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# A Systematic Review on Instructional Strategies Promoting K-12 Students' Creative Thinking in Mathematics

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**Abstract**

Researchers noted that creative thinking (CT) in mathematics is helpful to students' mathematics learning in the basic education. However, little has been known about how CT in mathematics is being promoted in mathematics instruction as documented by empirical studies. To address this gap, this systematic review was conducted to document instructional interventions published from 2015 to 2024 that aimed to promote K-12 students' CT in mathematics. The main objective of this study is to determine the instructional strategies that can promote K-12 students' CT in mathematics, and the methods used on how CT in mathematics was measured. Using the PRISMA method as a guide, 114 articles were collected from the most common open-access research databases (ERIC, Google Scholar), and 12 qualified for the review. It was found that (1) the application of contextual learning, (2) the use of problem posing activities, (3) the use of inquiry-based learning, (4) the use of problem-solving approach, (5) the use of cooperative learning, and (6) the use of interdisciplinary lesson can promote students' CT in mathematics. It was also found that the use of (1) problem solving tasks, (2) problem posing tasks, and (3) dialogic teaching episodes were the methods used to measure the students' CT in mathematics. The results suggested opportunities on how to develop school students' mathematical creativity as well as how to assess it in mathematics instruction. Furthermore, the systematic review identified gaps and discussed possible research focus.

**Keywords**: Creative thinking; Instructional strategies; K-12 education; Mathematical creativity; Mathematics; Students

## 1. Introduction

Creative thinking (CT) is a thought process of an individual that produces new, unique, or imaginative ideas (Ali et al, 2021). It is also the ability to form new ideas within a specific domain of knowledge or with other domains by either adhering to or transcending on the established symbolic rules and procedures (Leen et al., 2014) which are identified as novel and of high quality (Hong, 2013). According to the Organization for Economic Co-operation and Development (OECD, 2024), which is an international organization that conducts different assessments on an international scale to provide statistics-based actions and policies among participating countries, CT is an important skill that an individual must possess. Creative thinking is needed in the workplace as human resources should not rely on sole routine skills to be competitive and to be at par with the developing world. Thus, it is important that students must develop CT through education for them to become imaginative, develop original ideas, think outside of the box and solve problems which will help them prepare for a rapidly changing world that demands flexible and innovative workers equipped with “21st century skills” (Hong, 2013; Sternberg, 2017; OECD, 2024). In the results of the Programme for International Student Assessment (PISA) 2022, only 8.9% of the total assessed students reached the highest level of proficiency in CT (OECD, 2024). This particular international assessment assessed 15-year-old students' ability in mathematics, reading, science, and, for the first time, students’ proficiency in CT, with the reason of looking into the quality of basic education that the students received and the role it played in developing the students’ literacy in those specific areas. The result implies that most school students face challenges in thinking creatively, thus exploring the students’ CT is needed.

Creative thinking is also an important variable in mathematics education. Promoting CT in mathematics instruction is an important goal as it relates to other relevant constructs such as students’ mathematical ability and mathematical understanding (Leikin & Pitta-Pantazi, 2013; Hadar & Tirosh, 2019; Tubb et. al, 2020). Creative thinking in mathematics is one of the domain-specific views of creativity; however, mathematical creativity lacks an exact definition. The available definitions of mathematical creativity in the literature vary, but Craft (2003) pointed out that it is important to distinguish “everyday creativity” from “extraordinary creativity”, wherein the former describes creativity in simple tasks while the latter causes paradigm shifts in a specific body of knowledge. This kind of idea is depicted in how Sriraman (2005) defined creativity in mathematics at the professional level and at the K-12 level or the school level creativity, where the former refers to notable works in the world of mathematics while the latter refers to simple tasks such as in teaching and learning activities in a mathematics instruction. School level creativity can be described as the process that results in new solutions to a given problem or the formulation of new questions by viewing the old problem from a different angle, and not necessarily an extraordinary work (Nadjafikhah et al., 2012). This systematic review investigated the different mathematics instructional strategies that can stimulate students’ CT in the school level mathematical creativity.

