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Assessment of mathematical creative thinking: A systematic review

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ABSTRACT

With the increasing attention to mathematical creative thinking (MCT) in mathematics education, there has been a concomitant rise in the need to and interest in investigating how to assess MCT skills. Thus, a systematic review was conducted on how MCT has been assessed in the literature. We reviewed 70 journal articles to analyze specific MCT assessments from four perspectives: educational context, assessment of the familiar mathematics context, measurement tools, and reliability and validity of evidence. We found that (a) additional MCT measurements tools are necessary for secondary and high school levels; (b) the most familiar mathematics context for assessing MCT focuses Aon the curriculum of students according to the class level; (c) tools for assessing MCT often used open-ended questions, interview, multiple-choice, questionnaire, open-ended based on ethnomathematics, and Torrance Test of Creative Thinking (TTCT); and (d) the validity and reliability of the evidence of the MCT assessment tool should be collected and reported in further research. This systematic review identifies research gaps and topics for further research to conceptualize and assess MCT skills. The findings are expected to benefit researchers and teachers, to help them decide the best measurement tool to use in MCT assessment.

1. Introduction

Creative thinking (CT) is essential in solving mathematical problems or generating new ideas (Hadar & Tirosh, 2019). This process involves identifying the latest regular properties of objects and their transformation (Perry & Karpova, 2017). CT can also promote students' learning from their actions and experiences (e.g., events) in novel, personally meaningful manners (Alismail & McGuire, 2015). In addition, CT as a cognitive skill is vital for students to understand that they have processed results of a new idea or solution (Sitorus, 2016). Mathematical CT (MCT) is an essential competence for students and is usually based on either an underlying process or a manifested product. On the basis of the 21st-century framework, creativity can help students' rapidly changing competencies in the world. Consequently, assessments for evaluating MCT ability should be implemented in educational studies. According to Programme for International Student Assessment (PISA), MCT is the competence to engage productively in the learning, evaluation, and improvement of ideas that can result in original, practical solutions (OECD, 2019). Creativity assessment might be regarded as an attempt to identify creative abilities, solutions, synthesis in any area, or characteristics among students to understand their creative strengths and potential (S Kim, Choe & Kaufman, 2019.; Kozlowski, Chamberlin & Mann, 2019). These are the reasons of MCT is essential for students in school.

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The research on mathematics education has promoted the exploration of CT to develop a deep understanding of mathematics concepts (Aizikovitsh-Udi & Cheng, 2015; Hadar & Tirosh, 2019). Some researchers have argued that the essence of mathematics is thinking creatively, not merely arriving at the correct answer (Grégoire, 2016). Because teaching CT in mathematics is difficult and demanding, incorporating CT in specifically designed assessment materials can support teachers and increase the likelihood of student engagement (Ketelhut et al., 2020). As a central resource for teaching and learning, assessment materials provide students with opportunities to engage with the content and new skills (Hadar & Tirosh, 2019).

Many MCT definitions and assessment tools have been used. Researchers have defined MCT as students performing mathematical activities on the presumed nature of the cognitive process. In this manner, MCT is a cognitive process involving processing (Yusnaeni, AD & Zubaidah, 2017). In addition, mathematical creativity is the combining of mathematical ideas, approaches, or techniques in a new manner (Boud, Lawson & Thompson, 2015; Suherman, Vidákovich & Komarudin, 2021). Similarly, CT is generating and constructing arguments and the competence necessary for students (Lucas, Claxton & Spencer, 2013; OECD, 2019). Based on the definition of MCT, our conclusion is that MCT is characterized by creating something new from the results, ideas, descriptions, concepts, experiences, and knowledge related to mathematics that covered fluency, flexibility, originality, and elaboration.

The MCT tool has drawn increasing attention from researchers since Torrance promoted it as the Torrance Test of Creative Thinking (TTCT). The use of CT assessment was recorded as early as the 1960s, in the area of creativity research (Bolden, DeLuca, Kukkonen, Roy & Wearing, 2020; Torrance, 1966). Because each student's creativity level may differ, their interests, characters, and degrees of creativity may also differ. Said-Metwaly claimed that an increase in students' interest can be observed in the CT aspect, especially in mathematics, by using the MCT assessment tool (Said-Metwaly, Fernández-Castilla, Kyndt & Van den Noortgate, 2018). Moreover, the justification assessment of creativity was used to establish baseline data useful in diagnosing students' needs and curricula, evaluating efforts for creativity enhancement, assessing creativity efforts for creativity enhancement, and assessing creativity aspects, which are invaluable in explaining creativity functions.

An adapted version of the TTCT encompasses three creative aspects: flexibility, fluency, and originality. Chesimet described fluency as the ability to produce several response ideas to a mathematical question; flexibility as the ability to generate a wide range of ideas and various solutions to a mathematical task; and originality as the ability to produce distinct, personal ideas and solutions to problems (Chesimet, Githua & Ng'eno, 2016).

Some studies have analyzed the work related to MCT assessments using diagnostic tools. The literature has demonstrated that the test instruments effectively measure CT (Hidayat, Susilaningsih & Kurniawan, 2018). However, the diagnostic tools of CT can cognitively achieve the indicator of the fluent, elaborated thinking of students but have not been able to measure the indicator of flexible, original thinking. Sitorus also researched assessment tools. He stated that the CT stage can be assessed by implementing realistic mathematics (Sitorus, 2016) but was not able to measure CT skills. Mathematics activities and tasks asking students to perform a procedure in a routine manner represent an opportunity for student thinking—but this is not CT (Hadar & Tirosh, 2019).

