Fostering Creativity through Instruction Rich in Mathematical Problem Solving and Problem Posing

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Abstract: Although creativity is often viewed as being associated with the notions of "genius" or exceptional ability, it can be productive for mathematics educators to view creativity instead as an orientation or disposition toward mathematical activity that can be fostered broadly in the general school population. In this article, it is argued that inquiry-oriented mathematics instruction which includes problem-solving and problem-posing tasks and activities can assist students to develop more creative approaches to mathematics. Through the use of such tasks and activities, teachers can increase their students' capacity with respect to the core dimensions of creativity; namely, fluency, flexibility, and novelty. Because the instructional techniques discussed in this article have been used successfully with students all over the world, there is little reason to believe that creativity-enriched mathematics instruction cannot be used with a broad range of students in order to increase their representational and strategic fluency and flexibility, and their appreciation for novel problems, solution methods, or solutions.

Kurzreferat: *Kreativität fördern durch einen Unterricht, der reich ist an Situationen des mathematischen Problemlösens und Aufgabenerfindens.* Kreativität wird oft im Zusammenhang gesehen mit Begriffen wie "Genie" oder außergewöhnliche Fähigkeiten. Demgegenüber kann es für Mathematiklehrer jedoch produktiver sein, Kreativität als Orientierung für mathematische Aktivitäten zu nehmen, die auf diese Weise bei der Allgemeinheit der Schüler breit gefördert werden kann. In diesem Beitrag wird gezeigt, daß forschender Mathematikunterricht, der Aufgaben zum Problemlösen und zum Aufgabenerfinden beinhaltet, Schüler dabei unterstützen kann, mehr kreative Zugänge zur Mathematik zu entwickeln. Durch solche Aktivitäten und Aufgaben kann der Lehrer die Fähigkeiten seiner Schüler im Hinblick auf die Kernaspekte von Kreativität erweitern, nämlich Gewandtheit, Flexibilität und Neues. Die hier diskutierten Unterrichtsmethoden wurden weltweit erfolgreich angewendet, so daß es keinen Grund gibt, daran zu zweifeln, daß solch ein kreativitätsfördernder Mathematikunterricht nicht auch bei einem großen Teil aller Schüler eingesetzt werden kann, um ihre Gewandtheit und Flexibilität im Hinblick auf Darstellung und Strategien sowie ihr Interesse an neuartigen Aufgaben, Lösungsmethoden oder Lösungen zu fördern.

ZDM-Classification: C40, D40, D50

1. Introduction

Mathematics as an intellectual domain stands at or near the top of any hierarchical list of intellectual domains ordered according to the extent to which creativity is evident in disciplinary activity or production. Thus, it is ironic that for most students throughout the world, mathematics would almost certainly be among the set of school subjects least associated with creativity. Although genuine mathematical activity is intimately interwoven with creativity, schooling provides most students with little opportunity to experience this aspect of the domain of mathematics. The goal of this paper is to argue for a different kind of experience for students – a form of instructional activity that is enriched by concepts connected to the notion of creativity.

In this paper, I discuss creativity as it connects with the activities of problem posing and problem solving, which are both strong themes in contemporary discussions of mathematics education. In particular, I show how mathematical problem posing and problem solving are connected to key aspects of the classic and contemporary conceptions of creativity and also to the assessment of creativity. I illustrate the connection between these ideas and those of others who have argued for and demonstrated methods of providing various forms of inquiry-oriented mathematics instruction. In this way, I hope to demonstrate the feasibility of bringing creativity-enriched instruction to all students. That is, the instructional principles and activities proposed and discussed in this article are not applicable only to the teaching of exceptional individuals, but rather to the general student population.

