

Creativity and Giftedness in Mathematics Education: A Pragmatic view

Bharath Sriraman, University of Montana

Per Haavold, University of Tromsø, Norway

Introduction

Creativity has become an almost clichéd word found worldwide in national policy and curricular documents in addition to vision or mission statements of universities and schools districts. For instance, in the UK, *The National Advisory Committee on Creative and Cultural Education* (NACCCE) established in 1998 emphasizes the importance of creativity in schools today and considers it as a crucial component of education for the future (NACCCE, 1999). Similarly in the last 15 years, international conferences such as the quadrennial *International Congress on Mathematics Education* (ICME) as well as *The International Group for Mathematical Creativity and Giftedness* (MCG) have regularly featured working groups focused on the development of creativity and giftedness.

Unlike mathematics education, in the field of psychology J. Paul Guilford's speech at the American Psychological Association (APA) in 1950 is viewed as a turning point in creativity research (Kaufman & Sternberg, 2007). Guilford encouraged researchers to focus more on creativity and since then there has been an increased focus on creativity as a research field as evident in the proliferation of books and journals (e.g. *Journal of Creative Behavior*, *Creativity Research Journal*) within of the field psychology. Creativity research today is viewed as trans-disciplinary, i.e., both informed by and informing multiple domains of research (not necessarily overlapping), such as psychology, education, historiometry, cultural studies etc. In psychology the domains of gifted education and creativity constitute separate areas of inquiry with

occasional overlap. The former, viz., gifted education, is viewed as a sub domain within special education focused on addressing the cognitive, affective, programmatic and curricular needs of high ability students, whereas the latter, viz., creativity is more or less a domain in its own right (Kim, Kaufman, Baer, Sriraman, 2013). Yet in mathematics education the terms creativity and giftedness are sometimes used interchangeably with confusion on what the terms mean (Sriraman, 2005). Teachers often view creativity as a form of extra-curricular activity, separate from daily academic subjects (Aljughaiman & Mowrer-Reynolds, 2005). This as Beghetto (2013) argues can be attributed to the way the identification and enhancement of creativity became systematized in U.S. public schools following Sidney Marland's (1972) report to the U.S. Congress on the education of gifted and talented students (Kim, Kaufman, Baer, Sriraman, 2013). Marland's (1972) report viewed creativity as one of six possible indicators of giftedness, and called for specialized or separate education for students who demonstrated high-levels of potential or achievement.

Given this preamble, the purpose of this chapter is threefold. One purpose of this chapter is to unpack the confusion between the constructs of giftedness (often synonymous with highly able, high potential, high achieving) and creativity (often synonymous with deviance and divergent thinking) and give the reader a clear picture of the two constructs within the context of mathematics education. The second purpose of this chapter is to provide a synthesis of international perspectives in the area of gifted education and suggest implications for mathematics education. The third and last objective is to explore the state of the art within mathematics education, and explore futuristic issues.

Unpacking Creativity and Giftedness

Creativity is a paradoxical construct. One reason it's paradoxical is because its definitions tend to be elusive for many people, yet everyone knows creativity when they see it. Numerous other contradictions are present in characterizations of creativity. For instance, most people tend to equate creativity with originality and 'thinking outside of the box,' however creativity researchers note that it often requires constraints (Sternberg & Kaufman, 2010). Some people view creativity as being associated with more clear-cut and legendary contributions, yet others view it as an everyday occurrence (Craft, 2002). People also tend to associate creativity with artistic endeavors (Runco & Pagnani, 2011), yet scientific insights and innovation are some of the clearest examples of creative expression. Nevertheless, there are certain agreed upon parameters in the literature that help narrow down the concept of creativity (Sriraman, Haavold and Lee, 2013). In a nutshell, extraordinary creativity (or big C) refers to exceptional knowledge or products that change our perception of the world. Ordinary, or everyday creativity (or little c) is more relevant in a regular school setting. Feldhusen (2006) describes little c as an adaptive behavior whenever the need arises to make, imagine, produce or design something new that did not exist before in the immediate context of the creator. Finally, the relationship between giftedness and creativity has been the subject of much controversy (Leikin, 2008; Sternberg and O'Hara, 1999) as some see creativity as part of an overall concept of giftedness (Renzulli, 2005) whereas others hypothesize a relationship between the two (Sriraman, 2005). Whether or not creativity is domain specific or domain general, or if one looks at ordinary or extraordinary creativity, most definitions of creativity include some aspect of usefulness and novelty (Sternberg, 1999; Plucker and Beghetto, 2004; Mayer, 1999) depending on the context of the creative process and the milieu of the creator. Although there is general consensus amongst