Since its emergence, MCT skills competence has contributed to various fields of research. However, systematic reviews of the MCT assessment's current practice and the assessment have been limited, particularly in mathematics education. Research has demonstrated that the test used has not been oriented to CT skills. In addition, the review of the research revealed a lack of assessment tools in mathematics, making further research on assessing MCT unclear. This study aimed to systematically review studies on the assessment of MCT.

1.1. *Creative thinking*

Individuals engaging in CT use their minds to create a new set of thoughts from a collection of memories containing various ideas, descriptions, concepts, experiences, and knowledge (Gie, 2003). In other words, CT is characterized by the creation of something new from the results ideas, descriptions, concepts, experiences, and knowledge. CT is not only the generating and constructing of ideas but also a competence necessary for students (Lucas et al., 2013; OECD, 2019).

CT refers to the skills used to explore novel ideas or generate solutions while problem-solving. This definition builds on Guilford's division of creativity into eight constructs: flexibility, fluency, novelty, analysis, reorganization, redefinition, synthesis, complexity, and elaboration (Guilford, 1967). Others have proposed variations of Guilford's definition (e.g., Sternberg & Lubart, 1999; Torrance, 1988), and it or a variation of it is frequently used in CT research (e.g., Kadir & Satriawati, 2017; KANİ Ülger, 2016).

One study area concerns the cognitive processes involved in CT (S Suripah & Retnawati, 2019.). This research asks what occurs in individuals' perceptions when they think creatively. One answer is from the perspective of insight (Borodina, 2020). Researchers (e.g., Hadar & Tirosh, 2019; Sternberg & Lubart, 1999) have advocated that creative thinkers employ lateral thinking, in which thoughts jump flexibly from one aspect to another instead of merely following existing paths. Three types of thinking may dominate how creative individuals think: lateral, divergent, and convergent-integrative. Lateral thinking is a part of the cognitive system responsible for operating different perspectives in generating thinking systematically of new ideas (Hadar & Tirosh, 2019), and describe processes (De Bono, 2006). Researchers have defined fluency and flexibility as mediated through lateral thinking (Hilmi & Usdiyana, 2020; Torrance, 1966). Divergent thinking is a second answer to the question about what individuals do when they think creatively (De Bono, 1991). Furthermore, divergent thinking is a novel idea regarding what occurs in individuals brains while thinking creatively (Nurkaeti, Turmudi, Pratiwi, Aryanto & Gumala, 2020). In this area of divergent thinking, students formulate multiple solutions to an open-ended problem (Volle, 2018). Divergent thinking assessment refers to originality, novelty, fluency, flexibility, elaboration, and explanation. A third answer is the description of convergent-integrative thinking in which individuals identify critical elements of a problem and figure out how the pieces fit together. Convergent-integrative thinkers see new relationships, combine different ideas, determine patterns, and form new links between formerly disparate entities (Hadar & Tirosh, 2019). In addition, convergent thinking is a skill related to content knowledge, logic and reasoning, and intelligence. The areas of lateral thinking, divergent thinking, and convergence thinking are presented in Fig. 1.

In its application, divergent thinking criteria develop and follow the field of study (scope) of CT skills. For example, mathematics emphasizes four aspects: fluency, novelty, flexibility, and originality (Beghetto, 2017; Kozlowski et al., 2019; Leikin & Lev, 2007).

1.2. Mathematical creative thinking

The importance of engaging students in CT is widely recognized (Lai, 2011). Therefore, the program education goals of many countries promote MCT to develop the next generation of innovators. For example, the new 2013 curriculum (K–13) in Indonesia includes a focus on "critical and creative thinking" for problem-solving in the mathematics curriculum as a national goal for education (Kemendikbud, 2017).

CT in mathematics is needed to develop students' abilities. It can be understood by focusing on the responses of problem-solving students with out-of-the-ordinary thought processes and examining divergent production by determining the criteria of results through MCT indicators namely, flexibility, authenticity, and appropriateness (Haylock, 1997). Thus, problem-solving can be an approach to understanding the MCT abilities of students.

Some research reviews have suggested that MCT includes skills to answer mathematical problems and assess students' ideas of the concept (Hetzroni, Agada & Leikin, 2019a). MCT relates to divergent and convergent thinking; problem finding; problem-solving; observing new relationships; and making associations among techniques, ideas, and application areas (Hadar & Tirosh, 2019). As a result, Haylock said that CT almost always involves flexibility and demonstrated criteria per the Torrance Test type for creativity (CT products), namely, the number of acceptable responses, the number of types of responses, and the statistical infrequency of the responses in relation to the peer group (Haylock, 1997). Thus, students with different abilities and backgrounds will have the ability to answer problems per their abilities.

