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«Я НАЧАЛ ДУМАТЬ ПО-ДРУГОМУ…» – ВЛИЯНИЕ ДИДАКТИЧЕСКОГО СРЕДСТВА «НАПИСАНИЕ ИСТОРИЙ-ГОЛОВОЛОМОК» НА ВОСПРИЯТИЕ СТУДЕНТАМИ МАТЕМАТИЧЕСКИХ КОНЦЕПЦИЙ И ВОСПИТАНИЕ КРЕАТИВНОСТИ

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"I BEGAN TO THINK DIFFERENTLY..." – THE IMPACT OF THE DIDACTIC TOOL "WRITING PUZZLE STORIES" ON STUDENTS' PERCEPTION OF MATHEMATICAL CONCEPTS AND THE NURTURE OF THEIR CREATIVITY

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In a project aimed to develop mathematical creativity, 46 eleventh- and twelfth-grade students were asked to compose "mathematical puzzle story" in which were "hidden" mathematical concepts or objects that they had learned about. They then presented their puzzle stories to their classmates, who had to discover the object/concept. The students' responses to the assignment showed that they felt that it contributed significantly to their mathematical creativity. The description of the task along with examples of the students' puzzle stories were then presented to 32 mathematics teachers, who were asked to give their opinion of the potential such an approach might have in the development of mathematical creativity in students. This lecture will present examples of the students' stories and their reflections on their experience, along with the teachers' ideas concerning the possible contribution such an exercise might make in developing mathematical creativity in students.

Keywords: Mathematical creativity; Writing stories in mathematics; Assessment of creativity in mathematics; Reflection on creative procedure; Imagination; Team teaching.

Theoretical background

1. Unique Characteristics and the Importance of Expression in Writing

Some view the ability to express oneself in writing as the peak of the lingual pyramid and the most advanced achievement in human culture. Written expression has *unique characteristics* that distinguish it from verbal expression, and depending on the circumstances, a person will prefer to express himself in one way over another. The advantages and disadvantages of both modes of expression have been studied over the years by psychologists, educators, philologists and others. The psychologist Lev Vygotsky, for example, studied, among other things, the connections between psychological aspects and written and verbal expression, and his point of departure was defining the difference between both types of expression:

"Written expression is not merely the translation of verbal expression into written characters, and learning it does not end with learning how to write. If that were the case, we would expect to see, immediately upon learning the writing mechanism, written expression that is no less developed and rich than our spoken language, and as similar to it as a translation is similar to the source. However, this phenomenon does not exist in the development of written expression" [1, p. 236].

In reference to the unique characteristics of written expression, Vygotsky noted the following aspects [1]:

- Abstractness – in an analogy to mathematics, verbal speech is perceived as the "arithmetic of expression", and written speech is perceived as the "algebra of speech";
- Expression without sound – speaking without the tangible vocal aspect, but one expressed by thought and imagery;
- Inner speech – a person's speech for himself, when the basis of the written expression is a "draft of thoughts";
- Intentional expression –more conscious than verbal speech. We do not always pay attention to every word when speaking. When we write, we must pay attention to the words and sentence structure.

Vygotsky argues that children develop their ability for written expression spontaneously. In order to improve this ability, which is a manifestation of personal creation, children must be provided with suitable conditions and explicit and constant

guidance. In Vygotsky's opinion, *inadequate attention is devoted at school* to developing the students' ability to express themselves in writing. Researchers (e.g. [2]) point out that even nowadays teachers do not emphasize the issue enough. Mudlinger ([3]) suggested replacing the 1970's popular demand "Let them read!" to "Let them write!", noting that writing is an independent language skill and is not to be treated as a natural and obvious continuation of reading.

2. Creativity and Cognition

Studies of intelligence in general and genius in particular were conducted in the middle of the 19th century and beginning of the 20th century. These studies constituted the platform for the development of systematic studies in the field of creativity. The first attempts to scientifically engage in intelligence and the characteristics of genius were attributed to the English psychologist Sir Francis Galton who was referred to by some researchers as *"the first cognitive psychologist"*. Galton started engaging in these topics by a self-inquiry of his brain activity. In 1879 he wrote down some of his findings and explained the motivation for his work by his wish to comprehend how a sequence of associations turns from something vague crossing the threshold of consciousness into something conscious [4]. In the footsteps of Galton, additional researchers attempted to systematically explore various aspects associated with intelligence. The French psychologist Alfred Binet and his disciple Theodore Simon, who were contemporaries of Galton, developed a series of intelligence tests which were published for the first time in 1908 [5]. The enhanced version of the Binet-Simon exam consisted of 30 tasks in an ascending level of difficulty, the first ones being on such a level that everyone could perform them.

