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Predicting multidimensionality of mathematical creativity among students: Do mathematics self-efficacy, attitude to mathematics and motivation to mathematics matter?

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Abstract

Mathematical creativity is the focus of most curriculum in that students with this ability are prone to solving problems in society from a multidimensional perspective. However, studies of this nature, especially in Africa, are limited, and this poses a challenge to policy development. To cover this gap, the study sought to model the predictive effect of mathematics self-efficacy, motivation for mathematics, and attitude towards mathematics on mathematical creativity from a multidimensional perspective. The study adopted a cross-sectional survey using 654 mathematics students for the study. Two instruments–the mathematics self-efficacy, attitude towards mathematics, and mathematical motivation scales and the mathematical creativity test were used for data analysis after they had undergone a qualitative and quantitatively rigorous validation process. This was done using exploratory and confirmatory factor analysis with the average variance extracted and Fornell-Larcker criterion for convergent and divergent analysis, respectively, while Cronbach's alpha was used to determine the stability of the scales. Analysis was performed using hierarchical regression and the result showed that mathematics self-efficacy and attitude towards mathematics, when taken individually, are the only strong predictors of mathematics creativity from the perspective of fluency, flexibility, and originality components. Collectively, the three predictors were significant in contributing to the variance in mathematics creatively from the three dimensions assessed. However, mathematics self-efficacy was the strongest predictor, followed by attitude towards mathematics. The implications of the study were discussed for policy and curriculum redesign in mathematics education.

Keywords: mathematical creativity, mathematics self-efficacy, motivation to mathematics, attitude to mathematics, flexibility, fluency and originality , hierarchical regression

INTRODUCTION

Mathematics as a subject is essential not just for its computational rigors but also for its ability to shape individuals thinking abilities as well as handle complex issues. This explains why there is a current shift from mere computational operations to developing creative abilities in mathematics (Ofem et al., 2024b). Mathematics creativity is a multifaceted construct that

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Contribution to the literature

- Encourages a holistic approach to educational interventions that address multiple psychological dimensions simultaneously.
- Aids in the development of tailored educational strategies that address specific creative dimensions, rather than a one-size-fits-all approach.
- Suggests that attitude improvement programs could be integral to enhancing creativity in mathematical contexts.
- Provides empirical evidence supporting the development of educational strategies focused on boosting self-efficacy to enhance creative outcomes in mathematics.

defines the ability of the individual to generate new ways of handling mathematical issues as well as think critically in ways that look innovative within the realm of mathematics (Leikin & Levav-Waynberg, 2007). This means that mathematics creativity centers on learners' ability to look at a situation with an applied mindset, not just following traditional operational techniques, which may not provide the solution to answer certain questions. According to Grégoire (2016), creativity mathematics is not only centered on the computational aspect but the dynamics with which a student introduces in the mathematics solution. The importance of mathematical creativity has been documented in the literature (Hadar & Tirosh, 2019; Ketelhut et al., 2020). These include enhancing students' approach to a particular problem from a multidimensional perspective, enhancing solutions, and fostering originality and innovation (Leikin & Levav-Waynberg, 2007); fostering and promoting critical thinking (Dada et al., 2016); stimulating and cultivating mathematical curiosity (Hidi & Renninger, 2006); and applying mathematical knowledge in diverse areas that helped to promote interdisciplinary connections as well as building self-efficacy among students.

The researchers' attention was drawn to the study based on the observation that students who are competent in the operational method of mathematics do not possess the required skills to navigate new environments and problems that may not follow the traditional methods they are aware of in handling complex mathematical issues. They are limited when what seems to follow the traditional way of analyzing is presented to them. This situation has raised concern among stakeholders and administrators over this condition where students are trained to be rational thinkers. Various researchers have identified factors that are responsible for this, including a fear of making mistakes. Lack of intrinsic motivation as students may lack intrinsic motivation to engage in creative mathematical thinking, leading to passive learning and reliance on rote memorization (Hembree, 1990; Ofem et al 2024b), fear of making mistakes (Gallagher, 2006), too much emphasis on procedural knowledge (Silver, 1997), narrow curriculum focus (Boaler, 2016), fixed mindset beliefs (Dweck, 2006), teacher-centered instructional approaches (Hiebert & Grouws, 2007), and lack of exposure to real-world problems (Ginsburg, 2009), negative attitudes towards mathematics (Ma, 1999), and insufficient support for divergent thinking (Cropley, 2006). Among the various factors that are identified to influence mathematical creativity, mathematic self-efficacy, motivation for mathematics, and attitude towards mathematics have gained traction.

Mathematics self-efficacy is the confidence in one's ability to tackle any mathematical task necessary to solve a problem. It involves approaching mathematical challenges with assurance and persistence to find the correct solution, according to the social cognitive theory (Bandura, 1977). Likewise, motivation in mathematics significantly influences how individuals engage with and persist in mathematical activities (Anderman & Anderman, 1999). Motivated learners tend to dedicate time and effort to understanding mathematical concepts, seeking out difficult problems, and trying new ideas, all of which are vital for mathematical creativity (Hidi & Renninger, 2006). Additionally, attitude towards mathematics refers to one's disposition and emotional responses to the subject. Students with a positive attitude towards mathematics typically show greater interest, intrinsic motivation, and enjoyment in mathematical activities, while a negative attitude can hinder their willingness to engage with math and find creative solutions (Grootenboer & Hemmings, 2008).

Previous studies have examined mathematical creativity from diverse perspectives (Haavold, 2016; Joseph et al., 2019; Lev & Leikin, 2017; Mann, 2005; Shaw et al., 2022; Sriraman, 2004; Tabach & Friedlander, 2013; Walia, 2012). For example, Baran et al. (2011) found that subcategories of creativity do not relate to scores on a traditional math test. Schoevers et al. (2022) noted that in students' performance in mathematics, creativity is a strong determinant on all types of geometrical problems, particularly in open-ended, non-routine problems. Abhishek and Bhoodev (2016) identified that self-concept in mathematics, availability of resources, and creative simulations were crucial for predicting mathematical creativity. On the other hand, social-intellectual involvement and educational administration were found to be restrictive factors for mathematical creativity. Other studies have noted that mathematical creativity is related to so many psychological, environmental, personal, and family factors (Kattou, 2014; Tarun, 2001). The study of mathematical creativity does not have many empirical works, as the concept is difficult to measure. Most of the studies that were reviewed had mathematical creativity as a dependent variable. In other words, mathematical creativity was not considered a problem in and of itself. While each of these factors–’’mathematics self-efficacy, mathematics motivation, and attitude towards mathematics’’–has been independently linked to various aspects of mathematical performance and achievement, their combined influence on mathematical creativity remains less explored. Similarly, the inability of previous studies to conceive of mathematical creativity Investigating how these factors interact and predict mathematical creativity can provide valuable insights into the underlying processes involved in creative mathematical thinking.

The purpose of this research is to address the gap by investigating mathematics self-efficacy, motivation, and attitudes as predictors of students’ mathematical creativity. Using a quantitative research approach and validated measurement tools, it seeks to determine how these factors contribute to variations in mathematical creativity. By understanding the relationship between self-efficacy, motivation, attitudes, and creativity in mathematics, educators and policymakers can develop effective teaching strategies and interventions to promote creative mathematical thinking. Identifying the key factors influencing mathematical creativity will help create supportive learning environments that boost students’ confidence, motivation, and positive attitudes towards mathematics, ultimately enhancing their creative problem-solving skills and lifelong mathematical learning The following question was raised for the study:

What is the relative and composite contribution of the mathematics self-efficacy, motivation to mathematics (MAM) and attitude to mathematics on mathematical creativity among students?

LITERATURE REVIEW

Studies on Mathematics Creativity

Creativity is an essential drive for innovation and progress in human history. This is because creativity encourages and engineers’ new ideas and promotes the construction of original products. Thus, in a complex world like ours where there is a need to approach issues from a multidimensional perspective, creativity is essential, and it has been a topic for discussion in mathematics literature (Sriraman & Haavold, 2017). There is a growing need to deepen our knowledge of the complex nature of insights, particularly in mathematics. For secondary school students, mathematical creativity is essential as it extends beyond mere computational skills to include thinking creatively when conventional methods fail (Leikin et al., 2009). Mathematical creativity involves deep thinking, addressing issues that are complex, and making connections between techniques, ideas, and applications (Hadar & Tirosh, 2019). It can be described through three main aspects: flexibility, originality, and fluency. Researchers have incorporated these concepts, along with elaboration, into the mathematical creativity test (MCT) (Nufus et al., 2018; Sahliawati & Nurlaelah, 2020). Fluency refers to a student’s ability to generate multiple solutions (Kozlowski et al., 2019); flexibility is the ability to alter thinking strategies when traditional methods are inadequate (Leikin & Lev, 2007; Mann, 2005); and originality is the ability to find unique solution paths and create novel ideas, even at an unexpected level for the learner (Kozlowski et al., 2019; Siswono, 2011).