Researchers have applied the concepts of fluency, flexibility, elaboration, and originality to MCT (Nufus, Duskri & Kuala, 2018; Sahliawati & Nurlaelah, 2020) and the concepts of fluency, flexibility, and elaboration to mathematics CT (Gilat & Amit, 2013; Huljannah, Sa & Qohar, 2018). Fluency refers to mathematical creativity, namely, the ability to conceive multiple solutions (Kozlowski et al., 2019). Another perspective of creative mathematical thinking is flexibility (Leikin & Lev, 2007; Mann, 2005), namely, the ability to change thinking paths when encountering an impasse or thinking obstruction (Krutetskii, 1976; Leikin & Lev, 2007). Originality is also cited as novel, because it is associated with the ability of individuals to seek out an answer path that is particularly distinctive and uncommon for their information level (Siswono, 2011) and then create a solution to and novel ideas (Kozlowski et al., 2019). Last, elaboration describes the ability to allow in-depth reasoning behind an answer path (H Kim, Cho* & Ahn, 2004.).

1.3. Mathematical creative thinking assessment

Assessment plays a critical role when educators introduce MCT into teaching and learning in classrooms and teachers have more discussions on how to assess students' mastery of MCT skills in their real-life situations. In this systematic review, we categorized MCT assessment by referring to paradigms of assessment methods or tools in the literature. Some MCT studies have employed a selected-response test or a constructed test (e.g. studies have developed a paper-and-pencil test to assess students' MCT skills (Butler, 2018), a multiple-choice test as an assessment of MCT to assess algebra expression concepts (Tabach & Friedlander, 2017a), and open-ended questions to assess students' application of MCT skills in mathematical problem-solving). The open-ended approach based on ethnomathematics are another commonly used assessment tool. Numerous research have created tool for open-ended approach based on an ethnomathematical assessment to evaluate students' work and observe their CT process (Faiziyah, Sutama, Sholihah, Wulandari & Yudha, 2020; Zaenuri, Nastiti & Suhito, 2019), namely, the batik motif (patterns that combine lines, shapes, and isen to create a single entity that embodies batik as a whole) content of ethnomathematics and an ethnomathematics that allows users to build concepts of geometry material. In these tool phenomena, using another landscape of ethnomathematics content, for example, a tapis motif (pattern that covers a variety of line elements, such as straight lines, curves, zigzags, spirals, and various shapes such as triangles, rectangles, circles, kites, and regular polygons) is important to assess MCT in the mathematics concept perspective. Interviews and questionnaires

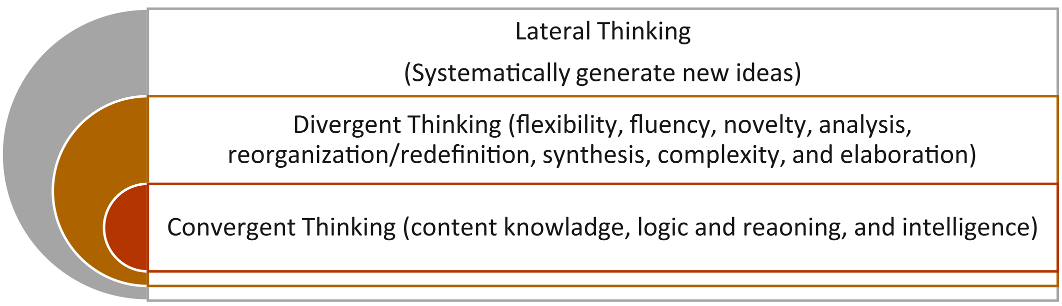

Fig. 1. Model of CT.

have also been used. For example, Istiqomah, Perbowo and Purwanto (2018) used interviews to examine secondary school students' cognitive knowledge of MCT concepts, and Murni, Bernard, Ruqoyyah and Chotimah (2020) designed a questionnaire to support students' final project in MCT. The TTCT has been used to explore mathematics solutions and thinking concepts: divergent thinking and convergent thinking (Ülger, 2016).

Researchers have examined the quality of MCT assessment, for instance, the validity and reliability of perception scales for MCT skills. Conducted validity has been designed as a multiple item test with a CT rubric devised by mathematicians and practitioners (Puspitasari & Wahyudin, 2020) that uses a confirmatory factor (Hetzroni, Agada & Leikin, 2019b).

This study aimed to systematically review the MCT measurement tool in more detail than other reviews have regarding CT in teaching and learning perspectives across all educational levels. In other words, we reviewed studies on assessment tools in MCT, what types of mathematical material were measured in those studies, and the validity and reliability of the evidence on MCT instruments (i.e., assessment tools).

Four research questions (RQs) formed the basis of this review:

- RQ1: What are the educational levels to which MCT assessments have been applied?
- RQ2: What are the mathematics contexts for assessing MCT?
- RQ3: What tools were used to measure MCT?
- RQ4: What is the validity and reliability of the evidence that supports assessing MCT?

2. Method

We conducted a systematic, structured literature review, in which we searched widely used, comprehensive digital databases for relevant information on MCT tools. To perform the review, we used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009). The steps used were as follows: we (1) identified the topics and searched for relevant studies; (2) screened documents to identify essential studies; (3) examined eligibility studies; and (4) included the documents of the analyzing, synthesizing, and describing studies Fig. 1. illustrates these steps: this flow diagram provides the information analysis in the stages of the systematic review, showing the PRISMA steps in reviewing articles on CT tools in mathematics.

Regarding the reference type, the original search of several databases was conducted to investigate articles published in scientific journals. Our aim was to obtain data on the CT tools in mathematics content, particularly articles on indexing institutions. Potentially relevant research was identified by SCOPUS, ELSEVIER, WoS, ERIC, EBSCO, WILEY, DOAJ, JSTOR, and SAGE.

