort to describe teachers who are creative in mathematics, as shown in Table 6, participants point out specific actions or teaching styles and personal traits that, in their opinion, define creative teachers. First and foremost, according to participants' statements before and after the program, creative teachers connect mathematics with students' everyday lives and interests, employing real-life and exciting situations in classroom practice. Furthermore, their way of teaching is mainly innovative and non-typical. As Jason explains, "*Creative teachers bring new ideas and innovative teaching methods into their classroom practice, utilizing technology, cooperative, and experiential learning, for example*". To accomplish the abovementioned objectives, they often choose to differentiate from the schoolbook. As Jason explains, "*A creative teacher does not stay intent on the textbook. Instead, he incorporates real-life problems into his teaching, aiming to develop students' mathematical thinking.*" Moreover, the opinion that creative teachers connect the school with society by associating teaching mathematics with social issues (e.g., social justice) is also expressed. Furthermore, after the program, they stress that creative teachers cultivate students' independence and initiative by applying not authority-style teaching.

Table 6. Teachers' perceptions of creative teachers, before and after their participation in the program

Perceptions of Creative Teachers	Number of Participants	
	Before the Program	After the Program
Actions / Teaching styles		
Connect mathematics with students' everyday life and interests	5	5
Innovative, non-typical way of teaching	3	4
Differentiate from the textbook	2	2
Connect school with society	1	1
Cultivate students' independence and initiative, not authority-style teaching	-	2
Personal traits		
Hard work	-	1
Enjoy their work	-	1
Imagination	1	-

In the international study conducted by Leikin et al. (2013), Indian teachers, much like our participants, also emphasized the importance of connecting mathematical creativity to real-life situations. This connection did not come as a surprise to us in the Greek context. Although participants had no prior knowledge of creativity, the significance of teaching mathematics through realistic situations and linking it to everyday life is highlighted in undergraduate programs offered by Greek pedagogical departments, as well as in educational programs designed for teachers' professional development. Helen, who teaches Grade 4, shared a real-life example during her interview: "*I asked, 'You brought money for 23 children and 9 adults, 10 euros each. How much money did we raise?' The students answered that 320 euros had been collected. I then extended the question: 'If 2 more children and 3 adults bring money tomorrow, how much will be collected in total?' The students answered correctly again.*"

Creative Pedagogy

During their interviews, participants put great emphasis on creative pedagogy or, in other words, the classroom environment, as well as procedures and teaching strategies that enhance students' mathematical creativity. These findings are summarized in Table 7. Before and after the program, connecting mathematics with students' everyday lives and interests is the most commonly mentioned creativity-fostering strategy. Regarding the classroom environment that provides the optimal circumstances for developing students' creativity, participants stress that freedom of speech is essential for communicating creative ideas. To this end, as they explain, students should feel their classroom is a safe environment to express themselves. As Andrew states, "*Today we face a significant challenge with children who are afraid to speak up and express themselves due to concerns about their image. Teachers need to help these children break free from these constraints. We can help them by building their confidence … supporting children to believe in themselves and to express their ideas freely*". Furthermore, according to the participants, collaboration and teamwork should be fostered to facilitate the exchange of ideas. Andrew elaborates on this: "*When I teach for creativity, I want the children to participate, to talk with their classmates, to engage in debate with each other, to have more lively interactions*". Participants also highlight the need for teachers to embrace fallibility or, in other words, accept the fact that original and creative ideas can often lead to mathematically wrong paths; however, this is not a reason to discourage students from expressing and exploring these ideas. After the program, participants' perceptions of the creativity-fostering classroom environment are almost identical to before.

Once again, participants emphasize the importance of connecting mathematics to students' interests and real-life experiences, which is a desirable approach and aligns with modern research and literature. However, this approach alone is not enough to promote creativity in mathematics. Other key processes that contribute to cultivating creativity in mathematics were scarcely addressed, such as problem expansion and encouraging students to seek multiple solutions or strategies. Furthermore, some creativity-enhancing approaches, like encouraging students to seek original solutions, stimulating their imagination, and fostering abstract thinking, were not mentioned at all.