According to Brandt (2023), CT is "instructionally malleable", which means that with the proper environmental conditions and support from implementation to assessment, teachers and mentors can foster CT among learners. In the literature, several instructional initiatives have been documented to enhance an individual’s CT, both in domain-general creativity or specific in mathematics. Smare and Elfatihi (2023) systematically reviewed the empirical studies that explored primary students’ CT but it was more particular on the studies’ focus of investigation and methodologies, and not on the students’ creative thinking in mathematics. Bicer (2021) also reviewed the suggested instructional practices in the literature that can promote the students’ mathematical creativity in K-16 education and identified discipline-specific instructional practices (e.g. problem solving and problem posing tasks) and general instructional practices (e.g. allowing students to make mistakes, establishing a collaborative classroom environment). However, the systematic review did not only focus on empirical studies and incorporated other sets of investigations about students’ CT in mathematics. Ali et al. (2021) also conducted a literature review on the effects of an open-ended approach to the students' CT in mathematics and found a positive link between the two.

It is also worth noting how CT in mathematics has been documented by researchers. Most research about individuals’ creativity were anchored to the creativity theory of

Guilford that relates divergent production to creative potential (Runco & Acar, 2012). He hypothesized several components for divergent thinking, but four important indicators were found to be more involved in the general creative thinking (Bicer, 2021). These indicators were fluency (the number of generated responses), flexibility (the diversity of generated responses), originality (the uniqueness of the responses), and elaboration (amount of detail used in the responses). The most used instrument by scholars to measure general creativity is the Torrance Tests of Creative Thinking (TTCT) of Torrance (1974) which acknowledged Guilford‘s four indicators of creative thinking. These indicators were also evident in mathematical creativity specifically in problem solving and problem posing, but in most cases only the indicators of fluency, flexibility, and originality were considered (Silver 1994; Silver, 1997; Kontorovich et al., 2011; Siswono, 2010). In problem solving, fluency refers to the ability to come up with many solutions or answers; flexibility refers to the ability to solve in different ways or to discuss many solution methods; and originality refers to the ability to generate a solution that is different from what was already given. In problem posing, fluency refers to the ability to generate many problems to solve; flexibility refers to the ability to pose problems that can be solved in different ways; and originality refers to the ability to create a different problem from what was already given. Although there exists a discussion that divergent thinking is not synonymous with creativity, it was found that divergent thinking tests can provide estimates of creative potential (Runco & Acar, 2012).

In order to have a broader scope of instructional strategies that can develop school students' CT in mathematics, this systematic review focused on the instructional interventions implemented in K-12 mathematics education. These empirical studies involved instructional strategies such as instructional materials, learning activities, a teaching pedagogy, or an instructional approach. These will give ideas to teachers on how to promote CT in mathematics in basic education as well as on the methods to use to measure it. In line with this, this systematic review answered the following research questions: (1) What instructional strategies were implemented to promote the K-12 students' CT in mathematics? (2) What are the methods used by empirical studies to measure the K-12 students' CT in mathematics?

## 2. Method

To have a systematic review on the different empirical studies conducted to promote the students' CT in K-12 mathematics education, the systematic review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method as a guide (Page et al., 2021). The databases that served as literature search sources were the Education Resources Information Center (ERIC) and Google Scholar because they are free to access unlike the subscription-based databases like Scopus and Web of Science. This makes the scholarly information and practical research-based documents easily accessible to the public, most especially by mathematics teachers who are not affiliated with a university or a research institution. The search terms used in both databases are (“creativity” OR “creative thinking” OR “creative”) AND ("mathematics" OR "mathematical") AND (“primary” OR “elementary” OR “secondary” OR “high school” OR “middle school” OR “K-12”), and these searched the studies' titles, abstracts, and keywords. A time frame was also set in the systematic review, focusing only on the studies published from 2015 until the start of the literature search on August 30, 2024. The time frame ensured that only the relevant and recent studies were gathered and helped narrow down the amount of possible studies from the vast literature.

The first 15 pages of ERIC (with 15 search results on each page) and Google Scholar (with 10 search results on each page) were screened manually. Since this systematic review focused on the intervention studies that promote K-12 students' CT in mathematics, titles with a focus beyond this context, and were irrelevant to the topic were disregarded right from the start of the identification of possible research articles. An example of the immediately disregarded study from the returned results is the study of Willemsem et al. (2024) titled "Strengthening Creative Problem Solving within Upper-Elementary Science Education". The title focuses on science education, which is not the scope of this systematic review. A total of 114 studies were identified from both databases, which were subject to further screening.