To select articles, we applied inclusion criteria: (1) the keywords "mathematical creative thinking" OR "creative thinking in

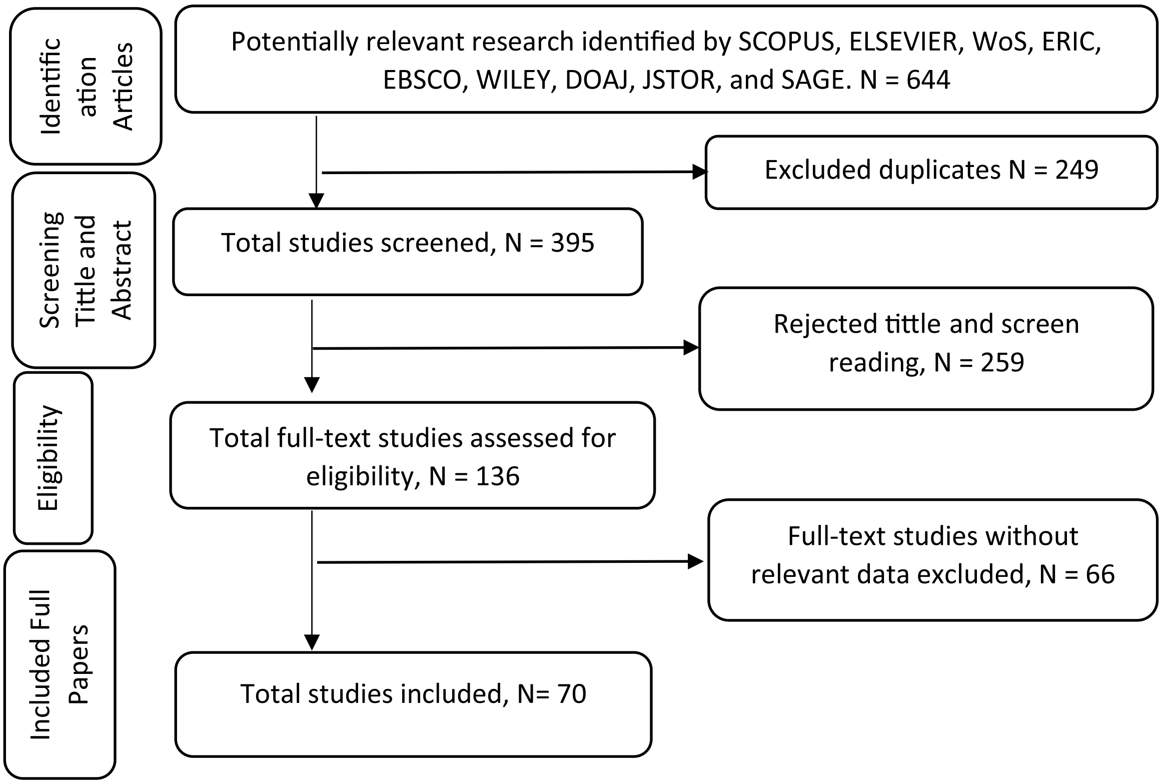

Fig. 2. Stages of the systematic review.

mathematics" in the, for instance, title, abstract and keywords, or main text; (2) written in English; (3) published between 2011 and 2021; (4) available in full text; (5) peer-reviewed journal articles; and (6) assessment results in empirical studies in terms of CT skills in mathematics. We found 644 articles. Next, the author downloaded the selected papers, each article was investigated by first and second authors, and two researchers analyzed and discussed the information.

To collect the articles, the author used articles on the search platform. In the first steps, the first author imported article references by using the EndNote XML format, the PubMed format, or the RIS text format. In this case, the author created a RIS text because this task is easy to perform in Mendeley Reference Management Software. After uploading the references, the system read multiple articles. The second steps are the title and abstract screening. In these stages, first and second authors reviewed titles and abstracts and decided whether to exclude or include an article on the basis of it being related to the research purposes. If the two authors' decisions on whether to include or exclude the article differed, an agreement was achieved by reviewing the article again. The next stage was a full-text review. In the last steps, extraction was conducted. Concerning the final investigation based on the extraction stages from the 644 original articles, the present 70 research studies on MCT and assessment tools. During the review, the selected articles were analyzed by using recorded keywords: (1) authors and publication year, (2) indicators of CT, (3) the tittle, (4) diagnostic tools/instruments, and (5) findings.

Based on the extraction data in Fig. 2, our focus was on the analysis and diagnostic instruments and the type of tests appropriate to assess MCT that were used. In the systematic review, we identified the level covered in the research, from elementary school through post-secondary education. In addition, the material was used primarily in mathematics. Next, a test tool was used to measure MCT, such as open-ended questions, multiple-choice questions, interviews, open-ended questions based on ethnomathematics, and the TTCT.

Bias risk was evaluated based on random sequence generation, disclosure, blinding, blinding the interveners, blinding of results evaluators, incomplete data results, selective data reporting, and other factors (Schuch et al., 2016). In this study, the factor that can be identified is selective reporting, namely, the journals' tendency only to publish articles that are considered significant. Because significant studies were more likely to be included in the systematic review than their unpublished counterparts, there is concern that the systematic review might overestimate the accuracy of the assessment tool (Keen, Blaszczynski & Anjoul, 2017).