creativity researchers on the defining criteria of creativity, minority views persist from the artistic domain, which view any definition as being too constrictive. Based on a synthesis of numerous definitions in the existing literature, Sriraman (2005) defined creativity (and in particular mathematical creativity) as the process that results in unusual (novel) and/or insightful solution(s) to a given problem or analogous problems, and/or (b) the formulation of new questions and/or possibilities that allow an old problem to be regarded from a new angle requiring imagination (Kuhn, 1962).

Even though a working definition is present, paradoxes carry over into educational contexts. Again consider, for example, mathematics. A sizeable body of literature suggests that learners do not typically experience mathematics as a creative subject (Burton, 2004), yet research mathematicians often describe their field as a highly creative endeavor (Sriraman, 2009). Similarly, educators may feel that content standards stifle their students and their own creativity, yet creativity researchers have argued that such standards serve as the basis for classroom creativity (Beghetto, Kaufman, & Baer, in press). These contradictions place educators in a difficult situation. Consequently, many find themselves feeling caught between the push to promote students' creative thinking skills and the pull to meet external curricular mandates, increased performance monitoring, and various other curricular constraints (Beghetto, 2013).

The research literature on mathematical giftedness and characteristics of highly able students of mathematics reveals that mathematical giftedness can be defined in terms of the individual's ability to (a) abstract, generalize, and discern mathematical structures (Kanevsky, 1990; Krutetskii, 1976; Sriraman, 2003); (b) the ability to think analogically and heuristically and to pose related problems (van Harpen & Sriraman, 2013); (c) demonstrate flexibility and reversibility of mathematical operations and thought (Krutetskii); (d) an intuitive

awareness of mathematical proof and discover mathematical principles (Sriraman, 2004a, 2004b). It should be noted that many of these studies involved task-based instruments with specific mathematical concepts/ideas to which students had previous exposure.

International perspectives

Julian Stanley's landmark Study of Mathematically Precocious Youth (SMPY) started at Johns Hopkins in 1971 introduced the idea of above-level testing for the identification of highly gifted youth, labeled as "mathematically precocious". For instance, from 1980-1983, in SMPY, 292 mathematically precocious youth were identified on the basis of the Scholastic Aptitude Test (SAT). These students scored at least 700 on SAT Mathematics before the age of 13. Other tests with good validity and reliability administered to determine mathematical giftedness are The Stanford-Binet Intelligence Scale (Form L-M) and the Raven's Advanced Progressive Matrices which is useful with students from culturally diverse and English as a second language backgrounds. SMPY also generated a vast amount of empirical data gathered over the last 30 years, and resulted in many findings about the types of curricular and affective interventions that foster the pursuit of advanced coursework in mathematics. Recently Lubinski and Benbow (2006) compiled a comprehensive account of 35 years of longitudinal data obtained from the Study of Mathematically Precocious Youth (SMPY), which included follow ups on various cohort groups that participated in SMPY. These researchers found that the success of SMPY in uncovering antecedents such as spatial ability, tendency to independently investigate and research oriented values were indicative as potential for pursuing lifelong careers related to mathematics and science. The special programming opportunities provided to the cohort groups played a major role in shaping their interest and potential in mathematics, and ultimately resulted

