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 Gilford'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 twofold. The first 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 and historical perspectives in the area of gifted education. We also suggest implications for mathematics education.

Unpacking Creativity and Giftedness

Theoretical perspective. 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.

Empirical investigation. 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-Panatzi, Sophocleous & Christou, 2013; Kattou, Kontoyianni, Pitta-Pantazi & Christou, 2013; 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).

Recently, Chamberlain and Mann (2014) proposed iconoclasm as the fifth sub-construct of the modern day construct of creativity. Iconoclasm refers to mathematically creative individuals' tendency to oppose commonly accepted principles and solutions. Iconoclasts are often nonconformist and open to new and uncommon solution paths. However, iconoclasm as a fifth sub-construct of creativity is currently a theoretical proposal; as Chamberlan and Mann (2014) concludes, empirical proof of existence is still needed. The authors therefore encourage the development of an instrument that investigates whether problem solvers will challenge commonly accepted algorithms, when they are faced with a relatively inefficient solution.

Although divergent production tests dominate research in creativity, it is worth mentioning that the practice of accepting divergent thinking as a proxy for creativity has been subject to a lot of criticism. The most obvious criticism is that creativity can just as well be the result of a convergent process. Also, because divergent thinking is a compound construct, it consists various different and separate mental processes, that cannot be isolated into the cognitive elements that turn ordinary thinking into creative thinking. The composite nature makes the construct nearly intractable with today's neuroimaging tools and there is therefore no theory that fully explains the brain activity of the creative process. In fact, one of the strongest findings in the literature, is that creativity is not particularly associated with any single brain region, excluding the prefrontal cortex (Dietrich & Kanso, 2010). Nevertheless, divergent thinking is still considered one of the more fruitful ways to study ideation and, thus, potential for creativity and problem solving (Runco & Albert, 2010).

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.

We now connect mathematical ability to the general construct of giftedness in mathematics Mathematical ability and giftedness in mathematics, on the other hand, has often been confounded with mathematical attainment and there is some truth to that idea. Benbow and Arjmand (1990) found a strong relationship between future academic success in mathematics and early identification of high mathematical ability. However, Ching (1997) demonstrated that hidden talent and creativity can go unnoticed in typical classrooms and Kim, Cho and 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 and Mason (1994) found that even students with grades A and B struggle with non-routine problems. In another study, Hong and Aqui (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.

Two other studies provide further evidence to support the distinction between academically gifted students and creative gifted students in mathematics. Livne and Milgram (2006) conclude that general academic ability predicted academic, but not creative ability in mathematics, while creative thinking predicted creative, but not academic, ability in mathematics. Leikin and Lev (2013) explored the relationships between mathematical excellence, mathematical creativity and general giftedness. Three groups 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. 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). These and other findings (see for instance Haylock, 1997; Haavold, under review) indicate that mathematical achievements in academic K-12 settings do not necessarily imply mathematical creativity.

Nevertheless, 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; Sak and Maker, 2006; Ganihar et.al. 2009; Kadir & Maker, 2011; Kattou et al., 2013; Tabach and Friedlander, 2013; Haavold, under review). In all the studies reported here, the authors conceptualized and operationalized mathematical creativity separately from achievement or ability, using separate task-based instruments. Mann (2005) and Kadir and 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 and Maker (2006) measured mathematical knowledge using well-structured and close-ended routine tasks requiring convergent thinking. Achievements in mathematics has also been identified using grades, standardized tests, prizes, professional career etc. Mathematical creativity, on the other hand, was measured using divergent production instruments.

Summary. A review of the literature therefore provide us with two seemingly contradictory findings: On one hand, we notice that there is a significant statistical relationship between mathematical creativity and mathematical achievement, but on the other hand we see that mathematical achievements do not necessarily entail mathematical creativity. An explanation for this is found in Sriraman's claim (2005), 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). Haylock (1997) argues 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.

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. 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).

Teaching the mathematically gifted

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 s*tudents 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 from1950s 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.

