Chapter 8
Mathematical Creativity at the Tertiary Level: A Systematic Review of the Literature

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8.1 Introduction

Van Nuys (2019) shared results from a study in which it was stated that creativity is the most needed skill for employees in companies in 2019 and 2020. Specifically in STEM, careers will be uncertain and require flexibility and, most importantly, creativity (Wilson et al., 2017). Creativity is an important piece of mathematical thinking according to many prominent mathematicians (Borwein et al., 2018; Karakok et al., 2015), and thus is important to foster in future mathematicians. As well, the Mathematical Association of America's Committee on the Undergraduate Program in Mathematics (Zorn et al., 2015) has emphasized the importance of mathematical creativity in its latest guidelines: "[A] successful major offers a program of courses to gradually and intentionally leads [sic] students from basic to advanced levels of critical and analytical thinking, while encouraging creativity and excitement about mathematics" (p. 9). Under Cognitive Goals and Recommendations, the guidelines also state that "[T]hese major programs should include activities designed to promote students' progress in learning to approach mathematical problems with curiosity and creativity and persist in the face of difficulties" (p. 10). Whether the focus is on industry, academia, or the classroom, creativity is ubiquitously important.

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Much of the above motivations for tertiary mathematical creativity fostering lie in the developmental perspective of creativity, that a person's creativity can be developed or fostered. Kozbelt et al. (2010) stated that developmental theories of creativity "help us to understand the roots of creativity, as suggested by the background of unambiguously creative persons, but they also often suggest how to design environments so that the creative potentials of children will be fulfilled" (p. 26). Developmental creativity pertains to the development of creative processes, persons, and press (environment), according to Rhodes (1961), whereas creative products are the end-results: "Although products are not the primary focus of developmental theories, they still play an important, but often tacit, role" (p. 26). Kozbelt et al. (2010) described that in the developmental theory of creativity, studies that have analysis of the creative process, including moments that influenced development of one's creativity, are important, as well as longitudinal studies to examine such development over time.

An abundance of scholarly work pertains to how to develop creativity in the primary and secondary classrooms (e.g., Beghetto & Kaufman, 2010; Starko, 2013), but the tertiary perspective is still growing (Kozlowski & Si, 2019). This literature constitutes an aggregate of the tertiary mathematics education literature on mathematical creativity, allowing researchers in the field to survey and add to the previous studies. Furthermore, because there is a need for enhancing students' creativity in mathematics classroom at the tertiary level, we explored the following research questions through systematic literature review: (i) What is the current state of research on tertiary mathematical creativity? (ii) To what extent is the developmental perspective of creativity present in current research?

8.2 Method

In this systematic literature review, we followed the guidelines set out by Newman and Gough (2020). We set our research questions and then searched the literature. Because this is a first review of the tertiary mathematical creativity literature, our review may be considered a "scoping review" (Newman & Gough, 2020, p. 15), as we are not taking a full conceptual framework. Scoping reviews "summarize literature in a topic area" and are an "effective means of highlighting the relevant literature to the researcher" (O'Flaherty & Phillips, 2015). In the second research question, we are using the developmental lens described above, which will be used as an analysis tool and rather than as a selection criterion.

We first used Google Scholar to search for publications in which tertiary mathematical creativity was studied. The first search was conducted with the terms "___ math creativity," where the blank was tertiary, undergraduate, and post-secondary. The second search was conducted substituting the blank with content-specific topics within tertiary mathematics: calculus, graph theory, real analysis, abstract algebra, differential equations, discrete math, precalculus, college algebra. Finally, we substituted the blanks with two terms separately, proof and proving, as they are important mathematical activities in upper-division courses. We restricted the selection of articles to content that is taught in tertiary mathematics and mathematics-only tracks for a focused systematic literature review. Therefore, in the search, we did not include articles about pre-service teachers or any article that used tertiary mathematics as a subset of a general, all-grades mathematics education article, although we acknowledge that there could be an intersection of both pre-service courses and topics such as number theory. This is not to discredit pre-service math courses at all, as they are important in the preparation of future teachers. We also narrowed our results to journal articles, book chapters, and dissertation publications. Accounting for all the criteria above, we found 29 artifacts total.

Each article was then put into a spreadsheet with author(s), title, journal, year, content topic (if specified), methods, results, and any other important information. We then analyzed each column, making observations about common themes.[1] We now present those themes.