in “happy” choices and satisfaction with the career paths chosen. Another finding was that significantly more mathematically precocious males entered into math oriented careers as opposed to females, which Lubinski and Benbow (2006) argue is not a loss of talent per se, since the females did obtain advanced degrees and chose careers more oriented to their multidimensional interests such as administration, law, medicine, and the social sciences. Programs such as SMPY serve as a beacon for other gifted and talented programs around the world, and provide ample evidence on the benefits of early identification and nurturing the interests of mathematically precocious individuals. Given the profound abilities of highly able students programming can be delivered for these students via acceleration, curriculum compacting, differentiation. There exists compelling evidence from longitudinal studies conducted in the former Soviet Union by Krutetskii (1976) that highly mathematically gifted students are able to abstract and generalize mathematical concepts at higher levels of complexity and more easily than their peers in the context of arithmetic and algebra. These results were recently extended for the domains of problem solving, combinatorics and number theory by Sriraman (2002).

The literature indicates that acceleration is perhaps the most effective way of meeting precociously gifted student’s programming needs (Gross, 1993). Mathematics unlike any other discipline lends itself to acceleration because of the sequential developmental nature of many elementary concepts. The very nature of acceleration suggests that the principles of curriculum compacting are applied to trim out the excessive amount of repetitive tasks. In addition, the effectiveness of radical acceleration and exclusive ability grouping, as extensively reported by Miraca Gross in her longitudinal study of exceptionally and profoundly gifted students in Australia indicates that the benefits far out-weigh the risks of such an approach. Most of the

students in Gross's studies reported high levels of academic success in addition to normal social lives. Simply put the purpose of curricular modifications such as acceleration, compacting and differentiation for mathematically precocious students is to tailor materials that introduce new topics at a faster pace which allow for high level thinking and independence reminiscent of research in the field of mathematics. Besides the use of curriculum compacting, differentiating and acceleration techniques, many school programs offer *all* students opportunities to participate in math clubs, in local, regional and statewide math contests.

Typically the exceptionally talented students benefit the most from such opportunities.

In many countries (such as Hungary, Romania, Russia and also the U.S), the objective of such contests is to typically select the best students to eventually move on to the national and international rounds of such competitions. The pinnacle of math contests are the prestigious International Math Olympiads (IMO) where teams of students from different countries work together to solve challenging math problems. At the local and regional levels, problems typically require mastery of concepts covered by a traditional high school curriculum with the ability to employ/connect methods and concepts flexibly. However at the Olympiad levels students in many countries are trained in the use of undergraduate level algebraic, analytic, combinatorial, graph theoretic, number theoretic and geometric principles. Whereas most extant models within the U.S such as those used in the Center for Talented Youth (CTY) at Johns Hopkins tend to focus on accelerating the learning of concepts and processes from the regular curriculum, thus preparing students for advanced coursework within mathematics, other models such as *Hamburg Model* in Germany, are more focused on allowing gifted students to engage in problem posing activities, followed by time for exploring viable and non-viable strategies to solve the posed problems (Kiesswetter,1992) . This approach in a sense captures an essence of the nature of

professional mathematics, where the most difficult task is to often to correctly formulate the problem and pose related problems . Another successful model of identifying and developing mathematical precocity is found in historical case studies of mathematics gifted education in the former USSR. The Russian mathematician and pedagogue Gnedenko (1991) claimed that personal traits of creativity can appear in different ways in different people. One person could be interested in generalizing and a more profound examination of already obtained results. Others show the ability to find new objects for study and to look for new methods in order to discover their unknown properties. The third type of person can focus on logical development of theories demonstrating extraordinary sense of awareness of logical fallacies and flaws. A fourth group of gifted individuals would be attracted to hidden links between seemingly unrelated branches of mathematics. The fifth would study historical processes of the growth of mathematical knowledge. The sixth would focus on the study of philosophical aspects of mathematics. The seventh would search for ingenious solutions of practical problems and look for new applications of mathematics. Finally, someone could be extremely creative in the popularisation of science and in teaching. The history of Soviet mathematics provides with a striking example of a coexistence of two different approaches to mathematics education, one embedded into the general lay public educational system implementing the blueprint based on the European concepts of the late 19th century, and the other one focusing mainly on gifted children and having flourished starting from 1950s onwards (Freiman & Volkov, 2004). The latter took the form of a complex network of activities including “mathematics clubs for advanced children” (Russian “кружки” (*kruzhki*), lit. “circles” or “rings”, usually affiliated with schools and universities but some were also home-based), Olympiads, team mathematics competitions, (*mat-boi*, literally “mathematical fight”), extracurricular winter or summer schools