During the 1950s, a scientific reference to the issue of creativity began also to be applied. Researchers such as Joy Paul Guilford, Alex Osborn, Genrikh Altshuller and Edward de Bono are considered today as precursors of the study of creativity. Moreover, at the same time, researchers started showing interest in the promotion of *creativity in an educational context* [6]. They maintained that creativity could drive economic and social changes [7].

As opposed to the psychometric approach, the ***cognitive approach*** to the research of creativity focused on the involved cognitive and mental processes, including the use of different representations, forming mental links between objects which apparently are not inter-connected as well as an ability to solve problems from varied fields [8]. In fact, the cognitive approach attempted deciphering the processes mentally performed on the entirety of the knowledge accumulated in the long-term memory. Furthermore, it tried decoding the way in which the parts of information became connected to each other in a way leading to a creative outcome. The theory of intelligences conceived by Sternberg [9] was a breakthrough. It was among the first to oppose the psychometric approaches to intelligence measurement, while underscoring a cognitive approach. Sternberg made a connection between the way of consciousness activity and the way of data processes and the three types of *components*: meta-components, performance components and information-acquisition-related components. According to him, the meta-components are processes used for problem solution and decision making, which are the key processes of human consciousness as they direct the person's actions. The performance components are the processes which put into effect what has been created by the meta-components. These are the basic processes which enable us to perform tasks. The information-acquisition-related components serve for acquiring new information and facilitate – the choice of information out of irrelevant information or by combination of parts of information. Sternberg [10] expanded the theory of intelligences to a sub-theory which engages in gifted individuals, arguing that they use these components in a more effective manner than others. More specifically, Sternberg explored the relation between the quality of performing a task and the extent of being familiar to the performing person. He divided the function of the previous experiment into two parts: *innovation and automation*. A new situation is a situation which people have not yet experienced. People with competences required for the performance of new tasks can identify new ways for solving them, such ways which most people would not notice. A process performed automatically, is a process which has been executed several times and it can be done without a special thought. Once a process becomes automatic, it can be executed parallel to other processes. According to Cianciolo and Sternberg [11], success in each area of life considerably depends on the individuals' ability to exploit their analytical, creative and practical competences.

3. The importance of fostering students' creativity in general and mathematical creativity in particular

During my years of work as a teacher in schools and colleges, I appreciated the fostering of students' mathematical creativity in general and of their mathematical writing abilities in particular, as one of the central aims of my teaching. Vygotsky [12] emphasized the unique importance of the development of a creative imagination among children from a young age, with whose help they get to know the world around them and themselves. He advocated creativity in many diverse domains, such as writing stories, theatre,

the arts etc., and built and explained the psycho-pedagogical basis of the development of a child's creative imagination. In his view, it is not possible to teach someone how to create, but teachers can encourage and cultivate their students' creativity. Creativity in a school setting allows students to express themselves in an unconventional manner and develop innovation, fluency and originality of mathematical thinking [13]. According to Feldhusen [14], originality is the essence of creativity and its final product.

The professional literature today calls for a change in the existing conception of the importance of creativity in education in general and in school in particular. It proposes *turning creativity into an integral part of the learning and teaching process* in schools, and particularly in the study of mathematics, and to develop this thinking skill and to regard creativity as an ability that is critical and not just "nice" [15]. In the view of Robinson [16], creativity is not only the gift bestowed on geniuses and "special" people, but rather "each one of us is born with a large amount of creativity, and the trick is to develop that ability. Educators must regard the development and cultivation of creativity as a goal to which time and effort should be devoted, and they should grant it the same status ascribed to "reading and writing" in schools [16, p. 68].