The studies to be reviewed must be written in English to scrutinize them further if they can help meet the goal of this review. During the screening, the first author read the title, abstract, and the available full text to gain a deeper understanding of the paper. More than that, an inclusion criterion guided the screening process. After removing the duplicates (n=3) and papers with no full-text versions (n=2), 109 studies were screened following the inclusion criteria. The inclusion criteria for the literature search are as follows: (1) a journal article, (2) have a focus on students' CT in mathematics, (3) set within K-12 mathematics education, and (4) explicitly state the process of the instructional intervention. Figure 1 showed the summary of the screening process.

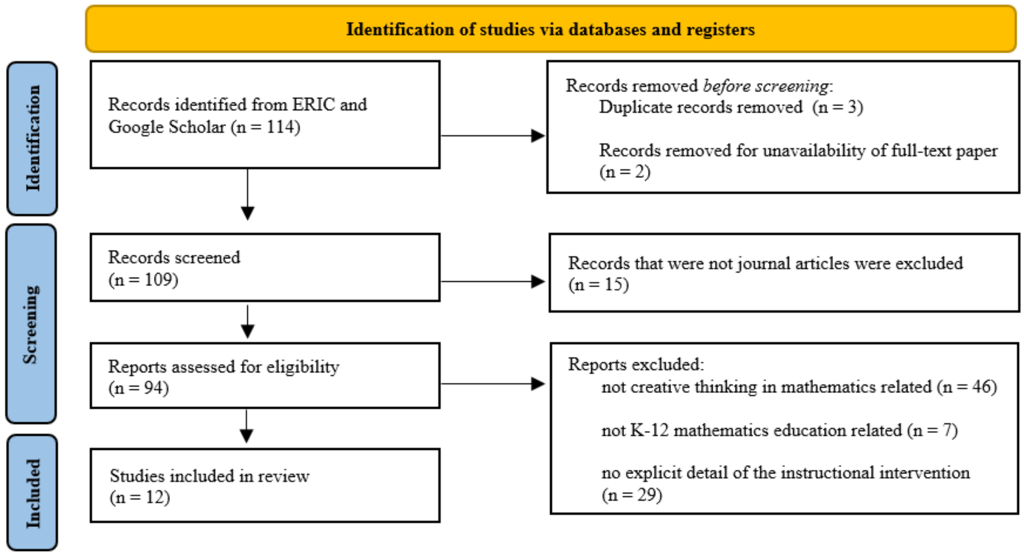


Figure 1. Summary of the screening process

The first inclusion criterion is that it should be a journal article to ensure the paper's quality. Bradford's Law states that journal articles provide the most quality scientific findings in the literature (Testa, 2009). Additionally, papers from conference proceedings were removed from the list as results from these papers can be similar to those available in journal publications (Ye et al., 2023). This criterion disregarded conference papers and unpublished works like online theses and dissertations. Of the 109 identified studies, 15 were omitted, as most were conference proceedings such as Bicer et al. (2019) and Tamur and Juandi (2020).

The second criterion is that the investigation set in the article should focus on the students' CT in mathematics. Although the search terms "mathematics" and "creative thinking" are among the keywords, the search results still returned studies about CT from other domains. Studies set in other domains and those that did not focus specifically on the construction of CT were disregarded like Suwistika et al. (2024), and Sur and Ates (2022). This criterion removed 46 articles from the list.

The third criterion is that the study should be set within K-12 mathematics education. This means that the participants involved in the study should come from pre-school to secondary education. Seven studies involving teachers' perceptions of students' CT and studies investigating undergraduate students such as Stolaki and Economides (2018), and Kurniasih and Hidayanto (2022) were removed from the list.

Table 1: Summary of reviewed studies (n = 12)