Another issue is whether close-ended or open-ended questions should be used in determining mathematical creativity (Bokhove & Jones, 2018; Kwon et al., 2006). Several researchers have opined that open-ended questions are more effective because they encourage creative thinking by requiring students to generate multiple solutions to a problem (Kwon et al., 2006; Leikin, 2009, 2018; Levav-Waynberg & Leikin, 2012; Silver, 1997). Numerous studies have explored the characteristics of students who exhibit mathematical creativity (Mann, 2005; Tabach & Friedlander, 2013; Walia, 2012). Sriraman’s (2004) study identified five principles that can enhance mathematical creativity, and Haavold’s (2016) research validated Sriraman’s (2004) model, revealing that mathematical creativity is influenced by mathematical achievement and motivation. While this discussion does not aim to exhaustively review research on the relationship between mathematical creativity and other factors, it is noteworthy that research on mathematical creativity in Nigeria, though limited, does exist (Sun, 2004; Tularam & Hulsman, 2015).

Studies on Mathematics Self-Efficacy

Bandura’s (1997, 2012) social cognitive theory provides the theoretical grounds for self-efficacy conceptualization, it primarily concerns an individual’s perception of their capability to manage or execute a specific task. This judgment about one’s ability to reach a set goal can significantly influence other actions that they take (Ardura & Galán, 2019; Diseth, 2011). Within the context of learning mathematics, mathematics self-efficacy is defined as an individual self-examination of the ability to perform certain mathematical task (Hackett & Betz, 1989, p. 262). In fact, some scholars have noted that for an individual to be sufficiently able to handle a mathematical task, it must be accompanied by self-efficacy, which is rooted in the belief in the correctness of the outcome and procedure (Rozgonjuk et al., 2020; Zakariya, 2021). Every effort that is carried out in mathematics must first be expressed in the ability to perform it; otherwise, the individual may not believe in what is done. If there is a lack of confidence in what is done in mathematics, it implies that the judgement about the answer may not also be right. This is why there is strong emphasis on the ability of the learner to believe in what they do with respect to mathematics (Lau et al., 2018). People with low self-belief to accomplish a particular task, may not be able to complete an assignment even if it is not a difficult task.

Efficacy in mathematics prompts some students to select the task and procedure to adopt in solving mathematics (Pajares, 1996; Zakariya et al., 2019). This is why mathematical self-efficacy is often considered a student's self-evaluation of their abilities in handling a particular task, which may be influenced by their internal drive to get it achieved. According to Bandura's (2012) theory, mathematical self-efficacy stems is a product of several factors such as mastery experience, social persuasion, physiological states, and vicarious experience. Mastery experience, among all, is considered the most influential for self-efficacy in mathematics (Akin & Kurbanoglu, 2011; Rozgonjuk et al., 2020; Usher & Pajares, 2009; Zakariya, 2021; Zakariya et al., 2020; Zientek et al., 2019) as it involves students' perceptions of their past academic successes in the subject. Understanding self-efficacy in mathematical creativity is crucial not only for enhancing academic performance but also for developing students' ability to think and solve problem, which are vital for comprehensive education (Rozgonjuk et al., 2020).

Previous research on self-efficacy in mathematics has been carried out (Mailizar et al., 2020; Negara et al., 2021). It is predicted in the literature that self-efficacy predicts not only academic performance but also provides a nexus with performance (Roick & Ringeisen, 2018; Yurt, 2014; Zakariya, 2021). Yusuf (2022) found that effective mathematical self-efficacy relates to academic performance. Michael and Michael's (2005) study found that mathematical self-efficacy relates to academic performance. Other studies also found that self-efficacy is essential in learning mathematics (Aremu & Tella 2009). As interesting, beautiful, and insightful as these studies have been in explaining the variances in students' performance in mathematics, it is not clear whether these factors will work well in explaining the total variation in mathematical creativity. Since mathematical self-efficacy is potent in explaining other dimensions of mathematics, it will be appropriate for this to happen with creativity in mathematics. More so, self-efficacy researchers have also focused on diverse areas which includes arts, writing, and language, paying less attention to mathematical creativity, particularly at the higher level of education in which these sought-after beliefs are supposed to be rooted in the learners who are to solve societal problems. This is an omission is unfortunate because of the prominence mathematics hold in the academic curriculum, and that academic success in these subjects is imperative in this age of rapid scientific and technological advancement. However, it is not to the knowledge of the researchers if studies exist that have attempted modelling this relation, and this is the rationale for examining this nexus.

Studies on Mathematical Motivations

Motivation is an essential construct for students' success in school (Artino, 2008; Eom et al., 2006; Keller, 2008; Widjaja & Chen, 2007). This is because motivation is a construct that attempts to explain the drive, either within or outside the individual, that determines the intensity, direction, and persistence of an individual to accomplish a particular task. It is rooted in the social determination theory of Ryan and Deci (2000). The basic ideas inherent in this theory are that motivation is determined by the level to which the program or activity provides a sense of autonomy, competence, and relatedness, that what causes a drive to rise could be internal or external (Saeed & Zyngier, 2012).

Different studies have examined students' motivation from a wide range of traditional educational settings (Schunk et al., 2014; Smith et al., 2005; Visser et al., 2017). Past studies have shown that individuals with an inner push for an action have the tendency to achieve that objective and display improved performance (Ferreira et al., 2011). Mathematics creativity cannot be developed if students are not motivated mathematically to be detailed, specific, and procedural so as to unearth hidden areas that may not be common to traditional students. The motivation students get to dig deep into their thoughts and think of innovative ways of handling problems could be very essential so as not to just produce students with quantitative skills without creativity. However, this nexus between mathematics motivation and mathematics creativity is still an issue of study, as the literature appears very scanty if not available. The available literature that has been accessed has been carried out over the past decade. This study will serve as a bridge between previous studies and now and provide a nuanced understanding of the impact of mathematical motivation on not only academic performance as it was used before but also on mathematical creativity, which is required in the ear of technological expansion.

Studies on Attitude to Mathematics

Attitude is an affective attribute that differs from other constructs like emotions, beliefs, and motivation, even though they can influence attitude towards whatever phenomenon occurs (Goldin et al., 2016). Attitude refers to individuals' dispositions about a phenomenon based on their comprehensive evaluation. The evaluation of the object of disposition makes it either positive or negative (Clore & Schnall, 2005). Therefore, students' attitudes towards mathematics can be conceptualized as the disposition of students either positive or negative that students hold about mathematics. Students with a positive disposition to the subject may enjoy the subject, pay attention to details, and unearth new ways of doing things (Kiwanuka et al., 2020; Mullis et al., 2020), and this could facilitate greater performances (Chouinard et al., 2007; Guo et al., 2015; Wigfield et al., 2016), while those with a negative attitude may not measure up to the task required to have a higher score, not even the disposition to be creative. Several studies have reported that students' attitudes towards mathematics have a strong correlation with academic performance in mathematics (Bhowmik & Roy, 2016; Chen et al., 2018; Dowker et al., 2019; Kiwanuka et al., 2020), while others have found contrary results (Köller et al., 2001; Mubeen et al., 2013; Papanastasiou, 2000; Phonguttha et al., 2009). While this inconsistence deserves further study, it is not the crux of this study. The researchers are amazed that, as relevant as mathematical creativity is, since students, especially those in tertiary institutions, are supposed to have developed these creative skills to navigate the world of technology adequately, it is not our knowledge if studies of this nature linking attitude to mathematics and mathematical creativity have been examined. It will be imperative to examine this to facilitate intervention strategies that can be used to improve students' creativity in mathematics.

The current study is novel in that it offers researchers and mathematicians a new perspective on the level of mathematical creativity, taking into cognizance the various factors that will contribute to its variance since advanced statistical models were used in the study. The nuanced understanding that this study provides will facilitate policy development, curriculum innovation in mathematics education, and intervention programs that will not only improve performance but also increase the level of creativity that is required in a scientific and technological society.

Conceptually, the researchers have assumed that mathematical self-efficacy relates to the fluent component of mathematical creativity. When motivation for mathematics is added to the model, there will be a change in the variance explained, and the subsequent addition of attitude towards mathematics will also contribute to a change in the fluent component of mathematical creativity. The chain continues for the flexibility and originality components of creativity when the independent variables (mathematics self-efficacy, mathematics motivation, and attitude towards mathematics) are added successively. This is illustrated in **Figure 1**.