8.3 Results

The two journals that had the largest number of articles were the Journal of Humanistic Mathematics (JHM, six articles) and Problems, Resources, and Issues in Mathematics Undergraduate Studies (PRIMUS, five articles). The JHM articles were all from a special issue that was guest-edited by our research group, which explains the frequency of articles from that journal. We believe that the number of PRIMUS articles is due to the position of the journal as a practitioner journal in tertiary mathematics, so mathematics instructors interested in mathematical creativity in their classroom may publish here. Each of these 11 articles had a description of how the authors fostered students' creativity in their own courses. For example, Kasman (2014) described a project system, including how they assessed creativity, in a course for students that required a minimum of one math course for graduation (i.e., a general education course). They used a rubric to value several aspects of graph theory or voting problems, one of which was creativity (worth 3 points out of 20). Kasman reported that the creativity in both mathematics and their aesthetics made them "delighted during the grading of these projects" (p. 489). Mayes-Tang (2020) also wrote about a first-year general education course where students created new geometrical concepts and built upon those concepts throughout the course. The author described fostering creativity by prompting the students to find properties or theorems with their created concept, and to present an end-of-semester, semester-long project on their new geometrical concepts, including the semester-long prompt to "find as many properties as you can for your newly-defined creation and formulate relevant theorems about it" (p. 267). They concluded with eight recommendations to implementing creativity-focused courses, including to "look

[1] Data analysis was concluded at the end of August 2020.

for creative moments in each class" and "set a grading structure for creativity-focused assessments that rewards effort and reflection over sophistication of results" (p. 271). Munakata et al. (2021) studied a general education mathematics course that focused on creativity. They studied both student effects, including seeing math differently, seeing math creativity, frustration, collaboration; and teacher effects, including not knowing what to expect and feeling out of their comfort zone. All three practitioner papers had both creativity and terminal math courses. This small number may be due to the experience being the last math requirement for students, coupled with the minimal requirements for content (Kasman, 2014). The other two PRIMUS articles (El Turkey et al., 2018; Omar et al., 2019) are from our research group and are situated within proof-based courses. Both offer a rubric, the Creativity-in-Progress Rubric on Proving (presented in full in Savić et al., 2017)), as a basis for actions in the classroom. The rest of the 18 articles were published in separate journals or books. Of the 29 articles, 27 were written in the last 10 years (2012–2021), of which 17 were written in the last 3 years (2019–2021). This indicates that the field of mathematical creativity in tertiary education is recently growing. Figure 8.1 shows an infographic of articles by year.

The most popular topic out of the 29 articles was calculus, with five articles. Three of the five articles were quantitative, including creating and validating a "learning model based on open-ended questions… to improve students' creativity in calculus learning in a valid and practical way" (Arsyad et al., 2017, p. 144). Mac an Bhaird et al. (2017) coded tasks from business, science, and pure calculus courses using Lithner's (2008) imitative/creative reasoning framework. They found that, in the business and science calculus classes, tasks were mostly imitative, and tasks on tests were almost 100% algorithmic (which is a subset of imitative). The authors