| Study | Grade / Country | Research design | Sample size | Instructional intervention | Duration of intervention | Method of measurement |
|---|---|---|---|---|---|---|
| Ayvaz and Durmus (2021) | Grade 7 (Turkey) | Qualitative (Action Research) | 6 | Problem posing activities | 30 hours | Problem Posing Test |
| Bicer et al. (2020) | Grade 3-5 (USA) | Quantitative | 205 | Problem posing activities | 20 minutes (twice a week for 4 months) | Problem posing tasks |
| Casing and Roble (2021) | Grade 11 (Philippines) | Quantitative | 100 | Posing-Exploring-Doing-Evaluating (PEDE) Productive Failure Model embedded in self-learning modules | 2 months | Multiple solutions tasks |
| Dang et al. (2023) | Grade 6 (Vietnam) | Quantitative | 229 | Creativity-enriched mathematics instruction, grounded in Realistic Mathematics Education (RME) principles | 21 hours | Mathematics Test with Creativity Rating Scale |
| Kadir and Satriawati (2017) | Grade 9 (Indonesia) | Qualitative (Action Research) | - | Open- inquiry approach | - | test in Mathematical Creative Thinking Skills |
| Kirisci et al. (2020) | Grade 7 (Turkey) | Quantitative (Solomon Four-Group Research Design) | 201 | Selective Problem Solving Model | 15 hours | Analogical Problem Construction Test and the Problem Analysis Test |
| Kwangpukieo and Sawangboon (2024) | Grade 10 (Thailand) | Quantitative | 40 | 5E Inquiry-Based Learning Approach with Supplementary Media | - | Creative thinking skill test with rubric |
| Lince (2016) | Grade 8 (Indonesia) | Quantitative | 130 | Numbered Heads Together (NHT) Model in group activities | - | test in Mathematical Creative Thinking Skills |
| Ndiung et al. (2019) | Grade 5 (Indonesia) | Quantitative | 101 | Treffinger Creative Learning Model with RME Principles | - | creative thinking skill test |
| Schoevers et al. (2019) | Grade 4 (Netherlands) | Qualitative (Case Study) | 22 | Open Interdisciplinary Lessons | 60-90 minutes/lesson (9 lessons) | dialogic teaching episodes |
| Tandiseru (2015) | Grade 12 (Indonesia) | Quantitative | 74 | Local Culture-Based Mathematical Heuristic-KR Learning | - | Creative Thinking Skill Test |
| Winarso et al. (2020) | Grade 8 (Indonesia) | Quantitative | - | Problem Posing; Contextual Learning | - | test of creative thinking ability |

The last of the criteria is that the paper should detail the intervention process done in the mathematics instruction. Most studies making it to the last screening stage were not intervention studies. Some were correlational studies relating students' CT in mathematics to other constructions like Palwa et al. (2024). Others did not explicitly detail how the intervention was employed in their mathematics instruction like Geng et al. (2019). These reasons invalidated 29 papers and left 12 studies in the final list for the systematic review.

The systematic review finalized the list with 12 studies, but one study implemented two instructional interventions, resulting in 13 interventions analyzed in this systematic review. Table 1 presented the summary of the reviewed studies. This systematic review categorized the instructional interventions based on their approaches and underlying mechanisms. While some interventions employed a combination of instructional strategies, the most emphasized strategy was categorized. It follows that each intervention was classified into a single category. On the other hand, the method on how the students' CT in mathematics were documented was also classified.

## 3. Results and Discussion

This section presented and discussed the categories of instructional strategies found to promote CT in mathematics, and the categories of methods used to measure CT in mathematics.

Table 2: Instructional strategies to promote K-12 students' CT in Mathematics

| **Instructional strategies** | **Study** | **Frequency (n=13)** | **Percentage** |
|---|---|---|---|
| Application of contextual learning | Dang et al. (2023)<br>Ndiung et al. (2019)<br>Tandiseru (2015)<br>Winarso et al. (2020) | 4 | 31% |
| Use of problem posing activities | Ayvaz and Durmus (2021)<br>Bicer et al. (2020)<br>Winarso et al. (2020) | 3 | 23% |
| Use of inquiry-based learning | Kadir and Satriawati (2017)<br>Kwangpukieo and Sawangboon (2024) | 2 | 15% |
| Use of problem solving approach | Casing and Roble (2021)<br>Kirisci et al. (2020) | 2 | 15% |
| Use of cooperative learning | Lince (2016) | 1 | 8% |
| Use of interdisciplinary lessons | Schoevers et al. (2019) | 1 | 8% |

### 3.1. Instructional strategies implemented to promote K-12 students' CT in mathematics

This systematic review noted the different instructional strategies implemented to promote K-12 students' CT in mathematics. Table 2 showed that the application of contextual learning, the use of problem posing activities, the use of inquiry-based learning, the use of problem solving approach, the use of cooperative learning, and the use of interdisciplinary lesson in a mathematics instruction can promote the students' CT in mathematics across the different levels in K-12 education.