for gifted children, publication of magazines on physics and mathematics for children (the most famous being the *Kvant*, lit “Quantum”), among others (Freiman & Volkov, 2004).

All these activities were free for all participating children and were based solely on the enthusiasm of mathematics teachers or university professors. This process led to the creation of a system of formation of a “mathematical elite” in the former USSR focused first and foremost on “extremely gifted children”, which was in a sharp contrast with the “egalitarian” regular state-run schools targeting “average students”. The young Andrey Kolmogorov (1903-1987), a highly precocious child, who went on to become one of the most eminent mathematicians of the 20th century, was able to benefit from the unique extra-curriculum pedagogical environment provided by this system.

State of the art and futuristic Issues

Mathematical creativity

The lack of a clear consensus regarding a definition of mathematical creativity, has often led to a functional and pragmatic investigation within specific contexts. Summarizing research on mathematical creativity, Haylock (1987) proposed two investigative models of mathematical creativity: the ability to overcome fixations in mathematical problem solving and the ability for divergent production. Creativity as divergent production was originally proposed by Guilford and Torrance and is grounded in both associative theory and Guilford’s theory of the Structure of Intellect (SOI) (Runco, 1999). Guilford (1959) considered creative thinking as involving divergent thinking, in which fluency, flexibility, originality and elaboration were central features. “Fluency” denotes the number of solutions to a problem or situation, “flexibility” the number of different categories of solutions, “originality” denotes the relative unusualness of the solution and elaboration refers to the amount of detail in the responses. Building on Guilford’s work,

Torrance (1966) developed the Torrance Test of Creative Thinking in order to assess individuals' capacity for creative thinking. Which in turn has inspired the use of different divergent production tests in numerous different contexts, including mathematics education (Aiken, 1973; Krutetskii, 1976; Haylock, 1987; Chamberlain & Moon, 2005; Leikin & Lev, 2013; Pitta-Panatz et al., 2013; Kattou et al., 2013; Haavold, under review etc.). The common theme of all such tests is problems and situations with many possible responses. As opposed to convergent thinking where the subject must seek one, and only one, solution, divergent thinking tasks open up for many possible solutions (Haylock, 1987).

The other investigative model proposed by Haylock (1987) focuses on the process, and not necessarily the product, of mathematical creativity and the importance of overcoming fixations. Creative thinking is closely related to flexibility of thought (Haylock, 1997). The opposite of flexibility is rigidity of thought and the ability to break from established mental sets is an important aspect of the creative process. Overcoming fixations as an aspect of mathematical creativity can be traced back to the writings of Hadamard and Poincaré and Gestalt psychology (Sriraman, Haavold & Lee, 2013). The Gestaltists described the process of creative problem solving through four stages: preparation, incubation, illumination and verification. Here, illumination occurs once the problem solver, either through conscious or unconscious work, is able to break from established mind sets and overcome certain fixations (Haylock, 1997; Dodd et al., 2003). A recent example of this approach can be found in Lithner's (2008) framework for creative and imitative reasoning, in which the author separates mathematical reasoning into two categories: creative mathematically founded reasoning and imitative reasoning. Creative mathematically founded reasoning is a sequence of arguments that is new to the reasoner and the arguments are plausible and based on mathematical properties. Imitative reasoning, on the other

hand, is built on copying task solutions or through remembering an algorithm or answer. The key difference is seen in the reasoner's ability to break from established mind sets and come up with novel and plausible reasoning sequences.