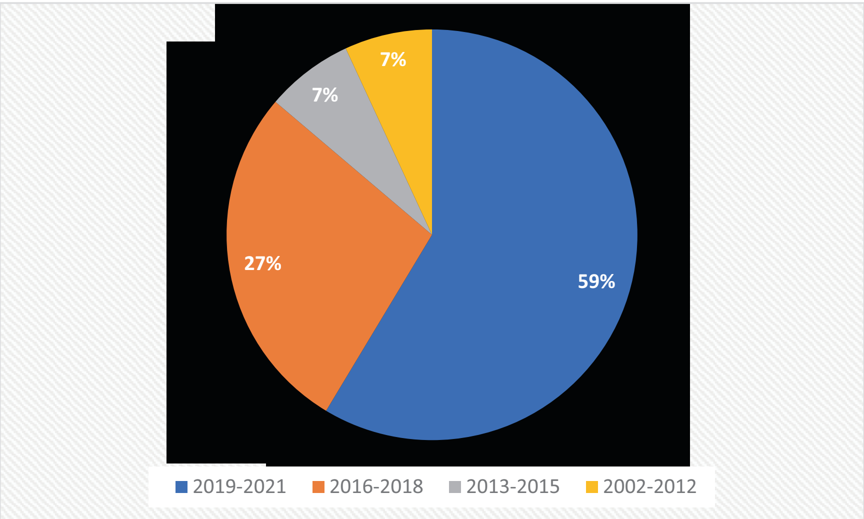

Fig. 8.1 Tertiary math creativity research by year

end with a reflection on business and science courses, claiming that they "need not have a lower proportion of CR [creative reasoning] tasks" (p. 160). Blyman et al. (2020) discussed a rubric that they used in calculus to assess math creativity with pre-post-semester tasks. They had mixed results and concluded that "evaluating creativity is a difficult task" (p. 169). The other two calculus articles included derivative TACTivities for moving and manipulating derivative calculations (Hodge-Zickerman et al., 2020), and an investigation of Hawaii Algebra Learning Project (HALP) and its strong positive impact on mathematical achievement and creativity (Roble, 2017). In the case of Roble, mathematical creativity was defined by Leikin's (2009) use of Torrance's (1966) fluency, flexibility, and originality categories.

The second-most discussed topics in our literature review were graph theory and combinatorics (four articles). There were two articles on the same course in combinatorics (Karakok, 2021; Omar et al., 2019), and there were two other articles that mentioned problems in combinatorics and graph theory in order to foster creativity (Hoshino, 2018; Zazkis & Holton, 2009). The latter two graph theory articles were (1) a systematic literature review of graph theory with a consideration for how the problems can foster creativity (Suriyah et al., 2020); and (2) an article about how an online application with graph theory fosters creativity (Wahyuningsih et al., 2020).

In our investigation, we found that the most articles (11) were descriptive, meaning that the authors described what happened in their classrooms or courses and how they fostered (or attempted to foster) mathematical creativity (e.g., Marciniak, 2020; Monahan et al., 2020). These 11 articles also did not use qualitative, quantitative, or any other coding techniques. These are separate from the three theoretical pieces that did not use coding (Grégoire, 2016; Hafizi & Kamarudin, 2020; Savic, 2016). For example, Grégoire (2016) claimed there was interplay between the intellectual abilities, personality of the student, and the educational environment. Hafizi and Kamarudin's (2020) main claim was that there was a growth of creativity research in Malaysia specifically in higher education and detailed mathematical creativity research happening in the country. Finally, Savić (2016) combined the theories of problem solving and creativity while discussing proof research.

The next most-used method was quantitative, which had eight publications that studied ways of gauging whether a student was creative, with two articles citing Torrance's Tests for Creative Thinking (Asahid & Lomibao, 2020; Singh & Kushwaha, 2019). There were seven qualitative studies, two of which were not part of our research group. The first one (Roble, 2017) discussed Multiple Solution Tasks (MSTs, Leikin, 2009) and pre-post testing of non-routine problems for achievement, along with student interviews about struggles in mathematics. Adiredja and Zandieh (2020) introduced anti-deficit perspectives in mathematical creativity, noting that students have creative examples of basis in linear algebra, and can generate mathematical creativity collectively as well as individually. Finally, there was a dissertation that had both qualitative and quantitative methods (Regier, 2020). The quantitative part was focused on fostering creativity in the classroom and its impact on self-efficacy. Surveys were created with influence from Cilli-Turner et al. (2019) for the students to gauge how their teachers provided