Table 7. Teachers' perceptions of creative pedagogy, before and after their participation in the program

Perceptions of Creative Pedagogy	Number of Participants	
	Before the Program	After the Program
Creativity-fostering strategies		
Connecting Mathematics with students' everyday life and interests	4	4
Interdisciplinary approach	1	2
Differentiating from the textbook	1	2
Enhancing students' self-confidence	1	-

Providing multiple stimuli	1	1
Expanding problems (by the teacher)	1	1
Encouraging students to search for multiple solutions or strategies	1	1
Encouraging students' cooperation	1	1
Encouraging students to think deeply and search for answers	1	1
Devoting sufficient time for students to think	1	1
Devoting sufficient time to creative problems	1	1
Encouraging students to expand problems	-	1
Connecting new concepts with previously learned ones	-	1
Classroom environment		
Freedom of speech, communication	6	7
Safe environment	4	4
Fostering collaboration and teamwork	3	3
Embracing fallibility	2	2
Joyful atmosphere	1	1
Encouraging and offering opportunities for creativity	1	1

Creative Tasks

Three themes of creative tasks emerged from participants' responses in the interviews and questionnaires. As seen in Table 8, these themes correspond to the content of the tasks, their structural characteristics, and students' involvement in problem posing. More specifically, regarding the content of creative tasks, before and after the program, participants indicate the value of tasks relating to students' everyday lives and interests because these tasks motivate students to solve them. According to Nicole, "*Creative tasks concern students. They regard students' everyday life and interests. When students find tasks interesting, they indulge in searching for different ways to solve them. When tasks are too vague or uninteresting, students are indifferent to them.*" Furthermore, Andrew refers to tasks related to social issues and injustices, explaining that, in his opinion, "C*reative tasks help children acknowledge their place in society and their connection to it. In their endeavor to solve these tasks, children understand their lives better. For example, asking a child to calculate how much money five kilos of a certain product cost do not explain to the child why his unemployed father cannot afford this product. Hence, a creative task is not only about mathematical concepts but also about understanding real-life relations and situations.*"

During the program, participants' perceptions regarding the structural characteristics of creative tasks changed considerably. Prior to the program, only three participants highlighted the importance of open-ended or multiple solution tasks, while non-routine problems were not mentioned at all. However, after the program, participants' perceptions have evolved. They all now state that multiple solution tasks are essential for developing creativity. According to Helen, "*(To foster mathematical creativity), a task should be open-ended, it should have many possible answers so that each student can propose solutions based on his way of thinking, his perception.*" Nicole further underscores the significance of multiple solution tasks to students' motivation, explaining that when she employed such tasks in her classroom, *"… each student tried to find at least one (solution), three or four students presented their own and now they have realized that a task can have many correct solutions. They gladly engage in the process and say, "I also found a solution!"*." Furthermore, after the program, participants acknowledge for the first time the role of non-routine problems in cultivating creativity. For instance, one criterion Nicole uses to identify creative tasks is "*… not to have a specific, single strategy or an algorithm that must be followed… (but) to allow students to explore various paths and employ different methods to find a solution.*"

Table 8. Teachers' perceptions of creative tasks before and after their participation in the program

Perceptions of Creative Tasks	Number of Participants	
	Before the Program	After the Program
Content of creative tasks		
Tasks that relate to students' everyday life and interests	4	5
Tasks that relate to social issues	1	1
Tasks that include construction	-	1
Tasks in the form of a game	-	1
Structural characteristics of creative tasks		
Multiple solution tasks (open-ended)	3	7
Non-routine problems	-	3
Ill-structured problems	1	2
Tasks that can be solved using multiple strategies (open-start)	1	2
Tasks that foster a non-stereotypical way of thinking	1	1
Tasks that foster abstract thinking	-	1
Students' task posing		
Students' task posing after encouragement from the teacher	3	2
Students' expanding tasks	1	2
Students' modifying tasks	-	1

Students' involvement in task posing is also a central emerging theme in participants' perceptions of mathematical creativity. Before and after the program, they often elaborate on the importance of students' task posing (although after explicit encouragement from the teacher), and students' expanding previously solved tasks. For example, Georgia states that "*Creative tasks usually allow students to expand them, to bring them closer to their interests… By extending them, students can decide to ask questions as they wish. This way, even a "closed" problem, which may not be creative, can lead to another problem.*"

Apart from describing the characteristics of creative tasks during their interviews, participants also chose tasks they considered to be creative when completing the questionnaires. They also elaborated on the reasons for their choices, offering better insight into their perceptions of creative tasks. Due to space limitations, presenting all seven participants' choices is impossible. Instead, the tasks proposed by two participants are described in the present study, which are, to a great extent, representative (for a further analysis of the tasks proposed, see (Zioga & Desli, 2019a).