Many studies have suggested that teachers use efficient methods to evaluate the creativity of students. So that these evaluation methods are not subjective, researchers base them on a variety of solid, defined and quantitative criteria. For example, Brookhart [17] suggests an evaluation method that focuses on the product of the creative assignment in various areas (e.g., poetry, prose, poster, project, presentation, story) in accordance with the specific criteria, such as variety of ideas and their expression in the product, variety of sources, connection between ideas, if the product "projects" innovation, etc. Other researchers emphasize the importance of criteria such as "processing/ refinement/ elaborateness or complexity, and also those that characterize the creative process: such as originality and conceptual flexibility, and claim that using these enriches the learner, who receives recognition for different aspects of the learning (see for example the examples in [18]).

Many studies mention the role of mathematical discourse, and particularly the importance of ***mathematical writing*** in the process of constructing students' mathematical concepts [19]. It is recommended to encourage *self-creation of mathematical problems* and not only to refer students to the problems in the textbooks [20]. A number of studies emphasize the importance of *building the formulation of a mathematical problem by the student*, the purpose of which is not only understanding the material being studied and not only developing the student's mathematical creativity, but also as a tool that assists the teacher in understanding the student's way of thinking [21]. Researchers in the field of mathematical creativity who have focused on encouraging mathematical creativity in students, point out the even teachers who recognize the important of nurturing creativity in students often do not make the effort for this in school [22].

Purpose of the research and Research questions

The purpose of the study was to investigate if writing mathematical puzzle stories contributes to the development of mathematical creativity in students. The research questions are:

1. How do students assess the influence that writing puzzle stories has on their mathematical creativity?

2. How do teachers assess the inherent potential that writing puzzle stories has on developing the mathematical creativity of students?

3. Is there a difference between the teachers' and students' assessments regarding the contribution that writing mathematical puzzle stories has on students' mathematical creativity?

Based on my previous experience, I hypothesized that viewing mathematical concepts and terms as "real entities" would allow students to become better acquainted with the ideas and, as a result, express their creativity. My assumption was that the students would recognize and appreciate the impact that the writing would have on their creativity, whereas, regarding the second question, the teachers would be ambivalent to the influence such a writing task would have on students' creativity, leading to a difference between what value students and teachers saw in the exercise.

Methodology

Participating in the study were 25 grade-eleven and 21 grade-twelve students who were studying advanced mathematics (matriculation level) in schools in northern Israel. Also participating were 32 secondary-school mathematics teachers who were told about the idea of writing puzzle stories and were shown the stories that the students wrote.

Using leading questions, the teachers were asked to assess the potential influence that writing mathematical puzzle stories might have on the students' learning process and on the development of their mathematical creativity. An example question: as a teacher of mathematics, would you use such activities in your class? Why or why not? If yes, how?

Research tools included the puzzle stories written by the students, questionnaires about "Your reaction to writing puzzle stories", the students' reflective journals, detailed interviews of

a sample of six randomly-selected students following the assignment, video recordings of the students working in groups and of their presentations to the class, and the teachers' written responses regarding their assessment of the potential that such an activity might have for students. The data were analyzed according to the rules for analyzing qualitative data.

Main findings

The reflections expressed by the students in the questionnaires and interviews following the task showed that writing the stories contributed to the development of their mathematical creativity. The students referred to their puzzle stories as an expression of a creative process. They judged their product in terms of quality and creativity. The students' self-assessment indicated four stages of creativity (similar to those of Wallas [23]): preparation (defining the issue), incubation (putting the issue aside for a period of time), illumination (discovering new ideas that arise), and verification (instructing their peers). For example:

"I didn't come up with the story immediately. The first evening I considered different ideas, and I realized that if I hid only one element it would be too easy to find, and the story would be too short. Suddenly I thought that a cosine in a triangle is a "short portion" to a "long part", and I also decided that the story would take place in water. Once I had the idea, the rest came to me as I wrote the draft of the story. At first I didn't think much, but then I rewrote it three times because I wasn't satisfied and because of the "creative agony". And each time, new ideas came to me".

"For a few days I was unable to invent the puzzle story. Then I decided that my heroes (the trigonometric functions) would be live entities… Why did I choose the island of Bermuda? Because I wanted a place that exists and at the same time doesn't really exist. The course of events was constructed slowly in my imagination and suddenly I felt that a rather fascinating plot had formed. It took me about an hour to write the story, and then I rewrote it four times, and each time I added to it or corrected things or made changes".