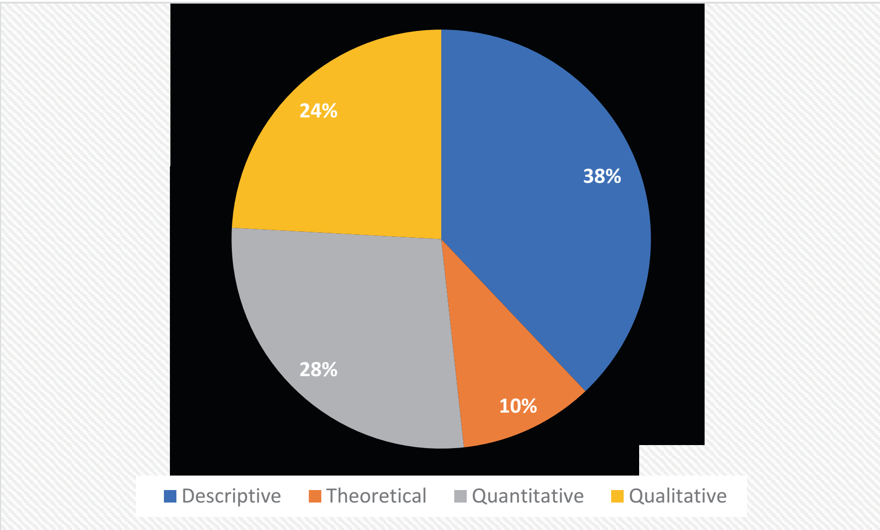

Fig. 8.2 Tertiary math creativity research by method

opportunities for them to be creative. The qualitative portions studied connections between problem-posing and motivation as well as linked fostering creativity with self-efficacy, which was also presented in Regier and Savic (2020). This indicates a balance of methods for research, which is demonstrated in Fig. 8.2.

Using the Kozbelt et al.'s (2010) definition of developmental theories of creativity mentioned in the introduction, most of the articles found (25 of 29, or 86.2%) took a developmental perspective, meaning that they assumed that creativity could be fostered or developed in classrooms. The four articles that we perceived as not developmental were all quantitative studies (Arsyad et al., 2017; Mac an Bhaird et al., 2017; Singh & Kushwaha, 2019; Tularam & Hulsman, 2015). However, the Arsyad et al. (2017) article was about creating a tool that could ultimately have the impact of increasing students' creativity, which is a secondary outcome of the developmental perspective. This secondary outcome is true for Mac an Bhaird et al. (2017), who wanted to look at reasoning tasks in summative assessments for the development of "mathematical reasoning skills" since it is an "important objective of teaching of mathematics at all levels, in particular at university" (p. 160).

8.4 Discussion and Future Research Directions

There is certainly much more that can be done in tertiary mathematics education with creativity. Compared to its place in primary and secondary education, mathematical creativity is new to the realm of tertiary mathematics education. We hope this chapter encourages the field to consider mathematical creativity at this level, including being creative in research methods, tools, and approaches to fostering creativity.

Our systematic literature review showed that very high or high-quality journals[2] have published only one article on creativity (i.e., Regier & Savic, 2020), in our search using the words "undergraduate/tertiary/post-secondary mathematical creativity." This speaks to how new the research subfield is, how much more work needs to be done for mathematical creativity at the tertiary level to be more valued, or how journals need to consider publishing more research on mathematical creativity at the tertiary level. Regardless of the reason, there is a gap between the value of creativity in the three areas of industry, academia, and the classroom with the publication rates of tertiary mathematical creativity. Most of the articles described what happened in a classroom; future syntheses should cross-examine each descriptive article and see the common themes or ideas. Mathematical content was not focused on one topic or area of mathematics. This makes us believe that mathematical creativity can be fostered in any aspect of tertiary mathematics education. In fact, according to Ervynck (2002), mathematical creativity *should* be fostered in *every* aspect of tertiary mathematics education.

There were limitations to this scoping review, including the limit on the keywords in searching. For example, in pre-service mathematics education, which was not considered in this chapter, there have been a number of articles on mathematical creativity, including those that conceptualize what teachers believe as mathematically creative (Bolden et al., 2010; Moore-Russo & Demler, 2018). This research at the pre-service level can have a huge influence on what future primary and secondary students see as mathematics (Aiken Jr, 1973; as cited by Fetterly, 2010). Future systematic reviews will hopefully take this review as a first step towards cataloging and broadening mathematical creativity.

8.5 Conclusion

Why is mathematical creativity so important in tertiary mathematics education? For some students, this might be their last experience of mathematics, so there is one last chance to change their beliefs about mathematics as more exploratory (Kasman, 2014; Mayes-Tang, 2020; Monahan et al., 2020; Munakata et al., 2021). For others, they will continue on to graduate school in mathematics, and creativity is a chance for them to feel like mathematicians (Omar et al., 2019). Mathematical creativity can also be a catalyst towards a more equitable classroom (Luria et al., 2017), although much more empirical work is needed to validate that theoretical claim

[2] We are using the rankings by Williams & Leatham (2017) to define a very high or high-quality journal. These journals include Journal of Research in Mathematics Education (JRME), Educational Studies in Mathematics (ESM), Journal of Mathematical Behavior (JMB), ZDM – Mathematics Education, For the Learning of Mathematics (FLM), Mathematical Thinking and Learning (MTL), and Journal of Mathematics Teacher Education (JMTE).