Helen's Tasks

Helen strongly connects creativity to fluency and students' real life in her interviews. These perceptions are also reflected in her choices of tasks when completing the questionnaire. More specifically, before the program, she proposed the task that can be seen in Figure 1, which was retrieved from the Grade 4 Greek school mathematics textbook. She explains why she believes it fosters creativity: "*It is creative because it is an open task, and it relates to students' everyday life*." The task she chose and the reasons for choosing it are in accordance with her statements during the interview. The particular task has, indeed, several correct answers, which are, in fact, different combinations of sums. However, reaching a solution does not require flexible, non-stereotypical, or original thinking. Despite the possible combinations of toys and prices, the solution is rather algorithmic and relies on adding two, three, or four decimal numbers. As a result, it cannot be regarded as a representative example of creativity-fostering tasks.

Figure 1. Helen’s choice of task before participating in the program

The task Helen chose as creative after participating in the program, as shown in Figure 2, was also taken from the school mathematics textbook. She explains why it is selected: “It has more than two or three solutions. It requires abstract and critical thinking.” Hence, Helen connects mathematical creativity to fluency, abstract thinking, and critical thinking. The task requires students to identify and write down all possible combinations of flavors that can be achieved with two scoops of ice cream. It is quite different from the typical Greek textbook tasks. It also prompts students to think in a non-algorithmic way and search for a suitable strategy that allows them to search for all combinations without eluding one.

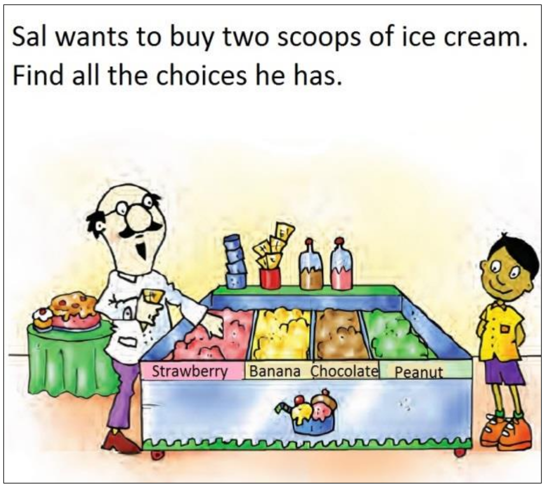

Figure 2. Helen’s choice of task after participating in the program

Although Helen does not mention anything else, the task can easily be extended or modified (for example, using the “What-if…” strategy) to allow students to gain more profound knowledge in combinations and simultaneously develop flexibility. More specifically, after students discover and understand the strategy to find all combinations that can be made with two scoops of ice cream, they can be encouraged to find all possible combinations with three scoops of ice cream (or with more than four flavors). This way, the task becomes more cognitively demanding and also requires (and fosters) flexible thinking in order to search for suitable strategies. Consequently, the specific task offers the opportunity for creativity development. However, when selecting it, Helen apparently did not realize the potential to extend it and cultivate students' mathematical creativity to a greater extent.

Nicole's Tasks

Nicole, a 1st-grade teacher, adopted a similar approach to Helen. Before the program, she presented the following task (Zioga & Desli, 2019b): "*Kostas played marbles and lost 4. Now he has 5 marbles. How many marbles did Kostas have before he played?*". She briefly mentions the reasons for choosing it: "*It cultivates the concept of addition. (It represents) addition situations beyond their stereotypical form*", indicating that she values the mathematical content of the problem. However, this is a relatively common task encountered in textbooks and does not require flexible or original thinking.