The students wrote that the task made them discover their ability to create mathematically, and they felt a sense of pride and enjoyment from their creations.

"For me, the writing of a puzzle story was fascinating and very interesting, because it gave me an opportunity to invent things of my own and I could use my imagination infinitely. This time, instead of solving something, I could make up the problem by myself, and hide concepts in it, and to solve it and to show it to my classmates".

"I've never written anything like this story in my life, because I'm used to solving riddles, not making them up. I wrote the puzzle story in rhyme. I love writing in rhyme. I got the idea the moment they gave out the problem, and I waited for that "wonderful moment" when the idea takes hold. The hard part was integrating the mathematics imaginatively into the piece, but I really enjoyed making up the story".

"The idea itself of this assignment was new and amazing, because there's nothing like it in our textbook or anywhere else. It's like it's on the subject, but something new and fun".

"For me it was interesting to see how new heroes and new plots were created right under my fingertips. I felt that it was my own creation to be proud of."

The students emphasized that having to share their stories with their peers inspired them to create an understandable, imaginative story, because they wanted their peers to appreciate their efforts.

As to the responses of the mathematic teachers, they demonstrated that the teachers were unable to appreciate the full potential of such an approach. Comments included sentiments such as the following:

"It seems to me that such an activity is more suitable for higher-level students and shouldn't be attempted in every group".

"This activity isn't suitable for every class. It is more suitable for classes were most of the students are committed to the general purpose and not just to the individual purpose".

The teachers saw the process of writing a puzzle story mainly as a set of algorithmic phrases, without appreciating the emotional and experiential aspects (see Figure). Many of the teachers held reservations and pointed out that, in their opinion, the students cannot cope with the assignment: to invent an imaginative mathematical story.

Reflecting on the process of writing her puzzle story, one student wrote:

"I started to think in a new way… What did I learn from the activity? To develop my thinking, my mind and my ability to investigate, analyse and look at a mathematical object from different aspects. Now I'm more open, more confident, more successful…I understood that mathematics is not a collection of exercises waiting for me to solve, but as a whole, living world that has room for individual thinking, expression, and creativity".

The most typical reflection of the students is expressed by this quote:

"I now realize that there is a hidden creativity in each of us, and we need to know how to use it. I got the confidence to search for the creativity inside me and put it to use".

"This assignment gave me the freedom and the confidence to flow with my thoughts. That's what allowed me to be creative".

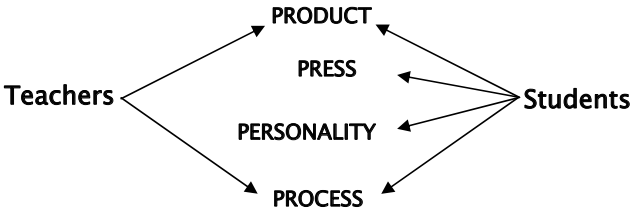

Figure – The effect of writing puzzle stories – developing creativity

The results show that, contrary to the teachers' assessments, students were able to express and develop their mathematical creativity. Therefore, it can be concluded that writing puzzle stories offers an effective tool to foster students' mathematical creativity.

Contribution of the study to the field of mathematical education

The present study strengthens the concept of using a didactic tool such as "writing puzzle stories" on various mathematical topics and presenting them in front of their peers. The results of the teachers' appraisal show that they may not appreciate the intrinsic advantages of such an approach, and thus will be unlikely to use it in their classes. However, making them aware of the positive reactions of the students may lead teachers to change their evaluation of the idea of the writing exercise and try it in their classes. Teachers do believe in the importance of fostering creativity in their students. In order that teachers can assess the contribution that a specific approach makes in cultivating student creativity, we suggest that they try the approach before making a decision. It is important for educators, mathematics teachers (and teachers in general) to develop writing skills in a mathematical context and implement activities that are based on unique and key attributes of written expression in their teaching.

During the lecture, a number of examples from the students' stories will be presented, alongside excerpts from their reflections on the experience of writing puzzle stories, as well as the teachers' views on the contribution of this approach to developing writing expressions in mathematics.

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