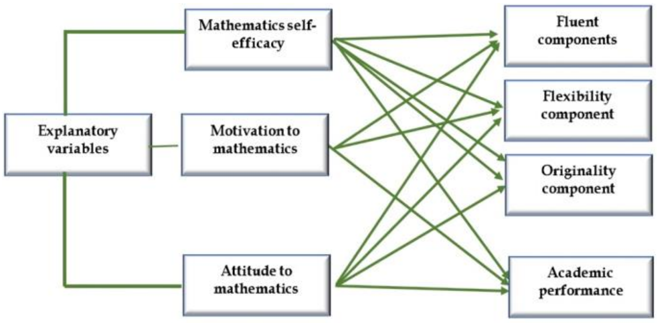

Figure 1. Conceptual model of mathematics self-efficacy, attitude and motivation on mathematics creativity (Ovat et al., 2024)

RESEARCH METHODOLOGY

The study utilized a correlational design to explore the relationships between the variables of interest. It was conducted as a cross-sectional survey, collecting information from different units simultaneously. A multistage sampling method was employed, starting with a stratified sampling technique among a population of 8,908 students from the mathematics departments of 60 tertiary institutions. A sample of 654 mathematics students was selected. The demographic breakdown of the sample included 326 males (49.84%) and 328 females (50.15%). Regarding age, 212 students (32.42%) were under 25 years, 234 students (35.77%) were between 25 and 35 years, and 202 students (30.88%) were 36 years or older. Institutions offering certificate courses, nursing school leaders, and monotechnic were excluded from the study as they did not have mathematics departments.

Instrumentation

The instruments used for this study were 'mathematics self-efficacy, motivation, and attitude to mathematics scales (MSMAMS)' and the 'mathematics creativity scale'. The MSMAMS consist of the three independent variables of the study. Although mathematics self-efficacy, attitude to mathematics, and MAM scales exist, the researchers developed new instruments due to cultural and contextual differences within the area in which the study is situated. This is not to say that the instruments as developed by other researchers are not important. Mathematics self-efficacy refers to an individual's belief to perform mathematical task and has a sample item, 'I feel confident in my ability to solve mathematical problems'. Attitude towards mathematics refers to an individual's disposition to mathematics and has a sample item: 'I find mathematics interesting and enjoyable'. Motivation for mathematics refers to the internal and external factors that drive an individual's to engaging with mathematical tasks. A sample item includes: 'I am moved to exploring new mathematical concepts and problems. Each of the subscales was measured with six items on a four-point Likert scale from strongly agree (SA) to strongly disagree (SD). Thus, a total of 18 items were used for measuring the explanatory variables.

The dependable variable is mathematical creativity. MCT is a power test that requires the use of difficult questions, requiring high-order mental ability. It should be noted that the answer to the problem is not the ultimate concern in MCT. Torrance (1966) divergent thinking tasks, which involve presenting individuals with open-ended mathematical problems or prompts and assessing the range and originality of their responses, were used for this study. There are other methods for measuring mathematical creativity (see Cropley, 2006; Hocevar, 1979; Plucker & Makel, 2004; Silver, 1997). In the Torrance (1966) model, responses are scored based on factors such as fluency (the number of ideas generated), flexibility (the variety of ideas), and originality (the uniqueness of ideas). The researchers developed a rubric for the three components of the MCT. For example, in fluency, examiners are guided by the statement, 'The students make a valid observation of the question. For flexibility, 'The students use another method in solving the problem' and for originality, 'the students make innovative interpretations or unexpected connections to other mathematical concepts. The experts followed this rubric to attach scores for every question. There are 10 questions in all, requiring 60 minutes to respond. These questions were developed using experts in mathematics education, both in colleges of education, polytechnics, and universities.

Validity of the Instrument

Quantitative methods were used for determining the validity of the scale using five experts in mathematics education and two experts in measurement and evaluation. These experts, who are lecturers with over a decade of experience in their respective fields, independently validated the instrument based on their accumulated expertise. Item scoring was evaluated against three criteria: precision, clarity, and relevance (Ofem et al., 2024a), utilizing the item content validity index (I-CVI) and scale content validity index (S-CVI). The MSMAMS instrument achieved scores ranging from 0.81 to 0.87 for relevance, precision, and clarity, and S-CVI values between 0.83 and 0.89 were recorded. According to guidelines (Polite et al., 2007; Yusoff, 2019), the I-CVI should be at least 0.80 for two experts, rising to 0.99 for three to five experts, 0.83 for six to eight experts, and 0.78 for nine or more experts. The obtained values fell within these acceptable ranges, which signals that the items in the instrument have content validity.

A pilot study was carried out by the researchers to delineate the dimensions of constructs in mathematics self-efficacy, motivation for mathematics, and attitude toward mathematics. This involved 150 students from institutions not included in the main study. Exploratory factor analysis (EFA) was carried out with principal component analysis and varimax rotation to identify these factors. Additionally, a preliminary validation of the MCT was performed to assess item difficulty, ensuring items were appropriately challenging yet within students' capabilities. Twenty students not part of the main study participated in this item analysis. Following standards set by Crocker and Algina (2006), items with difficulty indices ideally fell between 0.30 and 0.50. Consequently, items falling outside this range (0.29-0.50) were excluded. The reliability of the scale, based on the Kuder Richardson 21 method applied to the 10 retained items, yielded a coefficient of 0.78, indicating sufficient internal consistency.

Ethical Consideration

The study was a non-experimental study that poses no harm to the respondents. Thus, this type of study according to the Nigeria code for health research ethics (refer to https://bit.ly/3pK9ORh) does not refire ethical clearance. However, the researchers according to global best practices , submitted the study protocol to the institutional review board for approval and after a period of review, ethical clearance was (see IRC/FUNAI/004/0786).

Procedure for Data Collection

The collection of data involved research assistants that were trained from various institutions. The researchers thoroughly explained the study's purpose to potential participants, who were given the choice to participate or decline. Those who understood and agreed to participate provided written consent, as oral consent was not permitted. An interactive session allowed respondents to ask questions and receive answers. In the study, 654 participants were initially addressed, and their consent was obtained. Individuals who declined participation were respectfully excluded, and no coercion was used to persuade anyone to join the study. Participants were assured of anonymity and data security measures, including restricted access via an access code managed by the lead author and the use of a firewall to protect data from unauthorized access. Participants were informed that their responses will be analyzed and report, published in a reputable journal. Therefore, data from 535 participants were ultimately included in the study.

The model specification for this study is, as followed (Ofem et al., 2024a):

$$\text{Model 1: FLU} = \beta_{MSE} + \varepsilon\ (R^2) \tag{1}$$

$$\text{Model 2: FLU} = \beta_{MSE} + \beta_{MAM} + \varepsilon\ (\Delta R^2, R^2) \tag{2}$$

$$\text{Model 3: FLU} = \beta_{MSE} + \beta_{MAM} + \beta_{ATT} + \varepsilon\ (\Delta R^2, R^2) \tag{3}$$

$$\text{Model 4 : FLE} = \beta_{MSE} + \varepsilon\ (R^2) \tag{4}$$

$$\text{Model 5 : FLE} = \beta_{MSE} + \beta_{MAM} + \varepsilon\ (\Delta R^2, R^2) \tag{5}$$

$$\text{Model 6: FLE} = \beta_{MSE} + \beta_{MAM} + \beta_{ATT} + \varepsilon\ (\Delta R^2, R^2) \tag{6}$$

$$\text{Model 7 : ORI} = \beta_{MSE} + \varepsilon\ (R^2) \tag{7}$$

$$\text{Model 8 : ORI} = \beta_{MSE} + \beta_{MAM} + \varepsilon\ (\Delta R^2, R^2) \tag{8}$$

$$\text{Model 9: ORI} = \beta_{MSE} + \beta_{MAM} + \beta_{ATT} + \varepsilon\ (\Delta R^2, R^2) \tag{9}$$

Table 1. Quality criteria assessment of the constructs underlying the study

Items	N	Mean	Standard deviation	Standard error	λ	λ^2	Properties
Sef1	150	3.028	.571	.024	0.702	0.492	AVE = 0.645
Sef2	150	3.130	.443	.019	0.781	0.609	Disc = 0.803
Sef3	150	3.065	.555	.024	0.853	0.727	
Sef4	150	2.930	.679	.029	0.886	0.784	
Sef5	150	2.904	.695	.030	0.850	0.722	
Sum	**150**	**15.059**	**2.431**	**.105**	**4.072**	**3.337**	
Mot1	150	2.551	.695	.030	0.742	0.550	AVE = 0.737
Mot2	150	2.529	.699	.030	0.864	0.746	Disc = 0.859
Mot3	150	2.463	.715	.030	0.879	0.772	
Mot4	150	2.506	.761	.032	0.881	0.776	
Mot5	150	2.499	.756	.032	0.917	0.840	
Sum	**150**	**12.549**	**3.137**	**.135**	**4.283**	**3.686**	
Att1	150	2.444	.587	.025	0.74	0.547	AVE = 0.807
Att2	150	2.480	.602	.026	0.778	0.605	Disc = 0.899
Att3	150	2.431	.556	.024	0.827	0.683	
Att4	150	2.377	.536	.023	0.768	0.589	
Sum	**150**	**9.734**	**1.789**	**.077**	**3.113**	**2.426**	

Note. λ=factor loadings

Table 2. Discriminant validity of construct

Constructs	AVE	α	CR	1	2	3
Mathematics self-efficacy (1)	.640	.789	.865	**0.803**		
Motivation to mathematics (2)	.737	.822	.887	0.321	**0.859**	
Attitude to mathematics (3)	.807	.801	.887	0.232	0.143	**0.899**

The followings are the notes from the model. FLU means fluency; FLE means flexibility; ORI means originality; MSE means mathematics self-efficacy; MAM means motivation to mathematics; ATT means attitude to mathematics; R^2 means the coefficient of determination; ΔR^2 means the change in the coefficient of determination as a result of the addition of new variables; and ε means the error term.