After the program, Nicole proposed two tasks: "*The children in our school choir are 19. The boys are more than the girls. How many boys and how many girls could there be?*" and "*I have a collection of dinosaurs. They are more than 15 and less than 18. I can count them by twos. How many dinosaurs do I have?*". Indeed, these problems favor cultivating creativity as they allow for fluency and flexibility development beyond simply applying an algorithmic rule. However, both tasks were presented almost intact during the program for discussion and further modifications. Hence, Nicole hesitated to seek out new creative tasks or formulate her own.

Synthesis Across Themes

In the previous sections, the findings were presented based on distinct thematic categories for clarity. However, certain patterns emerge when these themes are considered in relation to one another. Teachers' conceptions of mathematical creativity appear to be closely connected to their perceptions of creative students and educators. For instance, participants emphasized flexibility and openness as key elements of creativity and tended to describe creative students as those who think differently and offer diverse solutions. Similarly, participants associated creative teaching with providing space for exploration and encouraging non-standard approaches. Hence, their beliefs about creativity and pedagogy appear to be consistent. However, when examining their task selection, this alignment is not always evident. While teachers emphasized originality as a key component of creativity, they often selected tasks that primarily promoted fluency or flexibility, without explicitly addressing originality. This indicates a discrepancy between theoretical understanding and practical choices. The connection between pedagogical beliefs and task selection is crucial, as task selection is closely tied to everyday instructional practices. Therefore, future professional development programs should aim to strengthen these connections in order to promote teaching practices that effectively foster students' creativity.

Participants' Perceptions of Mathematical Creativity and Their Evolution after the Program

In this paper, we aimed to shed further light on the perceptions underlying commonly observed practices of in-service teachers regarding mathematical creativity and its development in the classroom following their participation in a program focused on creativity in mathematics. Overall, participants' attendance at the program appears to have positively influenced certain perceptions of mathematical creativity. They reported gaining new insights into the potential of open-ended and non-routine tasks to foster creativity and expressed greater optimism about the feasibility of cultivating creativity in school settings. However, the changes observed after the program were not uniform, especially concerning perceptions related to creative tasks. In several cases, teachers' views on many aspects of creativity remained relatively stable. We discuss each key finding in turn as follows.

A major shift was observed in teachers' perceptions of the malleability of mathematical creativity in classroom contexts. Prior to the program, most participants were skeptical about the extent to which creativity could be nurtured in mathematics classrooms, often citing curricular constraints. For instance, Andrew described the current educational context as one in which students' creativity is actively suppressed. In contrast, participants in Aljughaiman and Mowrer-Reynolds' (2005) study were more optimistic, with 81% believing that creativity could be cultivated in schools. Following participation in the program, most of our participants confidently stated that creativity can indeed be developed in school settings. This is significant, as teachers who view creativity as a learnable and dynamic trait are more likely to adopt practices and tasks that nurture it. Another noteworthy shift involved the expansion of participants' perceptions of who can be creative in mathematics. After the program, teachers extended their views to include younger students, suggesting that the activities and discussions they engaged in helped them recognize that creativity can be fostered across all age groups.

Teachers' conceptions of tasks that promote mathematical creativity also evolved, particularly with greater recognition of the value of open-ended, multiple-solution tasks and non-routine problems that promote flexibility and fluency. In addition, participants began to assign a more active role to students—at least theoretically—by highlighting the value of problem modification and expansion as student-generated activities. However, certain perceptions remained relatively unchanged. Teachers continued to associate creative students with flexible, non-algorithmic thinking, self-confidence, curiosity, and intrinsic motivation—traits they viewed positively. These findings are consistent with those reported by Leikin et al. (2013), who also found strong associations between student creativity and flexibility, intrinsic motivation, and enjoyment of problem-solving. The belief that self-confidence enables students to take intellectual risks is also noted in previous studies (e.g., Aljughaiman & Mowrer-Reynolds, 2005). Unlike participants in Leikin et al.'s study, however, our participants did not mention the abilities to pose conjectures or discover mathematical patterns—two traits frequently linked to mathematical creativity.