Aside from organizational principles directed at the mathematically gifted, recent empirical studies have also found evidence that mathematical problem solving and problem posing can be used to develop creative abilities in mathematics for all students. Levav-Waynberg and Leikin (2012) describes a study in which one group of students learned geometry over the course of one year in an experimental environment that employed Multiple Solution Tasks (MST), while a control group of students did not receive any special intervention. MSTs are tasks that explicitly asks the problem solver to find more than one solution to a given mathematical problem. Creativity in geometry was measured according to fluency, flexibility and originality. All students in the experimental group improved according to the measured criteria, although originality was found to be a more internal characteristic and less dynamic than fluency and flexibility. Other recent studies (see for instance Jonsson, Norqvist, Liljekvist & Lithner, 2014; Vale, Pimentel, Cabrita, Barbosa & Fonseca, 2012) report similar findings, in which problem solving activities are found to improve creativity in mathematics. A possible explanation for this link between problem solving and/or problem posing and the development of creativity can be found in neuroimaging studies. In their review of studies on cognition and creativity, Jung, Mead, Carrasco and Flores (2013) conclude, among other things, that: a) diverse cognitive abilities, such as working memory, sustained attention, idea generation, cognitive flexibility that facilitates information flow between many different areas of the brain, may be necessary for the development of creativity and b) creativity is a sequential process of exploratory and eliminatory processes. In problem solving and problem posing activities, the students are involved in precisely a continuously process of exploration and elimination of new ideas and the students have to make use of a wide variety of strategies and different knowledge.

Future research

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 four 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. d) developing instruments for measuring creativity that includes the sub-construct of iconoclasm.

References

Aiken, L.R. Jr., (1973) *Ability and Creativity in Mathematics*. Columbus, Ohio: ERIC Information Center.

Aljughaiman, A., & Mowrer-Reynolds, E. (2005). Teachers' conceptions of creativity and creative students. *Journal of Creative Behavior, 39,* 17–34.

Balka, D. S. (1974). The development of an instrument to measure creative ability in mathematics. *Dissertation Abstracts International, 36*(1), 98.

Benbow, C. P. & Arjmand, O. (1990). Predictors of high academic achievement in mathematics and science by mathematically talented students: A longitudinal study. *Journal of Educational Psychology*, 82, 430-441.

Benbow, C.P., Lubinski, D. & Sushy,B. (1996). The impact of SMPY's educational programs from the perspective of the participant. In: C.P. Benbow and D. Lubinski (Eds*),* *Intellectual Talent* (pp. 266-300). Baltimore: Johns Hopkins University Press.

Beghetto, R. A. (2013). Nurturing creativity in the micro-moments of the classroom. In K. H. Kim, J. C. Kaufman, J. Baer & B. Sriraman (Eds.), *Creatively gifted students are not like other gifted students: Research, theory, and practice* (pp. 3-15). Rotterdam, The Netherlands: Sense Publishers.

Burton, L. (2004). *Mathematicians as enquirers: Learning about learning mathematics***.** Dordrecht, The Netherlands : Kluwer Academic Publishers.

Chamberlin, S. A., & Moon, S. (2005). Model-eliciting activities: An introduction to gifted education. *Journal of Secondary Gifted Education, 17,* 37-47.

Ching, T. P. (1997). An experiment to discover mathematical talent in a primary school in

Kampong Air.International. *Reviews on Mathematical Education*, 29(3), 94-96.

Cox, W (1994) Strategic learning in a level mathematics? *Teaching Mathematics and its Applications*, 13, 11-21.

Craft, A. (2002). *Creativity and Early Years Education*. London: Continuum Publications.

Dodds, R. A., Ward, T. B., & Smith, S. M. (2003). A review of experimental literature on incubation in problem solving and creativity. In M. A. Runco (Ed.), Creativity research handbook (Vol. 3). Cresskill, NJ: Hampton press.

Feldhusen, J. F., & Westby, E. L. (2003). Creative and affective behavior: Cognition, personality and motivation. In J. Houtz (Ed.), *The educational psychology of creativity* (pp. 95–105). Cresskill, NJ: Hampton Press.

Feldhusen, J. F. (2006). The role of the knowledge base in creative thinking. In J. C. Kaufman and J. Baer (Eds.), *Creativity and Reason in Cognitive Development.* New York: Cambridge University Press.

Freiman, V., and Volkov, A. (2004). Early Mathematical Giftedness and its Social Context: The Cases of Imperial China and Soviet Russia. *Journal of Korea Society of Mathematical Education Series D: Research in Mathematical Education*, 8(3),157-173.

Ganihar, N. N., & Wajiha, A. H. (2009). Factor affecting academic achievement of IX standard students in mathematics. *Edutracks,* 8(7), 25-33.

Gnedenko B. V. (1991) *Introduction in specialization: mathematics* (Введение в специальность: математика), Nauka, 235 pages. In Russian

Gross, M.U.M. (1993). Nurturing the talents of exceptionally gifted children. In K.A. Heller, F.J. Monks and A.H. Passow (Eds). *International Handbook of Research and Development of Giftedness and Talent* (pp. 473-490). Oxford: Pergamon Press.

Guilford, J. P. (1959). Traits of creativity. In H. H. Anderson (Ed.), *Creativity and its* cultivation (pp. 142-161). New York: Harper & Brothers Publishers.

Haavold, P. (2010). What characterises high achieving students' mathematical reasoning. In *The elements of creativity and giftedness in mathematics*. Sense Publishers.