As shown in **Table 1**, results for MSMAMS indicated a KMO value of 0.779, with Bartlett's test of sphericity yielding $X^2(128) = 2324.87$, $p < .001$, suggesting that the sample selected was adequate for conducting EFA. Further analysis revealed that due to cross loadings and factors loading less than 0.5, four items were removed (De Leeuw et al., 2003; Honaker et al., 2008; McCoach, 2010). The total variance explained by the three sub-variables of the independent variables was 69.13%, with mathematics self-efficacy contributing 29.57%, motivation for mathematics contributing 24.61%, and attitude towards mathematics contributing 14.94%.

To evaluate the convergent and divergent validity of the constructs, the Fornell-Larcker criterion, was utilized (Fornell & Larcker, 1981). Convergent validity is achieved if the average variance extracted (AVE) of a factor exceeds 0.50 (see Lee, 2019). For MSMAMS, the AVE value exceeded 0.50, indicating that the items retained in these factors are theoretically related to their latent factor. Similarly, the result in **Table 2** shows the divergent validity of the three subscales of the instruments, based on the Fornell-Larcker criterion. According to this criterion, a subscale is considered theoretically distinct ''if the square root of the AVE for each factor is greater than its correlation with other factors'' (Ab Hamid et al., 2017; Hilkenmeier et al., 2020). Thus, as shown in **Table 2**, the bolded values in the principal diagonal of the three latent factors are greater than their correlation with other factors. Therefore, the factors are theoretically different in measuring automated assessment in the presence of technological acceptance vectors. More so, the reliability of the measures was assessed using Cronbach's alpha and composite reliability, and the coefficients of the subscales for Cronbach's alpha were all higher than 0.70, which is the benchmark. This implies that the instrument has internal consistency.

Confirmatory Factor Analysis

The confirmatory factor analysis (CFA) was performed using the maximum likelihood (ML) estimation approach to examine the measurement model of the latent constructs. The CFA model as shown in **Figure 2** and **Table 3** included three latent variables: mathematics self-efficacy, MAM and attitude to mathematics, each measured by several observed indicators. The hypothesized model showed that the model indices were fit CFI = 0.920, TLI = 0.943, RMSEA = 0.06, SRMR = 0.08. This suggest that the latent constructs adequately capture the observed indicators.

RESULTS

Percentage Contributions to Mathematical Creativity

The hierarchical regression results in **Table 4** indicate that initially, mathematics self-efficacy explains 4.2% of the variation in fluency. Introducing motivation for

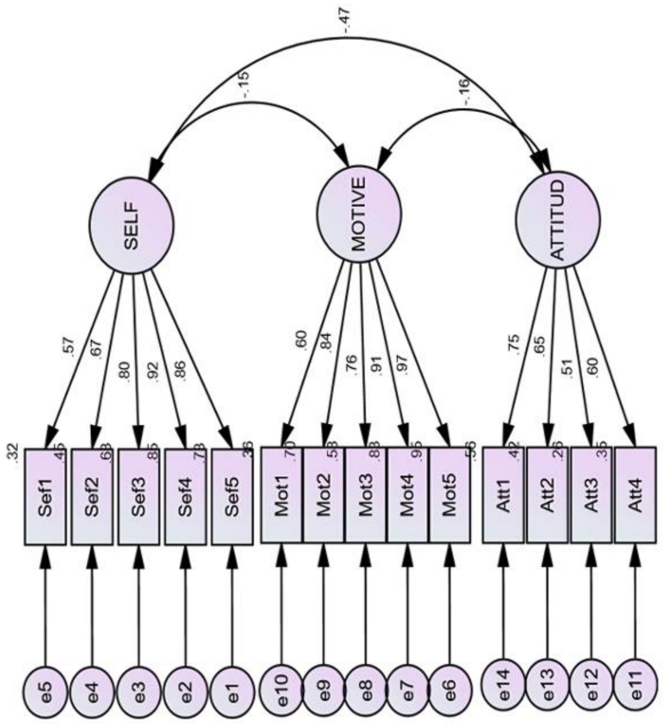

Figure 2. CFA of mathematics self-efficacy, attitude to mathematics and motivation to mathematics (Ovat et al., 2024)

Table 3. Fit summary statistic illustrating overall CFA model fit for institutional and attitude to research

S/N	Fit indices	Threshold	Predictors
1	χ^2/df	P< .20	.005
2	AGFI	p≥ .90	.902
3	NFI	p≥ .90	.910
4	CFI	p≥ .90	.920
5	GFI	p≥ .90	.918
6	TLI	p≥ .90	.943
7	IFI	p≥ .90	.923
8	RMSEA	P < .08	.006

Note. df: Degrees of freedom

mathematics in model 2 increases this contribution to 44.3%, showing a relative change of 0.01%. When attitude towards mathematics is added in model 3, the explained variance rises to 46.7%, with an additional R^2 change of 2.4%. Mathematics self-efficacy emerges as the strongest predictor of fluency in mathematical creativity (ΔF [1, 533] = 424.99, $p < .001$), followed by motivation for mathematics (ΔF [1, 532] = 213.00, $p < .001$), and attitude towards mathematics (ΔF [1, 531] = 157.00, $p < .001$).

Table 4 shows that mathematics self-efficacy initially accounts for 49.9% of the variation in flexibility. Introducing motivation for mathematics in model 2 maintains this contribution at 49.9%, with no change. Adding attitude towards mathematics in model 3 increases the explained variance to 150.9%, with an R^2 change of 0.01%. Among the predictors, mathematics self-efficacy is the strongest predictor of flexibility in mathematical creativity (ΔF [1, 533] = 532.06, $p < .001$), followed by motivation for mathematics (ΔF [1, 532] = 267.29, $p < .05$), and attitude towards mathematics (ΔF [1, 531] = 185.49, $p < .001$).

In assessing the contribution to originality, mathematics self-efficacy initially accounts for 31.8% of the variation. Introducing motivation for mathematics in model 2 slightly increases this to 31.9%, with a minor change of 0.01%. Adding attitude towards mathematics in model 3 raises the explained variance to 33.4%, with an R^2 change of 0.15%. Mathematics self-efficacy is the strongest predictor of originality in mathematical creativity (ΔF [1, 533] = 250.210, $p < .001$), followed by motivation for mathematics (ΔF [1, 532] = 126.01, $p < .001$), and attitude towards mathematics (ΔF [1, 531] = 90.321, $p < .001$).

Hypothesis Testing: Composite Contribution

The ANOVA results in **Table 5** showed the significant contribution of the predictors on fluency. Mathematics self-efficacy significantly contributes to fluency in model 1, with F (1, 533) = 424.93, $p < .001$. In model 2, the combined contribution of self-efficacy in mathematics and motivation for mathematics on fluency is significant, with F (1, 532) = 213.002, $p < .001$. Model 3 shows a significant combined contribution of self-efficacy in mathematics, motivation for mathematics, and attitude towards mathematics on fluency, with F (1, 532) = 157.09, $p < .001$. The ANOVA results in **Table 5** indicate that mathematics self-efficacy significantly affects flexibility in model 1, with F (1, 533) = 532.06, $p <$

Table 4. Hierarchical regression analysis of the relative contribution of mathematics self-efficacy, motivation to mathematics and attitude to mathematics on mathematical creativity (fluency, flexibility, and originality)

Variables	Model	R	R^2	Adj R^2	SE	ΔR^2	ΔF	df1	df2	ΔSig. F
Fluency	1	.666[a]	.444	.442	2.150	.442	424.79**	1	533	.000[b]
	2	.667[b]	.445	.443	2.150	.001	213.00**	2	532	.000[b]
	3	.686[c]	.470	.467	2.102	.024	157.08**	3	531	.000[b]
Flexibility	1	.707[a]	.500	.499	1.744	.499	532.06**	1	533	.000[b]
	2	.708[b]	.501	.499	1.743	.000	267.29**	2	532	.000[b]
	3	.715[c]	.512	.509	1.726	.001	185.49**	3	531	.000[b]
Originality	1	.565[a]	.319	.318	2.948	.318	250.20**	1	533	.000[b]
	2	.567[b]	.321	.319	2.946	.001	126.01**	2	532	.000[b]
	3	.581[c]	.338	.334	2.913	.015	90.321**	3	531	.000[b]

Note. **Significant at .05 level; SE: Standard error; & df: Degrees of freedom

Table 5. ANOVA result of hierarchical regression of composite contribution of three predictors on mathematical creativity