Ability and achievement in mathematics

Mathematical ability has often been confounded with mathematical attainment and there is some truth to that idea. Benbow & Arjmand (1990) found a strong relationship between future academic success in mathematics and early identification of high mathematical ability.

Furthermore, a significant statistical relationship between mathematical achievements and mathematical creativity has been reported in numerous studies. Using the Creative Ability in Mathematics Test, developed by Balka (1974), both Mann (2005) and Walia (2012) found a significant and positive correlation between mathematical creativity and mathematical achievements. Several other studies have found a significant correlational relationship between mathematical creativity and mathematical achievement in various forms (see for instance Prouse, 1967; Jensen, 1973; Kaltsounis & Stephens, 1973; McCabe, 1991; Ganihar et.al. 2009; Kadir & Maker, 2011; Haavold, under review). Here, it should be noted that both mathematical ability and mathematical achievements have mostly been measured using researcher developed task-based instruments. Though, achievements in mathematics has also been identified using grades, standardized tests, prizes, professional career etc.

However, Ching (1997) demonstrated that hidden talent and creativity can go unnoticed in typical classrooms and Kim, Cho & Ahn (2003) claim that traditional tests rarely identify mathematical creativity. This distinction between academic achievement in mathematics and creative talent in mathematics is seen throughout the literature. In Haavold (2010), three high achieving students in mathematics were given an unusual trigonometric problem and only with

some guidance were they able to display flexible and creative reasoning. Selden, Selden & Mason (1994) found that even students with grades A and B struggle with non-routine problems. In another study, Hong & Aqai (2004) focused on the distinction between academically gifted and creatively gifted students in mathematics. The authors compared cognitive and motivational characteristics of creatively talented students, academically gifted students and non-gifted students in high school. The two groups of gifted students scored higher than the non-gifted students in every category investigated, but the authors did not find any difference between the academically gifted and creatively talented students in term of ability, value or self-efficacy. They did, however, note that the creatively talented students used more cognitive strategies than the academically gifted students. Livne and Milgram (2006) provide further evidence to support the distinction between academically gifted students and creative gifted students in mathematics. The authors conclude that general academic ability predicted academic, but not creative ability in mathematics, while creative thinking predicted creative, but not academic, ability in mathematics. These and several other findings (see for instance Haylock, 1997; Leikin & Lev, 2013; Haavold, under review) indicate that mathematical achievements in academic K-12 settings do not necessarily imply mathematical creativity. However, one of the main challenges of summing up the state of the art on creativity and giftedness in mathematics are the many differing conceptualizations and operationalizations of both creativity and ability in mathematics found in the literature.

Creativity and ability

Sriraman (2005) claims that mathematical creativity in K-12 setting is seen on the fringes of giftedness. This idea is intuitively appealing as traditional mathematics teaching emphasizes procedures, computation and algorithms. There is little attention to developing conceptual ideas,

mathematical reasoning and problem solving activities (Cox, 1994). If we look at the literature, the general trend is a strong statistical relationship between mathematical achievements and mathematical creativity (see Prouse, 1967; Kaltsounis & Stephens, 1973; McCabe, 1991; Ganihar et.al. 2009; Kadir & Maker, 2011; Haavold, under review). Mathematical knowledge has also been found to be a strong predictor of mathematical creativity. Sak & Maker (2006) gave 841 1st through 5th grade students four types of math problems ranging from closed to open ended. The students' answers were compared on the basis of fluency, flexibility, originality and elaboration. They concluded that content knowledge was the strongest predictor variable of students' mathematical creativity. Tabach and Friedlander (2013) gave 76 students, ranging from 4th grade to 9th grade, three mathematical problems which were scored according to fluency, flexibility and originality. The findings indicate that mathematical creativity increased with age and that an increase in mathematical knowledge has the potential to raise the level in creativity as well. Kattou et al. (2013) investigated the relationship between mathematical ability and mathematical creativity by giving 359 elementary school students a mathematical ability and a mathematical creativity test. The authors reported a strong correlational relationship between mathematical creativity and mathematical ability. However, none of these studies investigates the relationship between high ability and creativity further.