2. Creativity: What is it and who has it?

In the psychological literature there are literally thousands of commentaries offered or studies conducted on the nature of creativity, its distribution within the population, and its origins and manifestations in human experience. Self-reports of exceptionally talented individuals, as well as analyses of their work provided by observers, have illuminated aspects of creativity in areas as diverse as literary or musical composition (Getzels & Csikszentmihalyi, 1976; Ghiselin, 1952), scientific discovery (Mansfield & Busse, 1981; Rothenberg, 1979), and mathematical thinking (Hadamard, 1945; Helson, 1983). Unfortunately, what has garnered a great deal of attention in these accounts is a so-called "genius" view of creativity.

According to the "genius" view of creativity, creative acts are viewed as rare mental feats, which are produced by extraordinary individuals who rapidly and effortlessly use exceptional thought processes (Weisberg, 1988). The genius view of creativity suggests both that creativity is not likely to be heavily influenced by instruction and that creative work is more a matter of occasional bursts of insight than the kind of steady progression toward completion which tends to be valued in school. Thus, there have been limited attempts to apply ideas derived from the study of creativity to the education of all students. But this view of creativity has been questioned in recent research, and it is no longer the only view of creativity available for application to education.

A new view of creativity has emerged from contemporary research – one which stands in sharp contrast to the genius view. This research suggests that creativity is closely related to deep, flexible knowledge in content domains; is often associated with long periods of work and reflection rather than rapid, exceptional insight; and is susceptible to instructional and experiential influences (Holyoak & Thagard, 1995; Sternberg, 1988). The contemporary view of creativity also suggests that persons who are creative in a domain appear to possess a creative disposition or orientation toward their activity in that domain. That is, creative activity results from an inclination to think and behave creatively. This emerging view of creativity provides a much stronger foundation on which to build educational applications. In fact, this view suggests that creativity-enriched instruction might be appropriate for a broad range of students, and not merely a few exceptional individuals.

The classical and contemporary views of creativity differ with respect to the nature of such aspects of creativity as "insight" and with respect to the distribution of a capacity for creative activity within the population. But there is little disagreement between these views of creativity on the centrality of the generative processes of problem posing and problem solving in creative activity.

3. The Relation of creativity to problem posing and problem solving

Problem posing, or problem finding, has long been viewed as a characteristic of creative activity or exceptional talent in many fields of human endeavor. For example, Getzels and Csikszentmihalyi (1976) studied artistic creativity and characterized problem finding as being central to the creative artistic experience. Related observations have been made about professionals in various science fields (e.g., Mansfield & Busse, 1981). And Hadamard (1945) identified the ability to identify key research questions as an indicator of exceptional talent in the domain of mathematics.

Problem posing, along with problem solving, is central to the discipline of mathematics and the nature of mathematical thinking (Silver, 1994). When mathematicians engage in the intellectual work of the discipline, it can be argued that the self-directed posing of problems to be solved is an important characteristic (Pólya, 1954). Mathematicians may solve some problems that have been posed for them by others or may work on problems that have been identified as important problems in the literature, but it is more common for them to formulate their own problems, based on their personal experience and interests (Poincaré, 1948). Professional mathematicians, whether working in pure or applied mathematics, frequently encounter ill-structured problems and situations which require problem posing and conjecturing, and their intellectual goal is often the generation of novel conjectures or results (Pollak, 1987). Thus, unlike the situation in school mathematics, in genuine mathematical activity, problems may occasionally be presented for solution by an outside source, but it is more common for them to arise out of attempts to generalize a known result, or as tentative conjectures for working hypotheses, or as subproblems embedded in the search for the solution to a larger problem.

As these observations suggest, the connection to creativity lies not so much in problem posing itself, but rather in the interplay between problem posing and problem solving. It is in this interplay of formulating, attempting to solve, reformulating, and eventually solving a problem that one sees creative activity. Both the process and the products of this activity can be evaluated in order to determine the extent to which creativity is evident. Among the features of this activity that one might examine are the novelty of the problem formulation or the problem solution, the extent to which shifts in direction or focus were evident during the process of reformulation or solution, and the number of formulations or reformulations generated or the number of different solution paths explored or solutions obtained. These are precisely the forms of cognitive activity assessed in tests of creativity.