*3.1.1 Application of contextual learning*

Four out of 13 interventions (31%) applied contextual learning in mathematics instruction to promote the students' CT in mathematics. Contextual learning allows students to build knowledge by finding the applications of a lesson to real-life situations (Johnson, 2002). The instructional intervention implemented by Dang et al. (2023) on Grade 6 mathematics classes in Vietnam is a creativity-enriched mathematics instruction grounded in Realistic Mathematics Education (RME) principles, which lasted for 21 hours. In this intervention, students explored a realistic problem. One of the activities employed in teaching the concept of ratio is when students measure the distance between their house and the school. The treatment group in the three schools who received the intervention showed more significant progress in giving more than one solution than students in the control group, both in the activities and mathematics questions. This indicated a progress in their CT. The same principles were also utilized in the intervention of Ndiung et al. (2019) as they combined it with the Treffinger Creative Learning Model in teaching fractions among Grade 5 students in Indonesia. This approach highlighted the use of a realistic problem suited to the students' experiences and knowledge and allowed them to explore and approach it in their ways. The experiment group that received the intervention had a higher measure of creative thinking skills than the students in the control group who received the conventional learning model.

Another approach to contextual learning was made by Tandiseru (2015) when he applied the Local Culture-Based Mathematical Heuristic-KR Learning in teaching the topic of geometric transformations among Grade 12 students in Indonesia. In his instructional intervention, he applied the local cultural context of the Toraja tribe and used the structure of their traditional house called "tongkonan" to teach the topic. Students worked out problems in ways that were different from what the teacher had presented. It showed that students taught with the intervention had higher results in their CT than students who received regular learning. Winarso et al. (2020) also used contextual learning in teaching circles among Grade 8 students in Indonesia. In his intervention, he provided the students with contextual problems involving the circle's central angle, arc length, and area, which they explored in relation to their daily lives. Students who received this intervention recorded a moderate level of CT but still higher when compared to a control group who received the expository learning.

The application of contextual learning dominated the interventions identified in this systematic review. Contextual learning is not just merely relating knowledge with real-world situations. It is more about using the students' experiences in their daily lives as an important tool to help them understand the concept better (Winarso et al., 2020). It can also be done by integrating one's local culture with mathematical concepts (Tandiseru, 2015) as well as by applying the RME principles in instruction (Dang et al., 2023; Ndiung et al., 2019). These initiatives were found to stimulate students' CT in mathematics. RME is a teaching and learning process that emphasizes the use of students' experiences in an active manner, and this helps students to gradually translate their concrete realities into abstract mathematical knowledge (Hasbi et al., 2019). More than that, applying RME principles was found to develop flexibility in the students' minds coming from a fixed one (Dang et al., 2023). Contextual learning highlights the use of working with realistic problems, making mathematics more familiar to the students. Students can approach these tasks in any way they can imagine, activating their creativity.

### *3.1.2 Use of problem posing activities*

Three out of 13 interventions (23%) acknowledged that problem posing activities improve students' CT in mathematics. Problem posing is referred to as creating own problems (Kopparla et al., 2019). Ayvaz and Durmus (2021) explored the CT in mathematics of seventh-grade gifted students in Turkey for 30 hours using problem posing activities. They utilized the three categories of problem posing situations according to Stoyanova and Ellerton (1996), which are structured, semi-structured, and free. These three categories differ on the sources where the students should create the problems from. It could be from a given solution (structured), from a given figure or picture (semi-structured), and from an idea or context only (free). The problem posing activities were embedded in three action plans, each focused on a single problem posing category. The series of action plans was reported to positively affect the students' performance not just in their ability to pose problems but also in terms of their mathematical creativity.

The same results were reported by Bicer et al. (2020). However, their instructional intervention only employed semi-structured problem posing activities among third, fourth, and fifth graders in the USA. Their intervention was done over 4 months, with 20 minutes for each intervention twice weekly. They only employed one form of problem posing category due to the reason that elementary students tend to generate a great number of identical problems if it is structured. At the same time, a lack of guidance may challenge them in the free category. In the study, students' CT recorded better in the problem posing group. On the other hand, the intervention employed by Winarso et al. (2020) did not specify the particular problem posing category used in their intervention. However, results showed that this intervention recorded the highest increase in the students' CT among contextual learning and expository learning.

Problem posing involves the process of creating mathematical problems in a particular context (Silver, 1994; Silver, 2013; Bonotto & Santo, 2015; Cai et al., 2023). Problem posing tasks can easily document the different aspects of CT in mathematics. In fact, problem posing can be associated with Sriraman's (2005) school level students' definition of mathematical creativity (Nadjafikhah et al., 2012; Bicer et al., 2020). Given that creativity lies in the ability of an individual to think differently and flexibly, this strengthens the importance of problem posing as a component of CT in mathematics (Ayvaz & Durmus, 2021). Aside from enhancing the mathematical creativity of students, problem posing interventions may change the perception that mathematics is only focused on finding answers as quickly as possible using a well-defined procedure (Boaler & Dweck, 2016).