3. Results

3.1. Educational levels of mathematical creative thinking assessments

A few studies have been conducted to implement MCT across several education levels. The education level for MCT assessment is presented in Table 1; in this table, we observe that 61.43% was from the secondary schools and that the high school and college levels are the levels used most in the studies on MCT tool use, at 20% and 14.29%, respectively. By contrast, in the reviewed study, the education level for MCT assessment was primary school, at 2.86%.

Although some MCT was in basic education programs, we present it also in the context of college to reveal the most recent developments in MCT. In general, studies on MCT assessment focused on elementary, junior, and senior high school. The finding indicates that research on CT, especially related to mathematics, is influential because it encourages students to perform their skills and can be used as a prior foundation to understand the other programs (Hsu, Chang & Hung, 2018).

The grade of the education level has also been demonstrated for MCT assessment. We analyzed several grades in the reviewed studies: the percentage of educational level at just 32.86% in 7th grade. In 8th grade, CT in mathematics assessment were second highest percentege, with 22.86%. However, consistent with the reporting finding, there were many results of MCT for senior high school and college students and, surprisingly, approximately 11.43% in 10th grade and 14.29% in undergraduate, respectively. Although CT was regarded as a critical component in this era (i.e., the 21st century), considerable evidence of the assessment in all levels of education is necessary (Wechsler et al., 2018).

Table 1
Educational levels of the reviewed MCT measurement.

Variables	Categories	Numbers	Percent (%)
Educational Level	Primary Education	2	2.86
	Junior Secondary Education	43	61.43
	Senior Secondary Education	14	20.00
	Primary + Junior Secondary Education	1	1.41
	College	10	14.29
Grade	4th	1	1.43
	6th	1	1.43
	7th	23	32.86
	8th	16	22.86
	9th	5	7.14
	10th	8	11.43
	11th	2	2.82
	12th	3	4.29
	5th and 7th	1	1.43
	Undergraduate	10	14.29

3.2. Familiar mathematics context for assessing mathematical creative thinking

The topic used on the MCT test varied across grade education levels. The sub-topic and subject competency are different from grades 4 to 12. For example, every subject competency was accommodated by The Ministry of Education and Culture, which organizes early childhood education, elementary education, secondary education and community education affairs, and culture management within the Indonesian Government. For the undergraduate level, there is no restriction because every higher educational institution can modify and create its curriculum. The general standard for higher education is provided by the national education department, but every institution or university has the authority to create and implement its educational system. The detailed topics of mathematical items are presented in Table 2.

Mathematical materials commonly used to assess CT are presented in Table 2; in this table, we observe that the mathematical materials from review studies have shown diversity in assessing CT and that the topics of mathematics placed first to be the most misled material was geometry and measurement with 19 concepts, followed by algebra with 10 concepts, number with 8 concepts, and probability and statistics with 1 concept. Hence, the material can facilitate the students in assessing CT from this material by following the applicable curriculum according to the class level (Huizinga, Handelzalts, Nieveen & Voogt, 2014; Taylor, 2013).

3.3. Tools for assessing mathematical creative thinking

In measuring and identifying students' MCT, assessment tools have been used. Examples of measurement tools are open-ended questions, interviews, questionnaires, the TTCT, and open-ended questions based on ethnomathematics. The frequency of each assessment tool is revealed in Fig. 3.

Open-ended tests comprise open-ended questions and are the most widely used tests to assess students' CT skills in mathematics. This test type provides students with the freedom to assume and write their ideas. The highest percentage of the assessment tool of MCT is open-ended to approximately 59% in the level of secondary school. Judging students' results or responses is difficult because students tend to write incomplete answers (Soeharto, Csapó, Sarimanah, Dewi & Sabri, 2019). However, open-ended questions provide flexibility for students to express their creative ideas. This argument was supported by Krosnick, who said that open-ended questions have many advantages, particularly prompting a limitless variety of answers, helping students categorize their ideas, and minimizing the answers given by students (Krosnick, 2018). Conversely, the drawbacks are that open-ended questions require specialized skills for obtaining purposeful answers, interpreting and analyzing student answers can be difficult, biased answers might be submitted if students do not perceive the topic of the question, and some responses might not be useful (Bartholomew, 2017). On open-ended tests, researchers used general questions that had many solutions and allowed students to work in various ways, and the goal were to help develop CT maximally per the abilities of each student.

In addition, we found a literature review that used open-ended questions based on ethnomathematics (e.g., Nuqthy Faiziyah et al., 2020; Zaenuri et al., 2019). An open-ended question can be formulated in several ways to obtain many correct solutions; otherwise, it can be solved in various ways. Students' answers to open-ended questions can be used to observe their CT process. In addition, students with low abilities can explain their thinking patterns in their answers to open-ended questions. Some research stated that mathematics is essential for students but that students often have difficulty learning it. This difficulty occurs because of cultural conflicts, namely, the mismatch between cultures observed inside schools and outside schools or communities (Khalifa, Gooden & Davis, 2016; Ogbu, 1992). Thus, understanding this phenomenon is the link necessary to bridge this problem. Observing the CT in mathematics that involves reality is possible with open-ended integration and ethnomathematics.

Table 2
Mathematics context for assessing CT.