4. Key concepts underlying the assessment of creativity

The Torrance Tests of Creative Thinking (TTCT) (Torrance, 1966; 1974) have frequently been used to assess the creative thinking of children and adults. An extensive program of research has validated this instrument as a predictor of creative production (Torrance, 1988). Three key components of creativity assessed by the TTCT are fluency, flexibility and novelty. Fluency refers to the *number* of ideas generated in response to a prompt; flexibility to apparent *shifts in approaches* taken when generating responses to a prompt; and novelty to the *originality* of the ideas generated in response to a prompt. Note the similarity between these components and the characteristics of creative activity evident in problem posing and problem solving, as discussed above. In fact, problem posing and problem solving are often involved in the assessment of creativity.

The notions of fluency, flexibility and novelty were adapted and applied in the domain of mathematics by Balka (1974), who asked subjects to pose mathematical problems that could be answered on the basis of information provided in a set of stories about real world situations. In his analysis of students' responses, fluency referred to the number of problems posed or questions generated, flexibility to the number of different categories of problems generated, and originality to how rare the response was in the set of all responses.

Problem-posing and problem-solving tasks have also been used by others to identify creative individuals. For example, Getzels and Jackson (1962) developed a battery of tests to measure creativity, of which one task asked subjects to pose mathematical problems that could be answered using information provided in a set of stories about real world situations. Getzels and Jackson scored the subjects' problems according to the complexity of the procedures that would need to be used in order to obtain a solution (i. e., the number and type of arithmetic operations used), and they used the results as a measure of creativity. Other tasks used by Getzels and Jackson assessed the fluency and originality of subjects as they solved problems that could have multiple answers or could be approached from multiple directions. Thus, the activities of problem posing and problem solving, and the creative features of such activity – fluency, flexibility, and novelty – are well established within the practice of assessing creativity. These activities and features can also be incorporated into the teaching of mathematics in order to develop in students a more creative disposition toward mathematics. And problem-posing and problem-solving activities can serve as the mediating vehicles to achieve this goal when they are used in inquiry-oriented mathematics instruction.

5. Creativity-enriched, inquiry-oriented mathematics instruction

Although there is no clear consensus on the nature of inquiry-oriented teaching, in mathematics or in any other domain, an inquiry approach to mathematics teaching would generally be characterized as one in which some of the responsibility for problem formulation and solution is shared between teacher and students. One way in which this has been done is to move the locus of instructional activity away from the textbook and the teacher as the only sources of problems to be solved in the mathematics classroom.

Authors from several different countries have written about instructional experiments in which students generate mathematics problems that are intended to be solved by themselves, their classmates, or future students. In the Netherlands, Van den Brink (1987) has reported an experiment in which first grade children wrote and illustrated a page of arithmetic sums for children who would enter first grade in the following year; and Streefland (1987) has employed similar authorship experiences for students. In the United States, Healy (1993) has used a similar approach, which he calls "Build-a-book," with secondary school students, in which they study geometry not by using a commercial textbook but by creating their own book of important findings based on their geometric investigations. In Australia, Skinner (1991) reports engaging primary grade children in an extensive amount of problem posing; the posed problems are shared among the students in the classroom and form the basis for much of the ensuing mathematics problem-solving activity. In all of these cases, students in these classrooms engage in generative processes of problem posing and problem solving that are likely to encourage the development of fluency, one of the key features of creativity.

The development of students' creative fluency is also likely to be encouraged through the classroom use of ill-structured, open-ended problems that are stated in a manner that permits the generation of multiple specific goals and possibly multiple correct solutions, depending upon one's interpretation. For example, consider the following "Fermi-style" problem: "How many cells are there in the body of an average adult male human?" (Schoenfeld, 1985). This problem calls for interpretation in order to identify a well-structured problem to be solved. Moreover, it is clear that this problem does not have a single exact answer; rather, a range of plausible solutions could be justified. The use of such open-ended problems can provide students with a rich source of experience in interpreting problems, and perhaps generating different solutions associated with different interpretations (Silver, 1994).