*3.1.3 Use of inquiry-based learning*

Two out of 13 interventions (15%) also noted the potential of using inquiry-based learning in mathematics instructions to enhance the students' CT in mathematics. Generally, inquiry-based learning is focused on the students' process of finding a solution to a problem through investigations rather than depending on what the teacher will provide (Kadir & Satriawati, 2017). In the study of Kadir and Satriawati (2017), ninth-grade students in Indonesia investigated a mathematical problem using an open inquiry. In this learning process, the students formulated the problem, formulated a hypothesis, tested the set hypothesis, and drew a conclusion. They found that after two cycles, students showed improvement in their CT. The same results were also reported by Kwangpukieo and Sawangboon (2024) when they designed a 5E (Engagement, Exploration, Explanation, Elaboration, Evaluation) lesson plan anchored to inquiry-based learning using support from other tools, specifically the GeoGebra and Mathigon web applications. The intervention was used to teach the topic of geometric transformations to tenth-grade students from Indonesia. It was noted that after the intervention, students achieved a proficient level of CT.

Inquiry-based learning is a good way to enhance students' CT in mathematics. According to Indarasati et al. (2019), inquiry-based learning was among the instructional methods that promote the exploration of mathematical concepts by shifting away from the established routine procedures. This approach highlights the students' investigation of a problem while teachers only act as a guide and provide support to lead students in determining conjectures and building new knowledge (Kadir & Satriawati, 2017). The exploratory nature of this approach provided opportunities for students to express their creative ability in the subject.

*3.1.4 Use of problem solving approach*

Two of the 13 interventions (15%) employed problem solving approaches and activities in the instruction and significantly affected the students' CT in mathematics. In the study of Casing and Roble (2021), the Posing-Exploring-Doing-Evaluating (PEDE)

Productive Failure Model was utilized to design Grade 11 learners' modules in Statistics and Probability implemented during the modular distance learning. This model highlighted the use of a productive struggle. This is in the form of exploratory problem solving, where the module's design posed a challenging problem that was carefully selected so that it would not be too difficult for the students to give up. Their study showed that the experimental group recorded higher CT scores than the control group, who received the Activity-Analysis-Abstraction-Application (4A's) model in their learning modules. Similarly, Kirisci et al. (2020) utilized the same approach but employed a more tedious problem solving process in their intervention. They exposed seventh-grade students in Turkey to a very structured problem solving model, the Selective Problem Solving (SPS). For 15 hours, students explored solving a problem using the processes of analogical problem construction and selective thinking. This was done because the researchers determined these processes as main components of CT in mathematics. They found that experimental groups performed better in the given processes than the control groups. This indicates that the application of SPS stimulates the students' creative thinking in mathematics.

Problem solving skill has also been a pioneering variable when exploring creativity in mathematics education (Silver, 1994; Silver, 1997). Creative thinking has been an important aspect in problem solving process. Kirisci et al. (2020) explained that generating different methods and original solutions, which are the aspects of mathematical creativity, is used in solving a problem. This illustrates that CT is manifested in a problem-solving process. However, aside from being the prior process in a problem solving, other researchers even associated CT in mathematics directly as the ability to solve non-routine problems (Chiu, 2009; Nadjafikhah et al., 2012). This highlighted the strong connection between the two variables and showed that problem solving is a way to promote students' CT in mathematics (Craft, 2005).

#### *3.1.5 Use of cooperative learning*

One of the 13 interventions (8%) reviewed focused on cooperative learning to develop the students' CT in mathematics. Cooperative learning is a strategy where students develop individual accountability in each task (Brahier, 2020). This particular strategy was shown to significantly affect students' CT as Lince (2016) employed the Number Heads Together (NHT) Model in teaching the area of a triangle among Grade 8 students in Indonesia. After utilizing this model in the instructional activities, it was found that the students' CT in the experimental class was better than the control group. Cooperative learning emphasizes the importance of the total involvement of the students in the activity. Lince (2016) discussed the following stages involved in the NHT model. During the overview of topics, students connect their previous knowledge with the topic presented by giving many ideas. Next is the initial review of the topics, where they present their ideas clearly to others, and some conflicting ideas within the group may occur. In the in-depth review, they must deliberate and finalize their ideas at the last stage. In these stages, mathematical creativity showed to be a product of collective effort.