(Kozlowski & Si, 2019). All these reasons for fostering mathematical creativity have at their core a developmental perspective that centers students. Also, all these reasons need more research to understand how mathematical creativity impacts students, including teaching actions that can foster creativity (Satyam et al., accepted) and the impacts on students' affect (Tang et al., accepted). We also need to expand our knowledge from the individual to the collective, thinking of fostering creativity in groups or teams (Heath, 2021) as not many of the articles include this perspective.

Based on the results of this review, we implore instructors of tertiary mathematics, many of whom are mathematicians, to consider a developmental perspective on creativity. Hirst (1971), when discussing creativity in mathematics education, stated:

There must be a recognition that worth-while investigations can take place at a lower level than the full-blown research problem, and the purpose of these must be seen as contributing to the student's mathematical development, and not the furtherance of the boundaries of the subject. (p. 28)

In the 50 years since that quote, we have seen momentum only recently towards this perspective. We hope that by examining this systematic literature review, researchers and instructors can add to the developmental perspective of tertiary mathematical creativity.

Appendix A: Table of all 29 Articles/Book Chapters Listed by Alphabetical Last Name

Author	Year	Title	Journal	Content	Methods	Develop?
Adams, Margaret	2020	Three Creativity-Fostering Projects Implemented in a Statistics Class	Journal of Humanistic Mathematics	Statistics	Rhodes 4P	Yes
Adiredja, Aditya P; Zandieh, Michelle	2020	Everyday examples in linear algebra: Individual and collective creativity	Journal of Humanistic Mathematics	Linear Algebra	Qualitative: Interviews, coding for originality of basis, vector space	Yes
Arney, Chris	2002	Building Creativity Through Mathematics, Interdisciplinary Projects, and Teaching with Technology	Changing Core Mathematics	All	Description of course	Yes

(continued)

Author	Year	Title	Journal	Content	Methods	Develop?
Arsyad, Nurdin; Rahman, Abdul; AHMAR, Ansari Saleh	2017	Developing a self-learning model based on open-ended questions to increase the students' creativity in calculus	Global Journal of Engineering Education	Calculus	Quantitative	No
Asahid, Remelyn L; Lomibao, Laila S	2020	Embedding Proof-Writing in Phenomenon-based Learning to Promote Students' Mathematical Creativity	American Journal of Educational Research	Mixed, but students in Diff Eq	Quantitative	Yes
Blyman, Kayla K; Arney, Kristin M; Adams, Bryan; Hudson, Tara A	2020	Does Your Course Effectively Promote Creativity? Introducing the Mathematical Problem Solving Creativity Rubric	Journal of Humanistic Mathematics	Calculus	Quantitative pre-post problem solving	Yes
El Turkey, Houssein; Tang, Gail; Savic, Milos; Karakok, Gulden; Cilli-Turner, Emily; Plaxco, David	2018	The creativity-in-progress rubric on proving: Two teaching implementations and students' reported usage	PRIMUS	Transition-to-proof, number theory	Reflections, student work	Yes
Grégoire, Jacques	2016	Understanding creativity in mathematics for improving mathematical education	Journal of Cognitive Education and Psychology	NA	Theoretical	Yes
Hafizi, Mardiah Hafizah Muhammad; Kamarudin, Nurzatulshima	2020	Creativity in mathematics: Malaysian perspective	Universal Journal of Educational Research	NA	Theoretical	Yes

(continued)

Author	Year	Title	Journal	Content	Methods	Develop?
Hodge-Zickerman, Angie; Stade, Eric; York, Cindy S; Rech, Janice	2020	TACTivities: Fostering Creativity Through Tactile Learning Activities	Journal of Humanistic Mathematics	Calculus	Descriptions of projects	Yes
Hoshino, Richard	2018	Supporting Mathematical Creativity Through Problem Solving	Teaching and Learning Secondary School Mathematics	Graph Theory, Combinatorics	Descriptions of problems	Yes
Karakok, Gulden	2021	Exploration of Students' Mathematical Creativity with Actor-Oriented Transfer to Develop Actor-Oriented Creativity	Transfer of Learning: Progressive Perspectives for Mathematics Education and Related Fields	Combinatorics	Qualitative: Case-study analysis	Yes
Kasman, Reva	2014	Balancing structure and creativity in culminating projects for liberal arts mathematics	PRIMUS	Math for Liberal Arts (voting theory, graph theory)	Descriptions of projects	Yes
Mac an Bhaird, Ciarán; Nolan, Brien C; O'Shea, Ann; Pfeiffer, Kirsten	2017	A study of creative reasoning opportunities in assessments in undergraduate calculus courses	Research in Mathematics Education	Business, Science, and Pure calculus	Quantitative: Coding tasks with Lithner's IR CR	No
Marciniak, Malgorzata A	2020	Creative Assignments in Upper Level Undergraduate Courses Inspired by Mentoring Undergraduate Research Projects	Journal of Humanistic Mathematics	Differential Equations	Descriptions of projects	Yes
Mayes-Tang, Sarah	2020	Designing Opportunities for Mathematical Creativity: Three Ways to Modify an Existing Course	PRIMUS	First year seminar	Reflections and end of class discussion	Yes