A number of other examples of the use of open problems in inquiry-oriented mathematics instruction can be found in the literature. For example, Silver and Adams (1987) provide examples of fairly simple, yet open-ended, problems that call for interpretation and might be used in teaching elementary school mathematics. Lesh (1981) has provided examples of "applied" problems that are much simpler than the example above regarding the cells in the human body, but ones that can nevertheless offer students valuable opportunities to tackle problems with multiple interpretations and possible solutions. At the secondary school level, Silver, Kilpatrick and Schlesinger (1990) have provided numerous examples of open problems that invite exploration and communication about mathematical ideas. Problem posing and open problems are also prominent features of geometry instruction that uses computer software tools, such as the Geometric Supposers (Yerushalmy, Chazan & Gordon, 1993). And Sweller, Mawer, and Ward (1983) have pointed to the potential efficacy of making instructional use of non-goal-specific problems (e.g., The radius of a circle inscribed in a square is 6 inches. Find out all that you can about the square and the circle.) as opposed to goal-specific problems (e.g., The radius of a circle inscribed in a square is 6 inches. Find the area of the square.). Additional examples of open-ended problems suitable for use with students, and discussions of critical issues in using open problems, are provided by Nohda (1995), Pehkonen (1995), and Stacey (1995).

As with the instructional approaches discussed above in which problems are generated by students rather than presented by textbooks, all of these tasks seek to engage students in problem posing and problem solving. As a result, students should develop their representational and strategic fluency, as they consider ill-defined situations in which they pose and then solve a number of problems, perhaps generating solutions for each of the different problems posed.

Students can not only become fluent in generating multiple problems from a situation, but they can also develop creative flexibility as they generate multiple solutions to a given problem. Complex, ill-structured problems such as the one presented above about cells in the human body certainly provide such opportunities, but even fairly simple problems can afford an opportunity for students to display an array of solution methods. For example, Silver, Kilpatrick, and Schlesinger (1990; pp. 16-19) provide an example of a classroom instructional episode in which a teacher and his students discuss multiple solutions to the following well-known problem: "In the barnyard I have some chickens and some rabbits. I count 50 heads and 120 legs. How many of each type of animal is in the barnyard?" In this episode, students displayed and discussed the validity, generalizability, and power of two algebraic approaches, a visual solution, and the use of successive approximations. In this case, individual students or groups of students working collaboratively may each generate only one solution, but the ensuing presentation and discussion of alternative approaches helps students become aware of different solution methods, thereby increasing their capacity to approach problems more flexibly in the future. Many opportunities for similar experience with multiple solutions and solution methods can be provided using the kinds of open problems discussed above.

Similar opportunities are available to students in classrooms in which "open approach teaching" or teaching with "open-end or open-ended problems" is employed in Japan (Hashimoto & Sawada, 1984; Nohda, 1986, 1995; Shimada, 1977). In this approach, students analyze problems and problem-solving methods through a process of solving a problem in one way and then discussing and evaluating a variety of solution methods that have been developed and presented by classmates. In one version of this approach, problem posing also plays a prominent role, as students pose mathematical problems that are related to but different from another problem that was solved on a previous day (Hashimoto, 1987). The use of problems that permit a class of students to generate multiple solutions is a key feature of this form of mathematics teaching, and it is clearly associated with the development of students' representational and strategic flexibility.

Another example of an instructional approach that is likely to encourage the development of flexibility has been developed by Brown and Walter (1983), and is often called "What-if-not?" This method of instruction emphasizes having students generate new problems from a previously solved problem using a process of varying the conditions or goals of the original problem. This instructional approach has been incorporated into mathematics teaching at the college and precollege levels, and it is highly likely to develop creative flexibility in students, as well as to foster a generally creative disposition toward mathematical activity.