#### *3.1.6 Use of interdisciplinary lessons*

One of the 13 interventions gathered (8%), Schoevers et al. (2019) employed interdisciplinary lessons that integrated geometry lessons with visual arts education. Their study investigated different instructional settings. Their well-designed lessons were employed both "in-school," which refers to within the classroom, and "out-of-school," which refers to any setting outside of school. Interactions and conversations between the teacher and students in these instructional environments showcased manifestations of the students' CT in mathematics. Interdisciplinary lessons are also a good approach to stimulate the students' CT. Schoevers et al. (2019) found that when mathematics lessons are integrated with other disciplines, making it an "open" lesson sparked creative thinking among the students. They described an "open" lesson as an instruction that provides an open atmosphere and promotes a certain degree of freedom, which creates new and useful mathematical concepts in the students' minds. Moreover, these lessons allow the students to be active learners as they freely engage in the learning process (Nadjafikhah et al., 2012).

Table 3: Methods used to measure K-12 students' CT in Mathematics

| Method of measurement | Study | Frequency (n=12) | Percentage |
|---|---|---|---|
| Problem solving tasks | Casing and Roble (2021)<br>Dang et al. (2023)<br>Kirisci et al. (2020)<br>Kwangpukieo and Sawangboon (2024)<br>Winarso et al. (2020) | 5 | 42% |
| Problem posing tasks | Ayvaz and Durmus (2021)<br>Bicer et al. (2020) | 2 | 17% |
| Dialogic teaching episodes | Schoevers et al. (2019) | 1 | 8% |
| Unspecified test of CT in mathematics | Kadir and Satriawati (2017)<br>Lince (2016)<br>Ndiung et al. (2019)<br>Tandiseru (2015) | 4 | 33% |

## 3.2. Methods used to measure K-12 students' CT in mathematics

This systematic review also noted the varied methods used by the empirical studies to measure the students' CT in mathematics. Table 3 showed the identified instruments were in the form of problem solving tasks, problem posing tasks, dialogic teaching episodes, and some unspecified tests of CT in mathematics.

### *3.2.1 Problem solving tasks*

Five of the reviewed studies (42%) used problem solving tasks as a way to measure students' CT in mathematics. In the quantitative study of Casing and Roble (2021), multiple solutions tasks that contained four open-ended questions were employed in both pre-test and post-test. Students' answers to the given tasks were measured in terms of fluency, flexibility, and originality. Problem solving activities were also analyzed in the quantitative study of Dang et al. (2023). The researchers analyzed students' solutions in terms of flexibility by noting the production of multiple solutions in the said test. More than that, the researchers also utilized teacher observation using a creativity rating scale to note the CT expressions of the students during the mathematics instruction.

Another quantitative study by Kirisci et al. (2020) specifically used a Solomon-Four Group research design, where they employed problem solving tasks in a more structured and systematic way. They administered an Analogical Problem Construction Test, which includes five open-ended problems, and a Problem Analysis Test, which covers 20 multiple-choice items in their pre-test and post-test. These tests utilize other perspectives of mathematical creativity and acknowledge the students' analogical problem construction and selective thinking as major components of students' CT in mathematics. Winarso et al. (2020) also employed pre-test and post-test with four questions to determine one's CT. These were scored using a rubric with the indicators of fluency, flexibility, originality, and elaboration. The same CT indicators were also identified in the study of Kwangpukieo and Sawangboon (2024), but they only employed a post-test wherein students answered various mathematics problems.

Problem solving tasks were found to be the most common way to measure students' CT in mathematics. Aside from the claim of other researchers that mathematical CT ability is the problem solving itself (Haylock, 1985; Silver,1997), problem solving activities provide opportunities to document an individual's mathematical CT in different aspects by looking into how students approach a particular problem (Leikin & Lev, 2007; Suherman & Vidakovich, 2022).

*3.2.2 Problem posing tasks*

Two studies (17%) utilized problem posing tasks to assess the students' CT in mathematics, aside from being the intervention itself. In the action research conducted by Ayvaz and Durmus (2021), the three categories of problem posing were administered in their study (structured, semi-structured, free), but the students' composite creativity (CQ) scores only considered the indicators of fluency and flexibility. Their study explained that the small sample size may affect the scores' reliability in the aspect of originality, which is why it was not considered. Moreover, the posed problems were assessed using the researchers' "Problem Posing Assessment Rubric" before calculating its CQ scores in both the pre-test and post-test to screen out the quality of the posed problems. On the other hand, Bicer et al. (2020) only employed a post-test in their quantitative study. The students were administered with a semi-structured problem posing category, and the posed problems were scored using a rubric in terms of fluency, flexibility, and originality. The mean score for the students' mathematical creative ability was calculated by adding their scores within the three indicators.