Participants' views of creative teachers remained fairly consistent before and after the program. They described creative educators as those who connect mathematics to students' everyday lives and interests, employ innovative instructional approaches, and depart from textbook-based instruction. These perceptions align with Craft's (1997) findings, which highlight teachers' willingness to adapt lessons to meet students' needs as a hallmark of creative pedagogy. Similarly, our findings resonate with those of Lev-Zamir and Leikin (2011), who emphasized pedagogical flexibility and originality as core features of creative teaching. After the program, our participants further described creative teachers as fostering student independence and initiative, avoiding authoritative teaching styles, and encouraging exploration without rigid guidance. Although not always explicitly stated, these practices promote student-driven idea generation and inquiry, processes that align closely with the creation of new mathematical knowledge.

Participants also emphasized the importance of a democratic classroom environment for fostering creativity—both before and after the program. They stressed the need for safe spaces in which students feel free to share their ideas, take risks, and collaborate. This aligns with Bereczki and Kárpáti's (2018) findings, which highlighted positive classroom relationships and collaborative structures as central to creativity-supportive environments. Another key element was the acceptance of fallibility: teachers acknowledged that creative endeavors often result in incorrect or incomplete solutions, a view also emphasized in the literature (e.g., Ervynck, 2002; Sriraman et al., 2011) and during the program itself.

A critical finding concerns the persistent neglect of tasks that promote originality, elaboration, or the discovery of new knowledge. Despite most participants associating creativity with originality (see Table 3), they did not prioritize tasks that could explicitly support this aspect. This disconnect—valuing originality in principle but not promoting it through task selection—suggests a gap between beliefs and practices. This finding contrasts with Shriki's (2010) and Bicer et al.'s (2022) studies, where participants identified originality-supporting tasks. One explanation may be that, even after the program, teachers have not fully internalized their role in selecting diverse task types that foster all facets of creativity.

The consistent omission of tasks promoting elaboration (e.g., abstract thinking and generalization) is less surprising, as such tasks are underrepresented in both the literature and in standard textbooks. Elaboration is rarely addressed in studies of mathematical creativity (e.g., Bicer et al., 2022; Kwon et al., 2006), possibly due to its difficulty to define and assess. Kozlowski et al. (2019) highlight the need for more inclusive assessment frameworks that incorporate elaboration. Our interviews and weekly discussions confirmed that participants were largely unfamiliar with elaboration-focused tasks and did not fully appreciate their potential. Levenson (2022) also found that teachers undervalued generalization in relation to creativity development. Our findings suggest that explicit training on elaboration-focused tasks during teacher preparation and professional development is necessary. This recommendation aligns with other studies emphasizing the importance of equipping prospective teachers with a robust understanding of mathematical creativity and related task types (e.g., Bolden et al., 2010; Desli & Zioga, 2015).

Overall, the changes in participants' conceptions following the educational program were more limited than those observed in earlier studies (e.g., Shriki, 2010; Levenson, 2015; Bicer et al., 2022). One likely explanation is that our participants were experienced in-service teachers, averaging 21 years of teaching. Their longstanding professional experiences may have led to more firmly held beliefs, which are more resistant to change. In contrast, participants in previous studies were prospective teachers still undergoing professional formation, and therefore potentially more open to new perspectives. These findings suggest that shifting in-service teachers' beliefs about creativity may require extended or more intensive interventions. The results highlight the ongoing need for targeted research and sustained efforts in teacher education to promote the meaningful integration of mathematical creativity into classroom practice.

Reflections on the Program

Looking back at the impact of our program on participants, we have realized that certain aspects need to be emphasized in future implementations. Despite addressing all emerging themes during weekly meetings, participants' perceptions of specific topics remained unchanged, reflecting their prior beliefs. For example, their views on the distribution of mathematical creativity among students did not evolve, likely because they continued to attribute creativity to specific personal traits based on preconceived notions. Therefore, themes and attributes where perceptions remained stable—such as beliefs about the distribution of creativity, creativity-fostering strategies, and tasks that promote originality and elaboration—can inform the design of future programs.

We also recommend that future programs explicitly address teachers' problem-posing abilities. This would enable teachers not only to recognize creative tasks but also to adapt and generate them—for example, by collaboratively "opening up" or extending existing problems. While our program did include activities where participants discussed, solved, selected, and modified tasks, they were not asked to create new ones. Moreover, task modification was addressed in only one meeting, during which participants were hesitant to engage actively. Thus, we suggest allocating more time and focus to task creation in future interventions.