In all the studies reported here, the authors conceptualized and operationalized mathematical creativity separately from achievement, ability or knowledge in mathematics, using separate task-based instruments. Mann (2005) and Kadir & Maker (2011), for instance, used the Iowa Test of Basic Skills in order to measure mathematical achievement. Haavold (under review) used students' grades in school, while in Kattou et al. (2013) mathematical ability was measured by 29 items in the following categories: quantitative ability, causal ability, spatial ability, qualitative

ability, and inductive/deductive ability. Sak & Maker (2006) measured mathematical knowledge using well-structured and close-ended routine tasks requiring convergent thinking. There is therefore arguably a large overlap between instruments that measure knowledge, ability and achievement within the literature, but a closer analysis is beyond the scope of this chapter.

As mentioned earlier, Hong and Aqui (2004) separated gifted students in mathematics into two distinct groups, referred to as creatively talented students and academically talented students. The authors found that the creatively talented students were more cognitively resourceful. Other studies that have looked more closely at high achieving and high ability students have reported related discrepancies that can add to our understanding of giftedness and creativity. Leikin and Lev (2013) explored the relationships between mathematical excellence, mathematical creativity and general giftedness. Three groups of 11th and 12th grade students participated in the study: gifted and highly intelligent students (G), students receiving high level instruction in mathematics (HL) and students receiving regular level instruction in mathematics (RL). Four problems, plus one bonus problem, were given to 51 students—6 from the G group, 27 from the HL group, and 18 from the RL group. The test was scored on the basis of fluency, flexibility, originality, and creativity. In addition, the correctness of the solutions was also evaluated. The G students had higher scores than the HL students on all the criteria, and the HL students had higher scores than the RL students on all criteria. Furthermore, the authors conclude that the differences are task-dependent. The G-factor had a significant effect on rich problems open for insight-based solutions, while it did not have an effect on more conventional, calculation problems. Based on the findings in the study, the authors propose that knowledge associated with solving conventional and algorithmic problems can be developed in all students. However,

problems that require some form of insight require a more particular ability level, such as the G-factor (IQ).

Haylock (1997) points out that mathematical attainment limits the student's performance on overcoming fixation and divergent production problems, but does not determine it. Low attaining students do not have the sufficient mathematical knowledge and skills to demonstrate creative thinking in mathematics. High achieving students in mathematics are usually also the most creative students in mathematics, but there are significant differences within the group of high achieving students. Within the group of high achievers in mathematics there are both low-creative and high-creative students. In Haavold (under review), mathematical achievement is reported to be a necessary, but not sufficient condition for mathematical creativity to manifest. Furthermore, both intrinsic motivation and an aesthetic sense of mathematics were found to have a medium effect on mathematical creativity, controlled for mathematical ability. According to Meissner (2000) and Sheffield (2009) mathematical knowledge is a vital prerequisite for mathematical creativity. Solid content knowledge is required for individuals to make connections between different concepts and types of information. Feldhausen and Westby (2003) assert that an individual's knowledge base is the fundamental source of their creative thought. Nonetheless, as the literature suggests, mathematical knowledge and ability in itself is not sufficient for mathematical creativity to appear. Another study that may shed some light on mathematical creativity, and as such also mathematical giftedness, was carried out by Pitta-Pantazi et al. (2013). Here, the authors investigated the relationship between mathematical creativity and cognitive styles. A mathematical creativity test consisting of five tasks was given to 96 prospective primary school teachers and was assessed on the basis of fluency, flexibility, and originality. Cognitive style was measured with the Object-Spatial Imagery and Verbal

Questionnaire (OSIVQ) with respect to three styles: spatial, object, and verbal. Using multiple regression, the authors conclude that spatial and object styles were significant predictors of mathematical creativity, while verbal style was not significant. Spatial cognitive style was positively related to mathematical creativity, while object cognitive style was negatively related to mathematical creativity. Furthermore, spatial cognitive style was positively related to fluency, flexibility, and originality, while object cognitive style was negatively related to originality and verbal cognitive style was negatively related to flexibility.