Number	Algebra	Geometry and measurement	Probability and statistics
1 Number	1 Algebra	1 Triangle	1 Probability
2 Ratio	2 Equation	2 Prism	
3 Fraction	3 Functions	3 Pythagoras	
4 Arithmetic operations	4 Trigonometry	4 Pyramid-shaped	
5 Sequence and Series	5 Relational and Functional	5 Cube	
6 Imaginer number	6 Linear Equation	6 Cuboid	
7 Social Arithmetic	7 Algebraic Expressions	7 Circle	
8 Derivative	8 Two-variable linear equations system	8 Parallelogram	
	9 Three-variable linear equation	9 Rectangular	
	10 Matrix	10 Quadrilaterals	
		11 Square	
		12 Angle	
		13 Cone	
		14 Rotation	
		15 Reflection	
		16 Transformation Geometry	
		17 Three-dimension	
		18 Two-dimension	

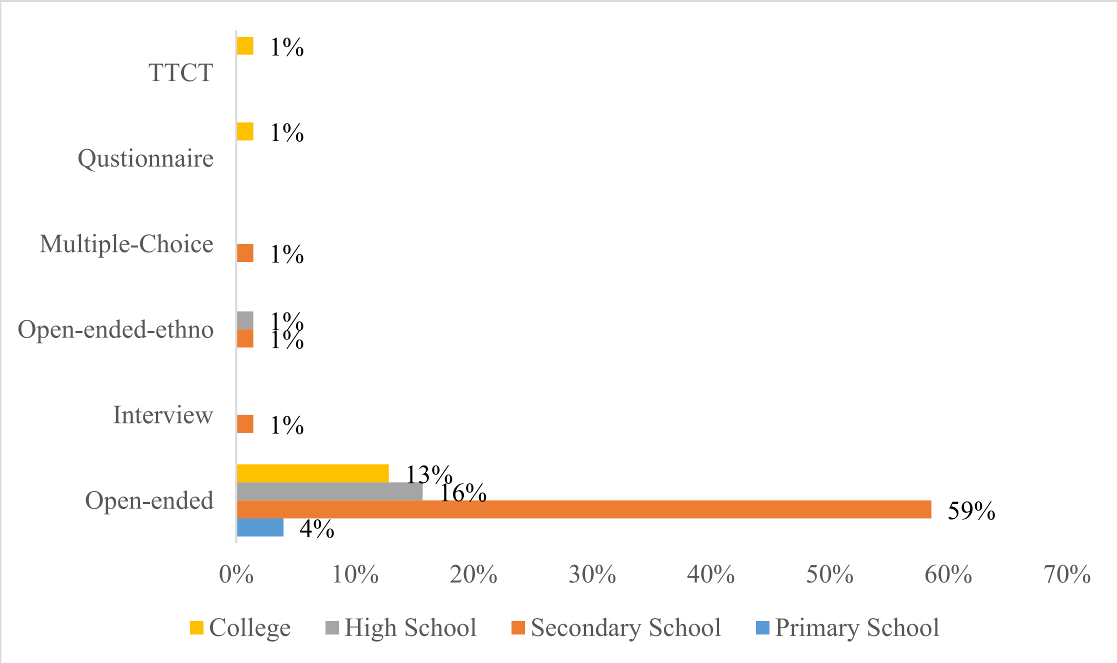

Fig. 3. Distribution of mathematical creative thinking tools used for measurement in the reviewed studies.

Ethnomathematics has cultural elements. It is a procedure to learn and combine the ideas, ways, and techniques used and developed by socioculture or members of different cultures (D'Ambrosio, 2016; Rosa & Orey, 2016). Ethnomathematics attempts to reposition mathematics from the different cultural roots of society so that it can connect to and revive students' critical reasoning and dialogues and so that students become critical reasoners, democratic, and tolerant by embracing cultural differences and seeing them as opportunities for mathematics education (D'Ambrosio, 2016; Prahmana & D'Ambrosio, 2020). Therefore, as a pedagogical innovation in mathematics teaching and learning, ethnomathematics aims to help students achieve in mathematics, become motivated, and improve creativity in performing mathematics.

The integration of ethnomathematics into open-ended problems adds a new nuance in mathematics and culture. Notably, we found in Indonesian society comprises various ethnicities and cultures. That is because we could see the potential of ethnomathematics context in terms of Indonesian context in classifying the rich of cultural characteristics. As aforementioned, approximately 2% of the studies used an open-ended integrated ethnomathematical assessment tool to measure CT in their research at the secondary and high school levels. For example, Zaenuri presented problems in learning by using a cultural context, especially Indonesian artifacts, namely, the Tomb of Kyai Semar, which are related to content on squares and rectangles. In addition, in measuring CT, open-ended questions integrated with ethnomathematics are used (Zaenuri et al., 2019). Furthermore, Indonesian batik motifs as a part of cultural heritage can be used to assess creative mathematical thinking regarding the geometry of transformation chapter (Faiziyah et al., 2020).

Multiple-choice tests as the MCT tool were observed. These tests can be used to assess students' CT in mathematics in large samples, are straightforward to use because they do not rely on complex answers, are often used to determine learning outcomes at the end of each semester and for graduation exams in the Indonesian context, and are used to determine the value that symbolizes the success of students after their participation in the learning process for a certain period. Based on the review results, multiple-choice tests are used because they are easy to manage and score, and conventional paper-and-pencil tests can be used, making it easy for researchers to assess MCT students. A limitation of multiple-choice tests is that they are restricted to the level of basic factual knowledge, whereas constructed-response formats require higher-order thinking. Notably, devising a multiple-choice test that measures CT is easy, although determining if a student is creative is difficult (Butler, 2018).