Many of the kinds of problem-solving and problem-posing experiences discussed above as being associated with the building of students' representational and strategic fluency and flexibility can also be used to develop in students an appreciation for and a capacity to produce novel solutions, solution methods, or problems. For example, in "What-if-not" instructional settings, as students generate problems by varying the goals and conditions of an original problem, they could be encouraged to generate a type of problem that is different from any that have been generated thus far. In "open approach" instructional settings, as successive solution approaches are discussed, students can identify and discuss the ways in which new solutions are similar to and different from those methods generated previously. And students in instructional settings in which they pose problems for classmates could be similarly challenged to generate or evaluate the novelty of a posed problem.

6. Creativity-enriched mathematics instruction: A summary and an example

Figure 1 summarizes the instructional suggestions regarding problem posing and problem solving that were discussed in the preceding section and illustrates their connection to the three core features of creativity discussed earlier in the paper: fluency, flexibility, and novelty.

The ideas and instructional examples discussed in this paper are closely associated with the tradition of "problem solving as art" popularized by Pólya (1954) and discussed extensively by Stanic and Kilpatrick (1988). As Stanic and Kilpatrick note, this view of mathematical problem solving is deeply tied to the nature of genuine mathematical activity, and it offers considerable promise for developing in students a more creative disposition toward mathematics. Nevertheless, it is also the case that teachers often find this view of problem solving difficult to implement in classrooms. The supply of curriculum materials specifically designed to support this view of mathematics instruction is small compared to the size of the set of materials that supports a more procedural and mechanical view of school mathematics. Nevertheless, if teachers examine the examples cited above and if they reflect on how these models might be adapted to their teaching, it should be possible for many teachers to apply the ideas discussed above in a manner that develops their students' creativity and mathematical proficiency in appropriate ways through problem-posing and problem-solving activities.

Limitations in space available in this article constrains the extent to which practical matters can be addressed adequately, but a simple, concrete example of how these ideas might influence the planning and implementation of mathematics instruction seems warranted. Let us consider the following problem and a variety of ways in which it might be used in connection to the ideas discussed above and summarized in Figure 1: "Show that the product of any four consecutive integers is divisible by 24."

Problem Solving	Creativity	Problem Posing
Students explore open-ended problems, with many interpretations, solution methods, or answers	->Fluency<-	Students generate many problems to be solved Students share their posed problems
Students solve (or express or justify) in one way; then in other ways Students discuss many solution methods	->Flexibility<-	Students pose problems that are solved in different ways Students use "What-if-not?" approach to pose problems
Students examine many solution methods or answers (expressions or justifications); then generate another that is different	->Novelty<-	Students examine several posed problems; then pose a problem that is different

Fig. 1:
Relation of Mathematics Problem-Solving and Problem-Posing Instructional Activities to Core Components of Creativity

This problem can be solved in several different ways. For example, students might generate examples of specific cases of products of consecutive integers, and then look for a pattern that could provide an adequate justification for the desired generalization. Alternatively, students could use number theoretic concepts to argue that $2^3 \times 3$ must be the greatest common factor of the product of four consecutive numbers. An example of argument that uses the divisibility properties associated with numbers in the string of consecutive integers is the following: One of the four numbers in the string must be even and another one must be a multiple of 4 (thereby together giving a common factor of 2^3), and one of the numbers in the string must be a multiple of 3 (thereby giving another common factor of

3, which means that the common factor must be at least 24), and the smallest non-zero product of four consecutive integers is 24 (thereby ensuring that the largest possible common factor of all such strings can be no greater than 24), and so we can conclude that the greatest common factor must be exactly 24. Other methods of solution and argument are also possible. Used in this way, the problem could build representational and strategic flexibility by providing students with exposure to several different solution methods for the same problem.

This problem could also be used in other ways to accomplish additional goals. For example, after solving the original problem, a teacher could have students use the "What-if-not" approach to vary the original problem's goal (e.g., What is the smallest guaranteed divisor? or What are all the possible factors?) or conditions (e.g., What if there were 3 consecutive integers, 5 consecutive integers, or N consecutive integers? or If the 4 integers were not consecutive, could a guaranteed largest divisor still be determined?).