Synthesis

The literature on creativity and giftedness is not conclusive, but it has provided certain parameters for our understanding. Numerous studies find a significant statistical relationship between mathematical ability, knowledge and achievements on one hand and mathematical creativity on the other hand. Mathematical ability seems to be a necessary, but not sufficient condition for mathematical creativity to manifest. Theoretical support for this conclusion is found in general creativity research within psychology. The *foundation view* suggests a positive relationship between knowledge and creativity. Since a knowledgeable individual knows what has been done within a field, he can move forward and come up with new and useful ideas (Weissberg, 1999). Deep knowledge within a field is essential to the creative process. Instead of breaking from a set of traditions, creative thinking builds on knowledge (Weissberg, 1999). However, the specific nature of this relationship is not known within the field of mathematics; mathematical creativity could be an aspect of mathematical knowledge or vice versa (Kattou et al., 2013). Studies that have looked more closely at the relationship between high ability (or knowledge/achievement) and creativity in mathematics have revealed certain interesting features.

The literature reviewed in this section suggests that certain features and factors are required for mathematical creativity to arise. In Leikin and Lev (2013) the gifted students (high IQ) scored higher than the other students on all measured criteria on all tasks in the mathematics creativity test. On the other hand, the authors conclude that the level of instruction (the L-factor) only has a minor effect on students' creativity. Kattou et al. (2013) found a strong correlational relationship between mathematical ability and mathematical creativity and suggested that mathematical creativity is a subcomponent of mathematical ability. Pitta-Pantazi et al. (2013) found that spatial cognitive style was positively related to mathematical creativity. In an attempt to validate a theoretical model for optimizing mathematical creativity in the classroom proposed by Sriraman (2005), Haavold (under review) found that internal motivation and an aesthetic sense of mathematics predicted creativity, controlled for mathematical achievement. Hong & Aquí (2004) separated gifted students into two distinct categories and found that creative gifted students were cognitively more resourceful than their academically gifted counterparts.

The literature clearly indicate that mathematical creativity as a product and process of human thought does not exist in a vacuum. High IQ, spatial cognitive style, intrinsic motivation, an aesthetic sense of mathematics, flexible use of cognitive strategies and deep mathematical knowledge have all been observed to statistically predict mathematical creativity. However, the nature of the relationship between mathematical creativity and other factors is not known. Based on the literature review, and what is currently known about giftedness and creativity in mathematics, we propose three future research designs to further shed some light on this topic: a) mathematical creativity can be developed. (Silver, 1997; Leikin, Levav-Waynberg & Guberman, 2011). A longitudinal study in which students can be tracked over an extended period of time can shed some light on how and why. By tracking the same students over time, observing the same

variables over time, it may be possible to say something about how the development of mathematical creativity in a school setting is related to teaching and other classroom. b) another alternative would be a cross sectional quantitative research design, but with a purposeful sampling procedure targeting gifted or high achieving students. This would allow the researcher to more specifically investigate the relationship between mathematical creativity and other concepts in a group of gifted or high achieving students. c) unlike the field of general psychology, there is still some confusion about giftedness and creativity in mathematics education (Sriraman, 2005). To move the research field forward, both theoretical and empirical work on conceptualizing and operationalizing creativity and giftedness is needed. In this chapter we attempt to unpack the confusion between creativity and giftedness, but much work still remain. Even though a definition of mathematical creativity is present (Sriraman, 2005), there is still a need for valid and reliable instruments for measuring mathematical creativity.

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