Haavold, P. (Under review). An empirical investigation of a theoretical model for mathematical creativity. Journal of Creative Behavior.

Haylock, D. (1987). A framework for assessing mathematical creativity in school children, *Educational Studies in Mathematics, 18*(1), 59–74.

Haylock, D. (1997). Recognizing mathematical creativity in school children. *International Reviews on Mathematical Education, 29*(3), 68-74.

Hong, E., & Aqui, Y. (2004). Cognitive and motivational characteristics of adolescents gifted in mathematics: Comparisons among students with different types of giftedness. *Gifted Child Quarterly,* 48, 191-201.

Jensen, L. R. (1973). The relationships among mathematical creativity, numerical aptitude and mathematical achievement. *Dissertation Abstracts International, 34* (05), 2168.

Jung, R., Mead, B., Carrasco, J. & Flores, R. (2013). The structure of creative cognition in the human brain. *Frontiers in Human Neuroscience,* 7.

Kadir, A. & Maker. (2011). Exploring the relationship between mathematical creativity and mathematical achievement. *Asia-Pacific Journal of Gifted and Talented Education,* 3(1), 34-45.

Kanevsky, L. S. (1990). Pursuing qualitative differences in the flexible use of a problem solving strategy by young children. *Journal for the Education of the Gifted, 13,* 115–140.

Kaufman, J. C., & Sternberg, R. J. (2007). Creativity. *Change, 39*(4), 55-58.

Kaltsounis, B., & Stephens, G. H. (1973). Arithmetic achievement and creativity: Explorations with elementary school children. *Perceptual and Motor Skills*, 36(3), 1160-1162.

Kattou, M., Kontoyianni, K., Pitta-Pantazi., & Christou, C. (2013). Connecting mathematical creativity to mathematical ability. *ZDM* 45(2), 167-181.

Kim, H., Cho, S., & Ahn, D. (2003). Development of mathematical creative problem solving ability test for identification of gifted in math. *Gifted Education International*, 18, 184-174.

K. H. Kim, J. C. Kaufman, J. Baer and B. Sriraman (Eds.) (2013). *Creatively Gifted Students are not like Other Gifted Students: Research, Theory, and Practice*, Rotterdam, The Netherlands: Sense Publishers.

Kiesswetter, K. (1992). Mathematische Begabung. Über die Komplexität der Phänomene und die Unzulänglichkeiten von Punktbewertungen (in German). *Mathematik-Unterricht*, 38, 5-18.

Krutetskii, V. A. (1976). *The psychology of mathematical abilities in school children.* (J. Teller, trans. & J.Kilpatrick & I. Wirszup, Eds.). Chicago: University of Chicago Press.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Leikin, R. (2008). Teaching mathematics with and for creativity: An intercultural perspective. In P. Ernest, B. Greer, & B. Sriraman (Eds.), *Critical Issues in Mathematics Education* (pp. 39-43). USA: Information Age Publishing Inc.

Leikin, R., Levav-Waynberg, A. & Guberman, R. (2011). Employing Multiple Solution Tasks for the development of mathematical creativity: Two studies. *Proceedings of the The Seventh Conference of the European Society for Research in Mathematics Education* – CERME-7.

Leikin, R., & Lev, M. (2013). Mathematical creativity in generally gifted and mathematically excelling adolescents: What makes the difference? *ZDM*, 45(2), 183-197.

Levav-Waynberg, A., & Leikin, R. (2012). The role of multiple of multiple solution tasks in developing knowledge and creativity in geometry. *The Journal of Mathematical Behavior*, 31(1), 73-90.

Levav-Waynberg, A., & Leikin, R. (2012). The role of multiple solution tasks in developing knowledge and creativity in geometry. *The Journal of Mathematical Behavior*, *31*(1), 73-90.

Lithner, J. (2008). A research framework for creative and imitative reasoning. *Educational Studies in Mathematics*, 67(3), 255–276.

Livne, M. L., & Milgram, R. M. (2006). Academic versus creative abilities in mathematics: Two components of the same construct? *Creativity Research Journal*, *18*, 199-212.

Lubinski, D., & Benbow, C. P. (2006). Study of Mathematically Precocious Youth after 35 years: Uncovering antecedents for the development of math-science expertise. *Perspectives on Psychological Science*, *1*, 316-345.

Mann, E. (2005). *Mathematical Creativity and School Mathematics: Indicators of Mathematical Creativity in Middle School Students* (Doctoral dissertation).

Marland, S. P. (1972). *Education of the gifted and talented: Report to the Congress of the United States by the U.S. Commissioner of Education*. Washington, DC: Department of Health, Education and Welfare.