A different approach to using this problem might involve stating it in a more open-ended fashion, such as "What conclusions can you draw about the product of any four consecutive integers?" This formulation of the problem is non-goal-specific and less well defined, thereby offering students an opportunity not only to determine that 2, 3, 4, 6, 8, 12, and 24 are factors of all such products, but also perhaps to detect other interesting features of such products. For example, students might be challenged to generate some characteristic of products of four consecutive integers that does not have to do with divisibility by some integer. In response, some student might generate the novel, and correct, hypothesis that all such products are exactly one less than a perfect square. The solution of this problem can itself be undertaken in a variety of ways.

Although only a single example of how these ideas might be applied is given here, it should be clear that this example illustrates a process that can be applied quite generally to many mathematics problems. It should be possible for teachers to use or adapt this approach in planning or implementing mathematics instruction in order to build their students' capacity for fluency, flexibility and novelty, and to help students develop a creative disposition toward mathematics. Interested readers are encouraged to consult the sources cited previously in discussing creativity-enriched, inquiry-oriented mathematics instruction; many excellent practical instructional examples can be found in those references.

In this article it has been argued that mathematics educators can view creativity not as the domain of only a few exceptional individuals but rather as an orientation or disposition toward mathematical activity that can be fostered broadly in the general school population. Support for this claim can be inferred from the fact that the instructional ideas discussed in this article have all been implemented with students in a variety of classroom settings around the world. Through the use of inquiry-oriented mathematics instruction that includes opportunities for problem posing and problem solving, teachers can assist students to develop greater representational and strategic fluency and flexibility and more creative approaches to their mathematical activity.

7. References

Balka, D. S. (1974): Creative ability in mathematics. – In: Arithmetic Teacher 21, p. 633–636

Brown, S. I.; Walter, M. I. (1983): The art of problem posing. – Hillsdale, NJ: Lawrence Erlbaum Associates

Getzels, J. W.; Csikszentmihalyi, M. (1976): The creative vision. – New York: Wiley

Getzels, J. W.; Jackson, P. W. (1962): Creativity and intelligence: Exploration with gifted children. – New York: Wiley

Ghiselin, B. (Ed.) (1952): The creative process. – New York: Mentor

Hadamard, J. (1945): The psychology of invention in the mathematical field. – Princeton, NJ: Princeton University Press

Hashimoto, Y. (1987): Classroom practice of problem solving in Japanese elementary schools. – In: J. Becker; T. Miwa (Eds.), Proceedings of the U. S.-Japan seminar on mathematical problem solving. Columbus, OH: ERIC/SMEAC Clearinghouse (ED 304 315), p. 94–119

Hashimoto, Y.; Sawada, T. (1984): Research on the mathematics teaching by developmental treatment of mathematical problems. – In: T. Kawaguchi (Ed.), Proceedings of the ICMI-JSME regional conference on mathematical education. Japan: Japan Society of Mathematical Education, p. 309–313

Healy, C.C. (1993): Creating miracles: A story of student discovery. – Berkeley, CA: Key Curriculum Press

Helson, R. (1983): Creative mathematicians. – In: R. S. Albert (Ed.), Genius and eminence: The social psychology of creativity and exceptional achievement. Oxford: Pergamon Press, p. 311–330

Holyoak, K. J.; Thagard, P. (1995): Mental leaps: Analogy in creative thought. – Cambridge, MA: MIT Press

Lesh, R. (1981): Applied mathematical problem solving. – In: Educ. Stud. in Math. 12, p. 235–264

Mansfield, R. S.; Busse, T. V. (1981): The psychology of creativity and discovery: Scientists and their work. – Chicago: Nelson Hall

Nohda, N. (1986): A study of "open-approach" method in school mathematics. – In: Tsukuba J. of Educ. Study in Math. 5, p. 119–131

Nohda, N. (1995): Teaching and evaluating using "open-ended problems" in the classroom. – In: ZDM, Zentralblatt für Didaktik der Mathematik 27 (No. 2), p. 57–61