Criterion variables	Model	source of variation	Sum of squares	df	Mean square	F	Sig.
Fluency	1	Regression	1965.177	1	1965.177	424.796**	.000b
		Residual	2465.750	533	4.626		
		Total	4430.927	534			
	2	Regression	1970.341	2	985.170	213.002**	.000c
		Residual	2460.587	532	4.625		
		Total	4430.927	534			
	3	Regression	2083.419	3	694.473	157.088**	.000d
		Residual	2347.508	531	4.421		
		Total	4430.927	534			
Flexibility	1	Regression	1619.540	1	1619.540	532.063**	.000b
		Residual	1622.393	533	3.044		
		Total	3241.933	534			
	2	Regression	1624.907	2	812.453	267.296**	.000c
		Residual	1617.026	532	3.040		
		Total	3241.933	534			
	3	Regression	1658.942	3	552.981	185.492**	.000d
		Residual	1582.991	531	2.981		
		Total	3241.933	534			
Originality	1	Regression	2174.685	1	2174.685	250.207**	.000b
		Residual	4632.586	533	8.692		
		Total	6807.271	534			
	2	Regression	2188.189	2	1094.095	126.012**	.000c
		Residual	4619.082	532	8.682		
		Total	6807.271	534			
	3	Regression	2300.000	3	766.667	90.321**	.000d
		Residual	4507.271	531	8.488		
		Total	6807.271	534			

Note. **Significant at .05 level & df: Degrees of freedom

.001. In model 2, the combined contribution of mathematics self-efficacy and motivation for mathematics on flexibility is significant, with F (1, 532) = 267.29, p < .001. Model 3 reveals a significant combined contribution of self-efficacy in mathematics, motivation for mathematics, and attitude towards mathematics on flexibility, with F (1, 532) = 185.49, p < .001.

Table 5 also shows that mathematics self-efficacy significantly influences originality in model 1, with F (1, 533) = 250.20, p < .001. In model 2, the combined contribution of self-efficacy in mathematics and motivation for mathematics on originality is significant, with F (1, 532) = 126.01, p < .001. Model 3 indicates a significant combined contribution of self-efficacy in mathematics, motivation for mathematics, and attitude towards mathematics on originality, with F (1, 532) = 90.32, p < .001. The ANOVA results confirm the significant composite contributions of mathematics self-efficacy, motivation for mathematics, and attitude towards mathematics on the overall creativity scores of the students. Each predictor, both individually and collectively, contributes significantly to the components of mathematical creativity, namely fluency, flexibility, and originality.

Hypothesis Testing: Relative Contributions

What is the individual effect of three predictors on mathematical creativity: fluency, flexibility, and originality cognitive? According to **Table 6**, self-efficacy in mathematics and attitude towards mathematics are the strongest predictors of the fluency, originality, and flexibility components of mathematical creativity. However, a cursory look at the models also revealed that motivation for mathematics is not a predictor of the three dimensions of mathematical creativity. On a composite note, two predictors (self-efficacy in mathematics and attitude towards mathematics) relatively contributed to mathematical creativity, but mathematics self-efficacy was the strongest predictor in all cases.

DISCUSSION OF FINDINGS

The study findings which revealed that self-efficacy in mathematics relates to fluency, flexibility, and originality dimensions of mathematical creativity, is both insightful and logical, and it also aligns with existing literature in educational psychology. This is because these three dimensions are useful for students to produce new mathematical ideas and adapt to new methods of handling problems as solutions. However, the findings have revealed that for this to occur, mathematical self-efficacy is essential. The rationale could be attributed to the theory of bandura: individuals who believe in their ability have the tendencies to engage in tasks, irrespective of how difficult they might be perceived. This aligns with the outcome of Negara et al. (2021) who stated that students with a high level of self-

Table 6. Individual contribution of three predictors on fluency, flexibility , originality, and overall mathematical creativity

Variables	Model	Predictors	B	t	SE	p-Val
Fluency	1	Mathematic self-efficacy	.666	20.611**	.040	.000
	2	Attitude to mathematics	.671	20.573**	.041	.000
	3	Motivation to mathematics	.034	1.057	.031	.291
Flexibility	1	Mathematic self-efficacy	.707	23.066**	.033	.000
	2	Attitude to mathematics	.712	23.057**	.033	.000
	3	Motivation to mathematics	.041	1.329	.025	.184
		Attitude to mathematics	.105	3.379**	.043	.001
Originality	1	Mathematic self-efficacy	.565	15.818**	.873	.000
	2	Attitude to mathematics	.571	15.853**	.882	.000
	3	Motivation to mathematics	.045	1.247	.053	.213

belief in mathematics not only perform well in mathematics but also adopt new strategies and methods for solving mathematical problems and arrive at similar solutions. This finding was shared by other authors (Roick & Ringeisen, 2018; Zakariya, 2021): self-efficacy in mathematics instils confidence in the learners, as well as goal-setting strategies that propel students' efforts in handling tasks that appear tedious, complicated, and confusing. This helps to increase their fluency in mathematics and reinforces their achievement in the subject.

Similarly, the result showed that mathematics self-efficacy is a strong predictor of the flexibility dimension of mathematical creativity. It should not be forgotten that flexibility is concerned with students' approaches to mathematical problems from a different perspective or variety of strategies. Thus, the findings align positively with research studies that have focused on adaptive problem-solving techniques. The outcome of the study could be due to the fact that students with high self-efficacy in mathematics may not focus on using one method to do the same thing as they have already believed in their ability to navigate many pathways to solve the problem (Hebert & Stipek, 2005). The finding of the study was supported by previous studies that have found that students with high trust in their abilities display stronger cognitive flexibility that helps them to multitask divergently. This is largely because students see the problem from a diverse perspective, which informs their development of new and innovative strategies to handle it (Aremu & Tella 2009).

The findings of the study also revealed that mathematical self-efficacy affects originality in mathematics. This aligns with a previous study that found that students with creative self-ability have the tendency to produce original ideas and solutions to problems in math (Karwowski, 2011). This could be more so because students with high self-efficacy abilities are always willing to take risks and utilize means that are very uncontroversial in handling mathematical tasks. The study was also supported by the outcome of Beghetto (2009), who found that self-efficacious students in mathematics are often very creative because of the confidence they have in themselves and are not afraid of taking risks or making mistakes, which to a greater extent limits the level of creativity that is required in mathematics. This belief in oneself to handle complex tasks often instigates more complex solutions to problems, thereby contributing to the greater originality of their mathematical work. This is not free from the limitations that some studies have highlighted. In fact, Yusuf (2022) study reported that as much as self-efficacy is important, teachers and students must not lose focus on domain-specific knowledge and skills that are essential to maximizing creativity. This is because students must first have an adequate understanding of the mathematical concepts, which must be manipulated from a diverse perspective in order to arrive at certain solutions.

The findings of the study also revealed that student's attitude to mathematics affects students' fluency, flexibility, and originality dimensions of mathematical creativity, which are in consonance with theoretical considerations in psychological literature. The rationale is that students who develop a positive disposition to mathematics have the tendencies to wade all forms of fear that sometimes limit their potential to do well. For example, fluency that is focused on the ability to generate ideas in response to a problem has a positive relation to attitude towards mathematics. Students who value and enjoy mathematics will be predisposed to employing new methods to produce multiple solutions. They are engaging persistently with mathematical tasks that will facilitate exploration of various problem-solving techniques, which inversely will help them generate more ideas (Kiwanuka et al., 2020). This also aligns with the study of Mullis et al. (2020) which found that student's disposition to mathematics is a significant predictor of higher achievement. Higher achievement often involves increased problem-solving fluency, as students who are positively disposed to mathematics are more likely to invest time and effort in practicing and mastering various mathematical concepts.

The outcome also revealed that students' attitudes towards mathematics predict flexibility in mathematical creativity, which aligns with adaptive and innovative thinking in mathematics. This could also be since flexibility means doing the same thing in diverse ways, and students with positive disposition to mathematics and are in constant practice may not follow traditional methods of solving complex problems to present multiple solutions. The study findings align with those of Lepper et al. (2005), who posited that where students display a positive attitude towards mathematics, their tendencies to engage in self-directed learning are high, and they set goals, supervise, and evaluate their strategies to achieve maximum results. It is clear that this self-regulated learning provides an opportunity for flexibility as students are willing to explore and experiment with different methods so as to make discoveries and learn from whatever mistakes they commit in the process. However, caution must be taken to ensure that competence and experience contribute meaningfully to flexibility and achievement in mathematics (Dweck, 2006).

The findings also revealed that attitude towards mathematics is a significant predictor of originality in mathematical thinking. That is, students whose disposition towards mathematics is positive are likely to develop novel and unique solutions to mathematical problems, a claim that is backed by psychologists in education. The rationale for this is that where students disposition to mathematics is positive, they could adventure to take intellectual risks that will not only help them provide solutions to the problem but also make new discoveries, which is a key component of originality (Dowker et al., 2019; Kiwanuka et al., 2020). More so, the study aligns with that of Beghetto (2009), who found that a positive attitude towards mathematics is essential because it stimulates the ability to experiment with so many things, not minding the mistakes they make that can be learned from, provided they yield a tangible solution to the problem.