Mayer, R. E. (1999). Fifty years of creativity research. In R. J. Sternberg (Ed.), *Handbook of Creativity*. 449-460.

McCabe, P. M. (1991). Influence of creativity and intelligence on academic performance. The *Journal of Creative Behavior*, 25(2), 116-122.

Meissner, H. (2000). *Creativity in Mathematics Education*. Paper presented at the meeting of the International Congress on Mathematics Education, Tokyo, Japan.

National Advisory Committee on Creative and Cultural Education (NACCCE) (1999) *All Our Futures: Creativity, Culture and Education*, London: DfEE

Pitta-Pantazi, D., Sophocleous, P.,& Christou. C (2013). Spatial visualizers, object visualizers and verbalizers: their mathematical creative abilities. *ZDM*, 45(2), 199-213.

Plucker, J., & Beghetto, R. (2004). Why creativity is domain general, why it looks domain specific, and why the distinction does not matter. In R. J. Sternberg, E. L. Grigorenko & J. L. Singer (Eds.), *Creativity: From Potential to Realization* (pp. 153–167). Washington, DC: American Psychological Association.

Polya, G. (1957). *How to solve it*. Garden City, NY: Doubleday and Co., Inc.

Prouse, H. L. (1967). Creativity in school mathematics. *The Mathematics Teacher*, *60*, 876-879.

Runco, M. A. (1999). Divergent thinking. In M. A. Runco & S. R. Pritzker (Eds.), *Encyclopedia of creativity* (pp. 577–582). San Diego, CA: Academic Press.

Runco, M.A. & Albert, R.S. (2010). Creativity research: a historical view. In Kaufman, J.C. & Sternberg, R.J. (Eds.) *The Cambridge Handbook of Creativity* (3-19). Cambridge: Cambridge University Press.

Sak U & Maker C. (2006). Developmental variation in Children's creative mathematical thinking as a function of schooling, age and knowledge. *Creativity research journal*, 18, 279-291.

Selden, J., Selden, A. & Mason, A. (1994) Even good calculus students can't solve nonroutine problems. In Kaput, J and Dubinsky, E , (eds.), *Research issues in undergraduate mathematics learning*. Washington, DC: Mathematical Association of America.

Sheffield, L. (2009). Developing Mathematical Creativity-Questions may be the answer. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in Mathematics and the Education of Gifted Students* (pp. 87-100). Rotterdam: Sence Publishers.

Silver, E. A. (1997). Fostering creativity though instruction rich in mathematical problem solving and problem posing. *International Reviews on Mathematical Education, 29*, 75-80.

Sriraman, B. (2002). How do mathematically gifted students abstract and generalize mathematical concepts. *NAGC 2002 Research Briefs*, 16, 83-87.

Sriraman, B. (2003). Mathematical giftedness, problem solving, and the ability to formulate generalizations. *Journal of Secondary Gifted Education*. *14*, 151–165.

Sriraman, B. (2004a). Discovering a mathematical principle: The case of Matt. *Mathematics in School*, *33*(2), 25–31.

Sriraman, B. (2004b). Gifted ninth graders' notions of proof. Investigating parallels in approaches of mathematically gifted students and professional mathematicians. *Journal for the Education of the Gifted*, *27*, 267–292.

Sriraman, B. (2005). Are mathematical giftedness and mathematical creativity synonyms? A theoretical analysis of constructs. *Journal of Secondary Gifted Education*, *17*(1): 20-36.

Sriraman, B. (2009). The characteristics of mathematical creativity. *ZDM 41*(1&2), 13-27.

Sriraman, B., Haavold, P., & Lee, K. (2013). Mathematical creativity and giftedness: a commentary on and review of theory, new operational views, and ways forward. *ZDM*, *45*(2), 215-225.

Tabach, M. & Friedlander, A. (2013). School mathematics and creativity at the elementary and middle-grade levels: how are they related?. *ZDM*, 45(2), 227-238.

Torrance, E. P. (1966). *Creativity: Its educational implications*. New York: Wiley.

Vanharpen, X.Y, & Sriraman, B. (2013). Creativity and mathematical problem posing: an analysis of high school students' mathematical problem posing in China and the USA. *Educational Studies in Mathematics*, 82(2), 201-222.

Vale, I., Pimentel, T., Cabrita, I., Barbosa, A., & Fonseca, L. (2012). Pattern Problem Solving Tasks as a Mean to Foster Creativity in Mathematics. In T. Y. Tso (Ed.), *Proceedings of the 36th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 4, pp. 171-178). Taipe, Taiwan, 18-22 july,2012.

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

Weisberg, R. W. (1999). Creativity and knowledge: A challenge to theories. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 226–250). Cambridge: Cambridge University Press.