Pehkonen, E. (1995): Use of open-ended problems. – In: ZDM, Zentralblatt für Didaktik der Mathematik 27 (No. 2), p. 55–57

Poincaré, H. (1948): Mathematical creation. – In: Scientific American 179, p. 54–57

Pollak, H. O. (1987): Cognitive science and mathematics education: A mathematician's perspective. – In: A. H. Schoenfeld (Ed.), Cognitive science and mathematics education. Hillsdale, NJ: Lawrence Erlbaum Associates

Pólya, G. (1954): Mathematics and plausible reasoning. – Princeton, NJ: Princeton University Press

Rothenberg, A. (1979): The emerging goddess. – Chicago: University of Chicago Press

Schoenfeld, A. H. (1985): Mathematical problem solving. – Orlando, FL: Academic Press

Shimada, S. (Ed.) (1977): On lessons using open-ended problems in mathematics teaching. – Tokyo: Mizuumishobo

Silver, E. A. (1995): The nature and use of open problems in mathematics education: Mathematical and pedagogical perspectives. – In: ZDM, Zentralblatt für Didaktik der Mathematik 27 (No. 2), p. 67–72

Silver, E. A. (1994): On mathematical problem posing. – In: For the learning of mathematics 14 (No. 1), p. 19–28

Silver, E. A.; Adams, V. M. (1987): Using open-ended problems. – In: Arith. Teacher 34 (No. 9), p. 34–35

Silver, E. A.; Kilpatrick, J.; Schlesinger, B. (1990): Thinking through mathematics: Fostering inquiry and communication in mathematics classrooms. – New York: The College Board

Skinner, P. (1991): What's your problem? Posing and solving mathematical problems, K-2. – Portsmouth, NH: Heinemann

Stacey, K. (1995): The challenges of keeping open problem-solving open in school mathematics. – In: ZDM, Zentralblatt für Didaktik der Mathematik 27 (No. 2), p. 62–77

Stanic, G. M. A.; Kilpatrick, J. (1988): Historical perspectives on problem solving in the mathematics curriculum. – In: R. I. Charles; E. A. Silver (Eds.), The teaching and assessing of mathematical problem solving. Reston, VA: NCTM, p. 1–22

Sternberg, R. J. (Ed.) (1988): The nature of creativity: Contemporary psychological perspectives. – New York: Cambridge University Press

Streefland, L. (1987): Free production of fraction monographs. – In: J. C. Bergeron; N. Herscovics; C. Kieran (Eds.): Proceedings of the Eleventh Annual Meeting of the International Group for the Psychology of Mathematics Education, Volume I. – Montreal: Canada, p. 405–410

Sweller, J.; Mawer, R. F.; Ward, M. R. (1983): Development of expertise in mathematical problem solving. – In: J. of Experimental Psych. 112, p. 639–661

Torrance, E. P. (1966): The Torrance tests of creative thinking: Technical-norms manual. – Princeton, NJ: Personnel Press

Torrance, E. P. (1974): The Torrance tests of creative thinking: Technical-norms manual. – Bensenville, IL: Scholastic Testing Services

Torrance, E. P. (1988): The nature of creativity as manifest in its testing. – In R. J. Sternberg (Ed.): The nature of creativity: Contemporary psychological perspectives. – New York: Cambridge University Press, p. 43–75

Van den Brink, J. F. (1987): Children as arithmetic book authors. – In: For the learning of mathematics 7 (No. 2), p. 44–48

Weisberg, R. W. (1988): Problem solving and creativity. – In R. J. Sternberg (Ed.), The nature of creativity. New York: Cambridge University Press, p. 148–176

Yerushalmy, M.; Chazan, D.; Gordon, M. (1993): Posing problems: One aspect of bringing inquiry into classrooms. – In: J. Schwartz; M. Yerushalmy; B. Wilson (Eds.), The Geometric Supposer: What is it a case of? Hillsdale, NJ: Lawrence Erlbaum Associates, p. 117–142

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