The findings that motivation in mathematics does not predict any component of mathematical creativity are intriguing and counterintuitive considering the volume of studies in the literature that have studied things like motivation and creativity. For example, the findings that motivation in mathematics does not predict fluency could be because motivation as a single factor may not be able to enhance creativity. This could also mean that while motivation facilitates engagement in a task, that may not automatically translate into the efficient cognitive process that is required for fluency. This could also be justified by individual differences, even though this is not the crux of the study. This substantiates the assertion of Hidi and Renninger (2006) that motivation is an essential construct in mathematics literature, but in the context of mathematical creativity, skills and strategies used as motivation are essential to enhancing creativity. More so, domain-specific knowledge is essential, as this will provide a basis for understanding concepts that will help in generating multiple solutions to a problem (Baer & Kaufman, 2005).

The same applies to flexibility and originality in the context of motivation in mathematics. The non-significant prediction for these two areas of mathematical creativity could not be because motivation is not important, but that cognitive flexibility requires a foundational understanding of the different approaches and the ability to alternate between methods so that one can solve a problem with a different method, which motivation alone may not be able to handle (Runco & Chand, 1995). Therefore, several factors may affect the cognitive flexibility of the students other than motivation. More so, motivation does not predict originality; it requires more than just engagement; it necessitates risk-taking, divergent thinking, and a conducive environment for creativity. If students are highly motivated but lack opportunities or support for creative exploration, their originality might not be significantly enhanced. The findings align with those of Silver et al. (2008), who found that factors such as creative self-efficacy and personality attributes, especially openness to experience, are very potent in fostering originality in mathematics.

The study's findings suggest that when self-efficacy in mathematics, MAM, and attitude to mathematics are combined, they become significant predictors of fluency, flexibility, and originality dimensions of mathematical creativity. The outcome of this study supports the earlier claim that mathematical creativity is not determined by one factor but a product of the interaction of multiple psychological, environmental, and personal attributes. This aligns with Bandura's (2012) position on triadic reciprocal causation, which states that environment, behavior, and individual attributes interact dynamically to influence human activities. In this context, several factors such as self-efficacy in mathematics, motivation to study mathematics, and attitude to mathematics are potent factors working mutually to influence each other to solve a problem from a flexible and original perspective.

This supports the notion that creativity in mathematics is not solely determined by any single factor but rather emerges from the interaction and integration of multiple psychological components. This is also supported by the findings of Beghetto (2009) and Karwowski (2011), which emphasized that the moment students' belief in their ability to solve problems from multiple perspectives, they are motivated to the subject and then develop a positive attitude that will help them engage multiple approaches to produce novel ideas and solutions.

Limitations of the Study/Suggestion for Future Studies

The study identified some limitations, even though it provided valuable insights into what matters in predicting mathematical creativity. The study was carried out with only public institutions, and the limited sample size may limit the generalizability of the findings to private schools and other institutions outside Nigeria. A wider study should be carried out with a larger sample size to enhance its generalizability. The scale used for the measurement of predictor variables is a self-report measure, and this may leave room for subjective and biased responses. Other methods should have been incorporated to triangulate the finings for a better picture of the construct under investigation. The study was more of a cross-sectional study that involved a snapshot of information collection that may limit the ability to establish a nexus between the predicted and criterion variables. Longitudinal studies may be very effective to determine this causality and track changes that may have occurred over time. Finally, measuring mathematical creativity is a difficult task, and treating it from the three perspectives may not be holistic enough to describe mathematical thinking. The study, even though it has multiple variables, may not be able to account for extraneous factors other than the variable selected affecting mathematical creativity. However, the limitation, as pointed out, does not mean that the findings are useless; it means contextualizing the findings so as to guide future researchers to address the problems.

CONCLUSION AND IMPLICATIONS OF THE FINDINGS

The study findings highlight the importance of self-efficacy in mathematics and attitude towards mathematics in predicting students' mathematics creativity in terms of fluency, originality, and flexibility dimensions. Students in higher education who demonstrate strong belief in their abilities to handle complex tasks as well as a positive disposition towards mathematics are likely to show a high level of mathematical creativity in the three areas assessed. Conversely, the study showed that motivation for mathematics alone is not enough to trigger this creativity in mathematics as assessed. The study also found that when all the variables are combined, they are significant contributors to variance in the fluency, flexibility, and originality dimensions of creativity. The study has several implications, such as developing intervention strategies that can promote the confidence of the students in their mathematical abilities through feedback and mastery experiences. A positive learning environment that can stimulate the appreciation of mathematics can be created through the integration of real-life applications of mathematics and collaborative learning to assist students in developing a disposition to mathematics that is positive. Similarly, the curriculum can be redesigned to be creative-activity-based to provide students with the opportunity to approach tasks from a multidimensional perspective. Teachers and educators can also be trained on how to foster creativity in mathematics through workshops and seminars.

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REFERENCES

Ab Hamid, M. R., Sami, W., & Sidek, M. M. (2017). Discriminant validity assessment: Use of Fornell & Larcker criterion versus HTMT criterion. *Journal of Physics: Conference Series, 890*, Article 012163. https://doi.org/10.1088/1742-6596/890/1/012163

Abhishek, K., & Bhoodev, S.(2016). Some environmental and attitudinal characteristics as predictors of mathematical creativity. *International Journal of Mathematical Education in Science and Technology, 48*(3), 327-337. https://doi.org/10.1080/0020739X.2016.1241435

Akin, A., & Kurbanoglu, I. N. (2011). The relationships between math anxiety, math attitudes, and self-efficacy: A structural equation model. *Studia Psychologica, 53*, 263-273.

Anderman, E. M., & Anderman, L. H. (1999). Social predictors of changes in students' achievement goal orientations. *Contemporary Educational Psychology, 24*(1), 21-37. https://doi.org/10.1006/ceps.1998.0978

Ardura, D., & Galán, A. (2019). The interplay of learning approaches and self efficacy in secondary school students' academic achievement in science. *International Journal of Science Education, 41*, 1723-1743. https://doi.org/10.1080/09500693.2019.1638981

Aremu, A., & Tella, A. (2009). The relationship between mathematics self-efficacy and achievement in mathematics. *Procedia Social and Behavioral Sciences, 1*(2009), 953-957. https://doi.org/10.1016/j.sbspro.2009.01.169

Artino, A. (2008). Motivational beliefs and perceptions of instructional quality: Predicting satisfaction with online training. *Journal of Computer Assisted Learning, 24*(3), 260-270. https://doi.org/10.1111/j.1365-2729.2007.00258.x

Bandura, A. (1997). *Self-efficacy in changing societies: Exercise of personal and collective efficacy in changing societies*. Cambridge University Press.

Bandura, A. (2012). Social cognitive theory. In P. M. Van Lange, A. W. Kruglanski, & E. Higgins (Eds.), *Handbook of theories of social psychology* (pp. 349-373). SAGE. https://doi.org/10.4135/9781446249215.n18

Bhowmik, M., & Roy, B. B. (2016). A study on the relationship between achievement in mathematics and attitude towards mathematics of secondary school students. *Scholar, 1*(2), 49-55. https://doi.org/10.21013/jems.v4.n3.p7

Boaler, J. (2016). *Mathematical mindsets: Unleashing student's potential through creative math, inspiring messages, and innovative teaching*. JB Jossey-Bass.

Bokhove, C., & Jones, K. (2018). Stimulating mathematical creativity through constraints in problem-solving. In N. Amado, S. Carreira, & K. Jones (Eds.), *Broadening the scope of research on mathematical problem solving* (pp. 301-319). Springer. https://doi.org/10.1007/978-3-319-99861-9_13

Chen, L., Bae, S. R., Battista, C., Qin, S., Chen, T., Evans, T. M., & Menon, V. (2018). Positive attitude toward math supports early academic success: Behavioral evidence and neurocognitive mechanisms. *Psychological Science, 29*(3), 390-402. https://doi.org/10.1177/0956797617735528

Chouinard, R., Karsenti, T., & Roy, N. (2007). Relations among competence beliefs, utility value, achievement goals, and effort in mathematics. *British Journal of Educational Psychology, 77*(3), 501-517. https://doi.org/10.1348/000709906x133589

Clore, G. L., & Schnall, S. (2005). *The influence of affect on attitudes*. In D. Albarracin, B. T. Johnson, & M. P. Zanna (Eds.), *The handbook of attitudes* (pp. 437-489). Erlbaum.

Crocker, L., & Algina, J. (2006). *Introduction to classical and modern test theory*. Wadsworth Publishing.

Cropley, A. J. (2006). In praise of convergent thinking. *Creativity Research Journal, 18*(3), 391-404. https://doi.org/10.1207/s15326934crj1803_13

Dada, O., Bassey, B., & Ofem, U. J. (2016). Institutional predictors of academic creativity of undergraduates in universities in Cross River State, Nigeria. *Global Journal of Education and Research, 15*(2), 145-150.