Aside from problem solving, problem posing is also generally associated with school level mathematical creativity (Nadjafikhah et al., 2012; Ayllon, 2016). Although problem solving sparks creativity in mathematics, in problem posing, students do not only need to focus on solving problems. Students can experience finding and developing their own problems in problem posing activities (Stoyanova & Ellerton, 1996; Runco, 2007). Other researchers argue that problem posing provides a richer experience than problem solving, because students in problem posing activities generate new questions from different perspectives, which is believed to be the real progress in science (Einstein & Infeld, 1938; Bevan & Capraro, 2021).

*3.2.3 Dialogic teaching episodes*

One study (8%) utilized dialogic teaching episodes to document the students' CT in mathematics. According to Schoevers et al. (2019), a dialogic teaching episode is likely a discourse between the teacher and the students wherein it has a topic that is continued, unchanged, and, more importantly, manifested the principles of dialogic teaching such as purposefulness, collectiveness, and reciprocity. This qualitative tool was the primary source of information in their case study identified from the video transcripts. These dialogic teaching episodes were not based on the CT indicators that are mostly used in the literature. However, Schoevers et al. (2019) operationalized mathematical creativity as an instance when a student expresses an idea, solution, or problem that integrates two or more concepts (where at least one can be a mathematical concept) or expresses an idea that is considered new to the student. When an individual think about reforming a network of concepts to improve it, even though no new mathematics is produced, that individual is still engaged in mathematical creativity (Sriraman, 2011). This kind of method gave emphasis on the students' expression of mathematical creativity as a creative process rather than focusing on the creative products and evaluating students if they are creative or not based on how they solve or generate problems in mathematics (Hong, 2013; Leikin & Pitta-Pantazi, 2013).

*3.2.4 Unspecified test of CT in mathematics*

Among the collected studies, four (33%) reported measuring students' CT in mathematics through tests of Mathematical CT Skills but did not specify what kind of tasks were included in these tests. Kadir and Satriawati (2017) administered a test at every end of their two cycles of intervention to identify the students' mathematical CT skills in terms of fluency, flexibility, and originality. Lince (2016) also measured the students' CT in mathematics with a pre-test and a post-test in four indicators: smooth (which refers to fluency), flexibility, authenticity (which refers to originality), and of detail (which refers to elaboration). Ndiung et al. (2019) only reported a post-test of CT skill test, while Tandiseru (2015) administered a CT skills test in terms of fluency, elaboration, originality, and flexibility.

## 4. Conclusion

This systematic review found varied instructional interventions employed across K-12 mathematics education that can promote the students' CT in mathematics. Unfortunately, intervention studies that documented the CT in mathematics of pre-school students were not included in this systematic review. This calls for further exploration of students' CT in that very young age group. Due to the limited access to other research databases, the generalizability of the results is also limited. Amidst these limitations, it was evident that K-12 students' CT in mathematics is indeed associated with problem solving and problem posing tasks. Teachers' strategies involved students to solve a realistic or a challenging problem, or to solve a formulated or a discovered problem through investigations. However, it was also evident that CT in mathematics can also happen with student-student or teacher-student interactions which is not bounded by solving and generating problems.

Creative thinking in mathematics is an important skill not just to foster innovativeness in the subject but also to foster an in-depth understanding of mathematical concepts. This also helps learners build a perception that mathematics does not only revolve around algorithmic operations. This further implies the need to strengthen students' CT in mathematics in the basic education. Teachers must plan their instruction with opportunities for students to express their creativity. They may integrate creative tasks in mathematics instruction, such as utilizing problem solving and problem posing activities, supporting students' expression of ideas, as well as giving emphasis on creativity during assessments.

The focus of this systematic review may be on the instructional interventions employed to promote the students' CT in mathematics. However, the possibility of other factors that helped the intervention to be effective were also acknowledged, such as the teacher who employed the intervention, the learning environment experienced by the students, and the interactions between them. It is further recommended that more instructional strategies should be explored to promote students' CT in mathematics across different educational settings, levels, and contexts.

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