Researchers used questions with one solution to indicate the CT level. For example, Tabach and Friedlander (2017b) evaluated students' CT in mathematics by using three indicators: originality, fluency, and flexibility. According to the Fig. 3, 1% of the MCT assessment tool was from multiple-choice questions in secondary school.

The assessment of MCT widely uses multiple-choice tests, but these tests have limitations. First, some researchers reduce the use of multiple-choice tests because they do not promote cognitive processes (Yonker, 2011). However, for some researchers, their use of a multiple-choice tool depends on the purpose of the test, including evaluating students' ability in the classroom (Butler, 2018). Second, the feedback provided is usually limited. Hence, there is little scope for the personalization of feedback (Chattopadhyay, 2016). Third, the use of multiple choices is usually driven by the need for efficiency rather than pedagogical principles that aim to encourage effective learning (Nicol, 2007).

Interviews are also used to investigate mathematical thinking in learning outcomes, particularly progress in CT learning. Tests used a specific subject and a different material framework. In the reviewed study, 1% of studies developed interviews that used qualitative items. Notably, some researchers (e.g., Istiqomah, Rochmad & Mulyono, 2017) used the interview to explore detailed information on students' cognitive knowledge. Additionally, the aim of interviews is not to have questions answered but to understand what students think and how they think about a mathematics concept (Skilling, Bobis, Martin, Anderson & Way, 2016).

Questionnaires are a communication medium in which questions are posed to collect respondents' information as answers. Among the reviewed studies, as aforementioned, 1% reported using a questionnaire to assess MCT. The questionnaire typically assessed non-cognitive outcomes, and some researchers used a questionnaire to assess CT skills. For instance, Murni, Bernard, Ruqoyyah and Chotimah (2020) employed a questionnaire to support or elaborate on applying CT knowledge to complete their final project. Although a questionnaire can be used as a tool to measure CT on a large scale quickly, it does not represent visual or procreative components of how students process CT (Van de Oudeweetering & Voogt, 2018).

The Torrance Test of Creative Thinking comprises verbal activities (thinking with words) and figural exercises (thinking with pictures) that showcase students' creative abilities. Torrance developed the TTCT in 1966; it is the most frequently used technique used to measure creativity skills worldwide, has been translated into over 35 languages (Lemons, 2011), and is the most well-known test in creativity. However, the TTCT test is based on only divergent thinking (Vartanian et al., 2020), a thought process used to generate creative ideas by exploring possible solutions (Forthmann et al., 2016). Additionally, Joy Paul Guilford suggested that measuring the ability to think creatively involves two thinking concepts: divergent thinking and convergent thinking (Guilford, 1988). The researchers using the TTCT test to assess CT as a skill used the TTC indicators of fluency, originality, and elaboration.

3.4. Validity and reliability of the evidence of the mathematical creative thinking assessment tool

Concerning the 70 articles, fewer than two fifths (40%) reported the reliability and validity of the evidence; approximately 21% presented the validity of evidence. The reliability of the evidence (i.e., expert judgment reliability) was provided to identify questions, especially for interviews. Expert judgment was used to assess the questions on the basis of the given rubric. If the experts' assessment is insufficient, the result has a flawed decision unless the problem has been revised based on expert advice. Some reviewed studies that employed multiple-choice, open-ended, and questionnaire questions reported that the test's internal consistency was tested by a sample outside of the research to measure the same MCT constructs per the item indicators. In addition, to build good reliability, we found that the TTCT test was used without performing a reliability test. By contrast, they used the TTCT questions tested for reliability with reliability coefficients ranging from.50 to.93; thus, because of the complexity of CT given, the TTCT can be considered as having reasonable reliability for research applications (Treffinger, 1985).

Some studies reported the validity of the evidence (e.g Puspitasari & Wahyudin, 2020.) has been correlated item test with indicator CT rubric, which does by mathematicians and practitioners construct the validity of mathematical creativity by using factor analysis approaches such as confirmatory factor analysis (CFA) to analyze with loading factor value >1.96 (Zainudin & Subali, 2019). Another case emphasized the importance of using data by using validation and triangulation. In addition, several studies stated that in their use of data to assess the validity of a questionnaire's content on CT, perceptions had been reported in the context of a validity index as an acceptable level. In other words, the validity of the content instrument and the validity of the face have also been presented as evidence that the questions were feasible to use (H. R Suripah, 2019.).

As demonstrated before, Zainudin developed 15 test items to measure CT. The measuring instrument has been tested at an average age of 12–15 years old. Each indicator of CT (i.e., fluency, flexibility, and originality) is validated with CFA to determine the sub-items directly. Although evidence of validity and reliability has been provided for CT assessments, most CT assessment tools have insufficient evidence of both. Thus, for researchers, using MCT assessment tools is difficult, especially in high-risk tests if this evidence does not exist.

4. Discussion

Researchers have explored CT, and it is the ability in the 21st century that was most used. This systematic review aimed to assess CT in mathematics, identifying what researchers have discussed and research gaps. Despite our small sample of reviewed studies, this paper contributes to the understanding of CT in mathematical practice. The results demonstrate that MCT tests are available for elementary school through post-secondary school.