Diseth, Å. (2011). Self-efficacy, goal orientations and learning strategies as mediators between preceding and subsequent academic achievement. *Learning and Individual Differences, 21*, 191-195. https://doi.org/10.1016/j.lindif.2011.01.003

Dowker, A., Cheriton, O., Horton, R., & Mark, W. (2019). Relationships between attitudes and performance in young children's mathematics. *Educational Studies in Mathematics, 100*(3), 211-230. https://doi.org/10.1007/s10649-019-9880-5

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Eom, H., Wen, J., & Ashill, N. (2006). The determinants of students' perceived learning outcomes and satisfaction in university online education: An empirical investigation. *Journal of Innovation Education, 4*(2), 215-235. https://doi.org/10.1111/j.1540-4609.2006.00114.x

Ferreira, M., Cardosob, A., & Abrantesc, J. (2011). Motivation and relationship of the student with the school as factors involved in the perceived learning. *Procedia-Social and Behavioral Sciences, 29*, 1707-1714. https://doi.org/10.1016/j.sbspro.2011.11.416

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39-50. https://doi.org/10.2307/3151312

Gallagher, R. (2006). Causes of students' lack of interest in mathematics: A review of the literature. *Australian Mathematics Teacher, 62*(4), 11-18. https://doi.org/10.1090/noti902

Ginsburg, H. P. (2009). The challenge of mathematics instruction: Supporting the construction of meanings. *ZDM Mathematics Education, 41*(5), 549-565.

Goldin, G. A., Hannula, M. S., Heyd-Metzuyanim, E., Jansen, A., Kaasila, R., Lutovac, S., & Zhang, Q. (2016). *Attitudes, beliefs, motivation and identity in mathematics education: An overview of the field and future directions*. Springer. https://doi.org/10.1007/978-3-319-32811-9

Grégoire, J. (2016). Understanding creativity in mathematics for improving mathematical education. *Journal of Cognitive Education and Psychology, 15*(1), 24-36. https://doi.org/10.1891/1945-8959.15.1.24

Grootenboer, P., & Hemmings, B. (2008). Mathematics lessons and teacher beliefs: Constructing identities in the mathematics classroom. *Mathematics Education Research Journal, 20*(2), 38-55.

Guo, J., Marsh, H. W., Parker, P. D., Morin, A. J., & Yeung, A. S. (2015). Expectancy-value in mathematics, gender and socioeconomic background as predictors of achievement and aspirations: A multi-cohort study. *Learning and*

Individual Differences, 37, 161-168. https://doi.org/10.1016/j.lindif.2015.01.008

Haavold, P. O. (2016). An empirical investigation of a theoretical model for mathematical creativity. *Journal of Creative Behavior, 52*(3), 226-239. https://doi.org/10.1002/jocb.145

Hacket, G., & Betz, N. (1989). An exploration of the mathematics efficacy/mathematics performance correspondence. *Journal of Research in Mathematics, 20*(3), 261-273. https://doi.org/10.2307/749515

Hadar, L. L., & Tirosh, M. (2019). Creative thinking in mathematics curriculum: An analytic framework. *Thinking Skills and Creativity, 33*, Article 100585. https://doi.org/10.1016/j.tsc.2019.100585

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education, 21*(1), 33-46. https://doi.org/10.2307/749455

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111-127. https://doi.org/10.1207/s15326985ep4102_4

Hiebert, J., & Grouws, D. A. (2007). The effects of classroom mathematics teaching on students' learning. *Second Handbook of Research on Mathematics Teaching and Learning, 2*, 371-404.

Hilkenmeier, F., Bohndick, C., Bohndick, T., & Hilkenmeier, J. (2020). Assessing distinctiveness in multidimensional instruments without access to raw data–A manifest Fornell-Larcker criterion. *Frontiers in Psychology, 11*, Article 223. https://doi.org/10.3389/fpsyg.2020.00223

Hocevar, D. (1979). The development of the creativity domain: The ball-stick-bird test. *Journal of Creative Behavior, 13*(4), 255-259.

Joseph, K., Scott, A., & Eric, M. (2019). Factors that influence mathematical creativity. *The Mathematics Enthusiast, 16*(1). https://doi.org/10.54870/1551-3440.1471

Kattou, M., Kontoyianni, K., Pitta-Pantazi, D., & Christou, C. (2013). Connecting mathematical creativity to mathematical ability. *ZDM Mathematics Education, 45*, 167-181. https://doi.org/10. 1007/s11858- 012- 0467-1

Keller, K. (2008). *Strategic brand management: Building, measuring and managing brand equity*. Pearson Prentice Hall.

Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of Science Education and Technology, 29*(1), 174-188. https://doi.org/10.1007/s10956-019-09798-4

Kiwanuka, H. N., Van Damme, J., Van den Noortgate, W., & Reynolds, C. (2020). Temporal relationship between attitude toward mathematics and mathematics achievement. *International Journal of Mathematical Education in Science and Technology, 51*, 1546-1570. https://doi.org/10.1080/0020739x.2020.1832268

Köller, O., Baumert, J., & Schnabel, K. (2001). Does interest matter? The relationship between academic interest and achievement in mathematics. *Journal for Research in Mathematics Education, 32*(5), 448-470. https://doi.org/10.2307/749801

Kozlowski, J., & Shouquing, S. (2019). Mathematical creativity: A vehicle to foster equity. *Thinking Skills and Creativity, 33*. https://doi.org/10.1016/j.tsc.2019.100579

Kwon, O. N., Park, J. H. J. S., & Park, J. H. J. S. (2006). Cultivating divergent thinking in mathematics through an open-ended approach. *Asia Pacific Education Review, 7*, 51-61. https://doi.org/10.1007/BF030 36784

Lau, C., Kitsantas, A., Miller, A. D., & Drogin,B. (2018). Perceived responsibility for learning, self-efficacy, and sources of self-efficacy in mathematics: A study of international baccalaureate primary years programme students. *Social Psychology of Education, 21*, 603-620. https://doi.org/10.1007/s11218-018-9431-4

Lee, H., Pallant, A., Pryputniewicz, S., Lord, T., Mulholland, M., & Liu, O. L. (2019). Automated text scoring and real-time adjustable feedback: Supporting revision of scientific arguments involving uncertainty. *Science Education, 103*, 590-622. https://doi.org/10.1002/sce.21504

Leikin, R. (2009). Exploring mathematical creativity using multiple solution tasks. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in mathematics and the education of gifted students* (pp. 129-145). Sense Publishers. https://doi.org/10.1163/9789087909352_010

Leikin, R., Berman, A., & Koichu, B. (2009). *Creativity in mathematics and the education of gifted students*. Sense Publishers. https://doi.org/10.1163/9789087909352

Leikin, R., & Lev, M. (2007). Multiple solution tasks as a magnifying glass for observation of mathematical creativity. In J.-H. Woo, H.-C. Lew, K.-S. Park, & D.-Y. Seo (Eds.), *Proceedings of the 31st International Conference for the Psychology of Mathematics Education* (pp. 161-168). The Korea Society of Educational Studies in Mathematics.

Leikin, R., & Levav-Waynberg, A. (2007). Exploring mathematical creativity using multiple solution tasks. In S. P. Lajoie, & L. Verschaffel (Eds.), *Applications and modeling in learning and teaching mathematics* (pp. 129-145). Springer.

Lev, M., & Leikin, R. (2017). The interplay between excellence in school mathematics and general giftedness: Focusing on mathematical creativity. In R. Leikin, & B. Sriraman (Eds.), *Introduction to interdisciplinary perspectives to creativity and giftedness* (pp. 225-238). Springer. https://doi.org/10.1007/978-3-319-38840-3_14

Ma, X. (1999). A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *Journal for Research in Mathematics Education, 30*(5), 520-540. https://doi.org/10.2307/749772

Mailizar, M., Almanthari, A., Maulina, S., & Bruce, S. (2020). Secondary school mathematics teachers' views on e-learning implementation barriers during the COVID-19 pandemic: The case of Indonesia. *EURASIA Journal of Mathematics, Science and Technology Education, 16*, Article em1860. https://doi.org/10.29333/ejmste/8240

Mann, E. (2005). *Mathematical creativity and school mathematics: Indicators of mathematical creativity in middle school students* [Doctoral dissertation, University of Connecticut].

Michael, J. & Michael, K. (2005). Mathematics self-efficacy of college freshman. *Journal of Developmental Education, 28*, 3.