(continued)

Author	Year	Title	Journal	Content	Methods	Develop?
Monahan, Ceire; Munakata, Mika; Vaidya, Ashwin; Gandini, Sean	2020	Inspiring Mathematical Creativity Through Juggling	Journal of Humanistic Mathematics	Gen ed terminal course	Description of class, journals, notes of class and focus groups.	Yes
Munakata, Mika; Vaidya, Ashwin; Monahan, Ceire; Krupa, Erin	2021	Promoting Creativity in General Education Mathematics Courses	PRIMUS	Gen ed terminal course	Description of class, journals, notes of class and focus groups.	Yes
Omar, Mohamed; Karakok, Gulden; Savic, Milos; Turkey, Houssein El; Tang, Gail	2019	I felt like a mathematician: Problems and assessment to promote creative effort	Primus	Combinatorics	Qualitative study: interviews, classroom artifacts – Best for teaching	Yes
Regier, Paul	2020	The impact of creativity-fostering mathematics instruction on student self-efficacy and motivation	Dissertation	Multiple	Qualitative, Quantitative	Yes
Regier, Paul; Savic, Milos	2020	How teaching to foster mathematical creativity may impact student self-efficacy for proving	The Journal of Mathematical Behavior	Introduction to proofs course	Qualitative: Teaching observations, interviews, coding for self-efficacy and sources	Yes
Roble, Dennis B	2017	Communicating and valuing students' productive struggle and creativity in calculus	Turkish Online Journal of Design Art and Communication	Calculus	Qualitative surveys, MST (Leikin, 2009) after HALP	Yes
Savic, Milos	2016	Mathematical problem-solving via Wallas' four stages of creativity: Implications for the undergraduate classroom	The Mathematics Enthusiast	NA	Theoretical	Yes

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Author	Year	Title	Journal	Content	Methods	Develop?
Savic, Milos; Karakok, Gulden; Tang, Gail; El Turkey, Houssein; Naccarato, Emilie	2017	Formative assessment of creativity in undergraduate mathematics: Using a creativity-in-progress rubric (CPR) on proving	Creativity and giftedness	Introduction to proofs course	Qualitative: Student work	Yes
Singh, Ram Dhani; Kushwaha, Sarita	2019	Components of Creativity and Mathematical Achievement in Undergraduate Students	Parisheelan	NA	Quantitative	No
Suriyah, Puput; Waluya, Stevanus Budi; Rochmad, Rochmad; Wardono, Wardono	2020	Graph Theory as A Tool for Growing Mathematical Creativity	Jurnal Pendidikan Edutama	Graph Theory	Systematic literature review	Yes
Tularam, Gurudeo Anand; Hulsman, Kees	2015	A Study of Students' Conceptual, Procedural Knowledge, Logical Thinking and Creativity During the First Year of Tertiary Mathematics.	International Journal for Mathematics Teaching and Learning	Precalculus	Quantitative: Likert 1–5, based on connection making	No
Wahyuningsih, Sapti; Satyananda, Darmawan; Qohar, Abd; Atan, Noor	2020	An Integration of “" Online Interactive Apps” for Learning Application of Graph Theory to Enhance Creative Problem Solving of Mathematics Students	International Journal of Interactive Mobile Technologies	Graph Theory	Quantitative: Creative PS scale	Yes
Zazkis, Rina; Holton, Derek	2009	Snapshots of Creativity in Undergraduate Mathematics Education	Creativity in mathematics and the education of gifted students	Various	Descriptions of problems, classrooms, and previous work	Yes

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