First, most research has focused on the end result of CT in learning at the elementary, middle, and college levels. Notably, although researchers find assessing CT difficult in regard to developmental students due to their limited understanding of mathematical concepts (Colmar, Liem, Connor & Martin, 2019), researchers have attempted to explore CT skills and apply cognitive development to them in the early stages in the classroom. However, there is no reason to suggest that primary and secondary schools are the only important stages for students to cultivate ideas in CT, and further research is necessary to enrich and deepen the literature on MCT measurement tools appropriate for primary and secondary school (Jablonka, 2020) and universities. Thus, researchers and practitioners can find appropriate resources for the CT skills development trajectory.

Second, more CT assessments should be developed to understand the process of CT applied in classroom educational contexts. We observed that all tests were designed for specific domains, and most of them used the CT indicators framework and CT indicators such as fluency, flexibility, originality, and elaboration. We also found studies that used a slightly different set of three indicators: fluency, elaboration, and novelty (Istiqomah et al., 2018; Nuha, Waluya & Junaedi, 2018). Fluency refers to mathematical creativity, namely, if the individual produces multiple solutions/ideas (Kozlowski et al., 2019). Regarding its relationship to mathematics, flexibility refers to individuals' ability to change thinking paths when they encounter an impasse or thinking obstruction or to generate different types of solutions/ideas (Krutetskii, 1976; Leikin & Lev, 2007). Inflexible individuals typically continue to pursue a solution path to no avail

(Imai, 2000; Kozlowski et al., 2019).

Additionally, originality has become an indicator of creative mathematical thinking (Beghetto, 2017; Silver, 1997), as it was initially by Chassell (1916), who suggested that originality was an indicator of mathematical creativity. Originality, also cited as novelty, is associated with an individual's ability to seek out an answer path that is particularly distinctive and uncommon solutions/ideas for that individual's information level (Siswono, 2011) and then create a solution and novel ideas (Kozlowski et al., 2019). Last, the indicator of mathematical creativity is elaboration (Imai, 2000). Elaboration describes the ability to allow in-depth reasoning behind an answer path (H Kim et al., 2004.).

Finally, in Indonesia context, the MCT tests are in the scope of certain content knowledge and mathematics subjects. The acquired knowledge from experience is applied to the current situation, helping students generate ideas and solutions. Furthermore, mathematics topics were provided in the curriculum of each education level. On the basis of the result, the test administered the topic from primary school to the undergraduate level for mathematics subjects.

Regarding the review and current search related to MCT conducted by researchers, they have demonstrated that open-ended questions on a test are frequently used as an assessment tool for MCT and that open-ended questions are used as the main instrument (Saputri, Pramudya & Slamet, 2020; Sari, 2019). The researchers also found open-ended questions based on ethnomathematics (Fig. 3) employed to integrate test instruments and produce valuable findings. This finding, namely, using an open-ended test and ethnomathematics to assess MCT, was novel. Thus, the assessment tool combines in mathematics both realistic and cultural aspects, namely, the ethnomathematics used in questions. And an open-ended ethnomathematics test is an appropriate tool to measure MCT.

Some studies presented promising results with a reasonable validity index (all the items are considered valid) and acceptable Cronbach's alpha reliability. That is, the assessment tool was appropriate to use. However, almost half the tests did not present validity and reliability. Presenting validity and reliability as indicators is an essential element of a quality assessment tool. This finding is aimed to assist researchers in developing new MCT instruments. In addition, other researchers preferred an assessment tool that had a validity index and reliability.

4.1. Limitations

This review has limitations. Primarily, the literature reviewed only emphasized using assessment tools to measure MCT, but most research emphasize the final outcome of MCT such as the effect of learning models on MCT skills. Additionally, our review did not focus on the students' intervention. Further, many studies report MCT interventions, but no research addresses MCT, especially in the development of assessment tools at all levels of education. In further research, developing an assessment tool is necessary, especially in an ethnomathematics context.

5. Conclusion

This systematic review assessed MCT measurement tools and identified research gaps and topics for further research in regard to measuring MCT skills. MCT skills improve the quality of education. Thus, this skill should be introduced in the early stages of schooling and focus on educational purposes. The implementation of MCT skills in educational practice can occur in many aspects, especially in assessment. A few studies of Indonesia context focused on MCT test development and used an ethnomathematics context.

In summary, the MCT assessment tools were used and applied to all education levels, especially secondary school students aged 13 – 15 years. Most studies employed open-ended assessments to evaluate MCT skills. The mathematics context was accommodated as a curriculum by the Government in every school. However, teachers are empowered to develop local curriculum-based assessment tools such as combining mathematics and culture, known as ethnomathematics. Finally, a few reviewed articles presented the validity and reliability of the evidence as an MCT assessment. These results might have been observed because MCT assessment is intentionally developed to help students avoid stereotyping and bias (Koch, D'Mello & Sackett, 2015). However, applying CT in mathematics measurement in regard to assessment MCT-based ethnomathematics at the education level may contribute to extending the literature.

6. Authors statement

All listed authors meet the ICMJE criteria. We attest that all authors contributed significantly to the creation of this manuscript, each having fulfilled criteria as established by the ICMJE

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Further reading

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