Mubeen, S., Saeed, S., & Arif, M. H. (2013). Attitude towards mathematics and academic achievement in mathematics among secondary level boys and girls. *Journal of Humanities and Social Science, 6*(4), 38-41. https://doi.org/10.9790/0837-0643841

Negara, H. R. P., Nuriaeiah, E., Wahyudin, Herman, T., & Tamur, M. (2021). Mathematics self efficacy and mathematics performance in online learning. *Journal of Physics: Conference Series, 1882*, Article 012050. https://doi.org/10.1088/1742-6596/1882/1/012050

Nufus, H., Duskri, M., & Kuala, U. S. (2018). Mathematical creative thinking and student self-confidence in the challenge-based learning approach. *Journal of Research and Advances in Mathematics Education, 3*(2), 57-68. https://doi.org/10.23917/jramathedu.v3i2.6367

Ofem, U. J., Iyam, M. A., Ovat, S. V., Nworgwugwu, E. C., Anake, P. M., Udeh, M. R., & Otu, B. D. (2024a). Artificial intelligence (AI) in academic research. A multi-group analysis of students' awareness and perceptions using gender and programme type. *Journal of Applied Learning & Teaching, 7*(1). https://doi.org/10.37074/jalt.2024.7.1.9

Ofem, U. J., Nworgwugwu, E. C., Ovat, S. V., Anake, P. M., Anyin, N. N., Udeh, M. I., & Undie, R. A. (2024b). Predicting affective and cognitive learning outcomes: A quantitative analysis using climate change vectors. *Eurasian Journal of Science and Environmental Education, 4*(1), 1-12. https://doi.org/10.30935/ejsee/14405

Pajares, F., & Miller, M. D. (1994). Role of self-efficacy and self-concept beliefs in mathematical problem solving: A path analysis. *Journal of Educational Psychology, 86*(2), 193-203. https://doi.org/10.1037/0022-0663.86.2.193

Papanastasiou, C. (2000). Effects of attitudes and beliefs on mathematics achievement. *Studies in Educational Evaluation, 26*(1), 27-42. https://doi.org/10.1016/s0191-491x(00)00004-3

Phonguttha, R., Tayraukham, S., & Nuangchalerm, P. (2009). Comparisons of mathematics achievement, attitude towards mathematics and analytical thinking between using the geometer's sketchpad program as media and conventional learning activities. *Australian Journal of Basic and Applied Sciences, 3*(3), 3036-3039. https://doi.org/10.2139/ssrn.1285446

Plucker, J. A., & Makel, M. C. (2004). Assessment of creativity. In J. C. Kaufman, & J. Baer (Eds.), *Creativity across domains: Faces of the muse* (pp. 307-326). Lawrence Erlbaum Associates Publishers.

Polit, D. F., Beck, C. T., & Owen, S. V. (2007). Is the CVI an acceptable indicator of content validity? Appraisal and recommendations. *Research in Nursing & Health, 30*, 459-467. https://doi.org/10.1002/nur.20199

Roick, J., & Ringeisen, T. (2018). Students' math performance in higher education: Examining the role of self-regulated learning and self-efficacy. *Learning and Individual Differences, 65*, 148-158. https://doi.org/10.1016/j.lindif.2018.05.018

Rozgonjuk, D., Kraav, T., Mikkor, K., Orav-Puurand, K., & Täht, K. (2020). Mathematics anxiety among STEM and social sciences students: The roles of mathematics self-efficacy, and deep and surface approach to learning. *International Journal of STEM Education, 7*, Article 46. https://doi.org/10.1186/s40594-020-00246-z

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68-78. https://doi.org/10.1037/0003-066X.55.1.68

Saeed, S., & Zyngier, D. (2012). How motivation influences student engagement: A qualitative case study. *Journal of Education and Learning, 1*, 252-267. https://doi.org/10.5539/jel.v1n2p252

Sahliawati, M., & Nurlaelah, E. (2020). Mathematical creative thinking ability in middle school students. *Journal of Physics: Conference Series, 1469*, 012145.

https://doi.org/10.1088/1742-6596/1469/1/012145

Schoevers, E., Kroesbergen, E., Moerbeek, M., & Leseman, P. (2022). The relation between creativity and students' performance on different types of geometrical problems in elementary education. *ZDM Mathematics Education,54*, 133-147. https://doi.org/10.1007/s11858-021-01315-5

Schunk, D. H. (2014). *Learning theories: An educational perspective*. Pearson Prentice Hall.

Schunk, D. H., Meece, J. L., & Pintrich, P. R. (2014). *Motivation in education: Theory, research, and applications*. Pearson.

Shaw, S. T., Luna, M. L., Rodriguez, B., Yeh, J., Villalta, N., & Ramirez, G. (2022). Mathematical creativity in elementary school children: General patterns and effects of an incubation break. *Frontiers in Education, 7*, Article 835911. https://doi.org/10.3389/feduc.2022.83591

Silver, E. A. (1997). Fostering creativity through construction rich in mathematical problem solving and problem posing. *ZDM-International Reviews on Mathematical Education, 29*, 75-80. https://doi.org/10.1007/s11858-997-0003-x

Silver, E. A. (1997). Fostering creativity through instruction rich in mathematical problem solving and problem posing. *ZDM Mathematics Education, 29*(3), 75-80. https://doi.org/10.1007/s11858-997-0003-x

Siswono, T. Y. E. (2011). Level of student's creative thinking in classroom mathematics. *Educational Research and Reviews, 6*, 548-553.

Smith, A., Stirling, A., & Berkhout, F. (2005)The governance of sustainable socio-technical transitions. *Research Policy, 34*(10), 1491-1510. https://doi.org/10.1016/j.respol.2005.07.005

Sriraman, B. (2004). The characteristics of mathematical creativity. *The Mathematics Educator, 14*(1), 19-34.

Sriraman, B., & Haavold, P. (2017). *Creativity and giftedness in mathematics education: A pragmatic view*. National Council of Teachers of Mathematics. https://doi.org/10.1007/978-3-319-77487-9_33-7

Sun, C. (2004). *Severe critique from mathematician Shing-Tung Yau: Mathematics Olympiad in China kills children's curiosity*. http://news.xinhuanet.com/edu/2004-12/25/content_2379632

Tabach, M., & Friedlander, A., (2013). School mathematics and creativity at the elementary and middle-grade levels: How are they related? *ZDM, 45*, 227-238. https://doi.org/10.1007/s11858-012-0471-5

Tarun, K. (2017). Mathematical intelligence and mathematical creativity: A causal relationship. *Creativity Research Journal, 29*(2), 212-217. https://doi.org/10.1080/10400419.2017.1303317

Torrance, E. P. (1966). *Torrance tests of creative thinking: Norms-technical manual*. https://www.ststesting.com/gift/TTCT_InterpMOD.2018.pdf

Tularam, G. A., & Hulsman, K. (2015). A study of students' conceptual, procedural knowledge, logical thinking and creativity during the first year of tertiary mathematics. *International Journal for Mathematics Teaching & Learning, 19*(1), 1-41.

Usher, E., & Pajares, F. (2009). Sources of self-efficacy in mathematics: A validation study. *Contemporary Educational Psychology, 34*, 89-101. https://doi.org/10.1016/j.cedpsych.2008.09.002

Visser, L., Schoonenboom, J., & Korthagen, F. (2017). A field experimental design of a strengths-based training to overcome academic procrastination: short-and long-term effect. *Frontiers in Psychology, 8*, 1949. https://doi.org/10.3389/fpsyg.2017.01949

Walia, P. (2012). Achievement in relation to mathematical creativity of eighth grade students. *Indian Streams Research Journal, 2*(2), 1-4.

Widjaja, A., & Chen, J. (2007). Online learners' motivation in online learning: The effect of online-participation, social presence, and collaboration. In C. Muniarti, & R. Sanjaya (Eds.), *Learning technologies in education: Issues and trends* (pp. 72-93). Soegijapranata Catholic University.

Wigfield, A., Tonks, S. M., & Klauda, S. L. (2016). Expectancy-value theory. In K. R. Wentzel, & D. B. Miele (Eds.), *Handbook of motivation at school* (pp. 55-74). Routledge.

Yurt, E. (2014). The predictive power of self-efficacy sources for mathematics achievement. *Education Sciences, 39*, 159-169. https://doi.org/10.15390/EB.2014.3443

Yusoff, M. S (2019). ABC of content validation and content validity index calculation. *Education in Medicine Journal, 11*, 49-54. https://doi.org/10.21315/eimj2019.11.2.6

Yusuf, Z. (2022) Improving students' mathematics self-efficacy: A systematic review of intervention studies. *Frontiers in Psychology, 13*, Article 986622. https://doi.org/10.3389/fpsyg.2022.986622

Zakariya, Y. (2021). Self-efficacy between previous and current mathematics performance of undergraduate students: An instrumental variable approach to exposing a causal relationship. *Frontiers in Psychology, 11*. https://doi.org/10.3389/fpsyg.2020.556607

Zakariya, Y. F., Nilsen, H. K., Goodchild, S., & Bjørkestøl, K. (2020). Selfefficacy and approaches to learning mathematics among engineering students: Empirical evidence for potential causal relations.

International Journal of Mathematical Education in Science and Technology, 53, 827-841. https://doi.org/10.1080/0020739X.2020.1783006

Zakariya, Y., Goodchild, S., Bjørkestøl, K., & Nilsen, H. K. (2019). Calculus self-efficacy inventory: Its development and relationship with approaches to learning. *Education Sciences, 9*, Article 170. https://doi.org/10.3390/educsci9030170

Zientek, L. R., Fong, C. J., & Phelps, J. M. (2019). Sources of self-efficacy of community college students enrolled in developmental mathematics. *Journal of Further and Higher Education, 43*, 183-200. https://doi.org/10.1080/0309877X.2017.1357071