In addition, we propose a more practice-oriented approach to professional development. Specifically, future programs could incorporate hands-on activities in which teachers classify and analyze tasks—and students' responses—based on the four indices of creativity. Such activities could enhance teachers' ability to distinguish between various creative traits and develop a deeper understanding of how these traits are expressed in students' mathematical thinking.

CONCLUSION

This study examined how in-service primary school teachers' perceptions of mathematical creativity evolved following participation in a professional development program. The findings suggest that while the program facilitated meaningful shifts in certain areas—most notably, teachers' recognition that mathematical creativity can be cultivated in school and their growing appreciation of multiple-solution and non-routine tasks—other areas of conceptual development remained limited. Specifically, participants showed increased readiness to support students' fluency and flexibility in mathematical problem solving. However, they continued to experience difficulties in identifying or designing tasks that effectively promote originality and elaboration, two critical components of creativity. These results point to the need for more targeted support and sustained engagement if teachers are to develop a well-rounded understanding of mathematical creativity and implement it in practice.

The implications of these findings are particularly relevant for curriculum developers, teacher educators, and policymakers. In contexts such as Greece, where national curricula and textbooks are undergoing revision, there is a pressing need to embed the development of creativity explicitly within learning goals and instructional resources. Teacher guides should offer concrete examples of creativity-enhancing tasks and outline strategies for assessing creativity in students' mathematical work. Furthermore, the outcomes of this study underscore the importance of designing professional development programs that provide teachers with structured opportunities to modify, extend, or "open up" existing textbook problems in ways that target all four creativity indices: fluency, flexibility, originality, and elaboration. Beyond formal training, embedding creative tasks into everyday instructional materials and classroom practices could offer more accessible and sustainable pathways for cultivating mathematical creativity in primary education.

Several limitations of the present study must be acknowledged. First, the small sample size restricts the generalizability of the findings, as participants may not reflect the broader population of primary school teachers. While their insights revealed meaningful tendencies, more extensive research involving a larger and more diverse group is necessary to confirm these trends. Second, the voluntary nature of participation may have introduced a self-selection bias, as those who enrolled in the program were likely predisposed toward professional development and innovation in teaching. Consequently, the effects observed in this group may not be as readily replicated across the general teaching population. Lastly, the study relied primarily on self-reported data gathered through interviews and questionnaires. Future research would benefit from incorporating classroom observations and the analysis of instructional artifacts to examine how teachers implement creative practices in situ. Such approaches could offer deeper insights into the translation of professional development outcomes into classroom realities and inform the design of more effective interventions.

Declarations

Author Contribution : MZ: Conceptualization, Writing - Original Draft, Investigation, Formal Analysis, Methodology, and Visualization.

DD: Conceptualization, Writing - Review & Editing, Formal Analysis, Methodology, and Supervision.

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Appendix A

Questionnaire for creative tasks

A. Please fill in the following information:

Sex: Years of teaching experience:

Age: Post-graduate studies:

Grade you teach:

B. Choose from any mathematics book you wish (school textbook or not), a task that, in your opinion, promotes students' mathematical creativity (creative thinking in mathematics).

Grade	
Teaching objective	
Description of the task	
Source – From where did you retrieve it? (Title and page)	
Please explain shortly why this task is, in your opinion, creative.	Thank you for your time!

Appendix B

Interview questions

1. What do we mean by the term "creativity"? Which individuals do you consider to be creative?

2. What is mathematical creativity? Which individuals are creative in mathematics?

3. With which personality traits is mathematical creativity associated with?

4. What influences mathematical creativity?

5. Can mathematical creativity be cultivated in school?

6. What kind of tasks, in your opinion, foster students' mathematical creativity? What characteristics should a task have for you to consider it is creativity-fostering? Can you give some examples?

7. What criteria do you use to decide whether a mathematical outcome results from creative thinking?

8. Do you employ creative tasks during teaching? If yes, from where do you retrieve ideas?

9. How do you teach them?

10. Which students are creative? Which students are creative in mathematics?

11. Which teacher is creative? Which teacher is creative in mathematics?

12. What can a teacher do to foster mathematical creativity in their classroom?

13. Which classroom environment favors the cultivation of mathematical creativity?

14. Can a person be creative in mathematics but not in other domains?