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METHODS FOR CREATIVITY STIMULATION OF STUDENTS IN MATH COURSES

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Abstract: *The purpose of the present paper is to highlight, using a comparative study, different methods for the stimulation of the creativity of students taking part in classes of Algebra, Geometry, Differential Equations, Special Mathematics. It is analyzed and exemplified the development of the students' creativity with: scientific contents taught at mentioned disciplines; the teaching and learning methods used at courses and seminars having the goal of teaching this content; the employed methods and evaluation tools; other approached strategies of differentiate instruction. The creativity of the teacher is also taken into consideration.*

Key words: *creativity, flexibility, fluidity, originality, perspicacity.*

1. Introduction

One of the manifestations of learning is the student's ability to come up with original solutions to new problems. This ability is one of the criteria by which the teacher may assess whether the student has grasped the taught mathematics (Sarrazy & Novotna, 2013).

All learners should have access to mathematics education that promotes their creativity which would consequently have an impact on their future success (Wessels, 2014). Another need is to offer innovative, constructivist and socioculturally driven learning programmes to target the development of students' critical thinking, reasoning and analytical skills whilst engaged in working and communicating mathematically to solve mathematics problems that are authentic, interesting and challenging (Afamasaga-Fuata'I & Sooaemalelagi, 2014).

The solving of the problems has an important role in the field of the mathematical activities for the cultivation and the education of creativity and inventiveness. To develop a creative thinking, the students must be encouraged in their activities; their effort should be appreciated and stimulated even when their answers are not correct. The development of the thinking and creativity potential is realized through activities that stimulate independently the intelligence and the originality (Dobritoiu, 2015).

The creativity is a multidimensional concept and it can be exhibited in various domains: arts, cognitive sciences, psychology, philosophy, etc. In accordance with the Encyclopedic Dictionary (1993) the creativity is defined as "complex features of the human personality, consisting in the capacity to realize something new, original" unlike the British

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Encyclopedia that defines it as being "the ability to find a new solution of a problem, a new method or a new device." Creativity typically refers to the act of producing new ideas, approaches, or actions. It is manifested in the production of creative outcomes (Leikin, Subotnik, Pitta-Pantazi, Singer, & Pelczer, 2012).

The creative thinking is the main component of the creativity, and the main factors of the creativity in mathematics are: the sensitivity toward the problems, the fluency and flexibility of thinking, the originality, the perspicacity and the ingenuity. The sensitivity toward the problems consists in the ability to think of combined problems, to reformulate a problem, which eventually was presented in vague terms, to transcribe in mathematical symbols an enunciation given in a natural language, to formulate more conclusions for a given problem, to analyze and systematize rules that are applied in demonstrations, to abstract and to generalize.

The fluency of thinking is the ability to show more methods of solving a given problem. When this thing is requested, the teacher should ask explicitly that students show, for a given problem, a certain number of solving methods, at least equal with the number of methods known to him. The flexibility of thinking is ability to progress easily from a situation to another. Practically, in the solving of math problems, the students' thinking should be determined, they must find rules and combinations of rules, they should formulate hypothesis that should be verified. The perspicacity and the spontaneity are other factors that consist in the capacity of students' thinking to give correct answers in a short time, to rapidly perform calculus operations and judgments, to observe, from a number of objects or mathematical phenomenon, their properties, those required by the problem respectively (Valcan, 2012, 2013). Each of these features has its significance; the most important remains the originality, which generates the value of the result of the creative work. The originality is expressed through the novelty of the answers or solutions, through the ingenuity of their formulation (Nicola, 1994).

Mathematical creativity ensures the growth of mathematics as a whole. However the source of this growth, the creativity of the mathematician is a relatively unexplored area in mathematics and mathematics education (Sriraman, 2009). The formation and the stimulation of the creative thinking of one person can never be considered to have reached the maximum limit of its possibilities and of life requirements. In university, the results of the work of each teacher, relate mainly to the students' mass, with each one's particularities.

In order to fix and apply the concepts taught, the teacher must direct students at an activity of permanent exploration and association of the concepts learned. A concept, definition or theorem is well mastered by students only when it can be exemplified properly or successfully applied in problem solving or in practice.

The training and the development of the capacity of creation on didactic activities from mathematic education involve the students' transformation from a passive receiver of knowledge in a direct participant in his own training by using of the active-participative methods and strategies (Valcan, 2013).

The present paper outlines solutions, processes to raise the quality of teaching in mathematics, through the choosing of those scientific contents which, taught to students, will help in increasing their creativity; through using those methods of teaching theory and of solving math problems that lead to students' engaging in resolutive activities so that they will develop their creativity by using those methods and assessment tools addressed for the same purpose. It is discussed also the teacher's creativity.

2. Cultivating Students' Creativity through Scientific Content Taught

Solving mathematical problems is one of the safest paths that lead to the development of creative thinking of students. This do not involve attending during classes at many types of problems or solving methods, but creating new learning situations, where the student will respond as appropriate, following an investigative approach.

Seminars problem solving through multiple paths is a way to develop logical thinking, its flexibility, cultivation and education of students' creativity.

By proposing to students this kind of problems that admit several solutions, we develop their thinking and imagination; we cultivate their creativity because they are forced to find different ways to solve each problem.

For example, at a seminar of differential geometry, it is required to solve through independent work the problem: Let be a curve in space with the equations:

$$\begin{cases} x^2 + z^2 - 4 = 0, \\ x^2 + y^2 - 4 = 0. \end{cases}.$$

Write the tangent equations and the equation of the normal plane in $M(\sqrt{3}, 1, 1)$ at the given curve. There were obtained two solutions, one elegant, original, and the second classical, corresponding to the solved model resolved before, on the blackboard.

Another way to develop the flexibility and originality of students' thought during linear algebra curses is the solving of the same type of problem, but in different vector spaces.

For example, after at the blackboard it is solved the next problem: show that in the vectorial space of the matrices $\left(\mathrm{M}_n(\mathrm{K}), +, \cdot, K\right)$ the subsets defined through

$$\mathrm{S} = \left\{A \in \mathrm{M}_n(\mathrm{K}) \mid {}^{\mathrm{T}}\mathrm{A} = A\right\} \text{ (symmetric matrices)},$$
$$\mathrm{A} = \left\{A \in \mathrm{M}_n(\mathrm{K}) \mid {}^{\mathrm{T}}\mathrm{A} = -A\right\} \text{ (anti-symmetric matrices)}$$

form vectorial sub-spaces and $\mathrm{M}_n(\mathrm{K}) = \mathrm{S} \oplus A$, then demonstrate as homework the same problem in the real vectorial space of the defined functions on a symmetric range with respect to the origin, considering as subsets of it: the set of odd functions and the set of even functions. Another example is the solving during the algebra seminar of some exercises with bases change in different vectorial spaces. The applying of the theorem for the base changing in the vectorial space of matrices, of the functions and in the vectorial arithmetical space, will lead to the development of the flexibility of students' thinking.

Also, complicating a problem solved during a seminar, through the introduction of new data or through the modifying of the question contributes largely to the development of the flexibility of students' thinking.

Their flexibility of thinking is cultivated when, at a seminar, with the goal of problem solving are used the knowledge from different branches of mathematics.

For example, at a seminar of differential geometry it is solved a problem, for which are necessary on one hand the knowledge of linear algebra (the solving of a nonlinear system of equations) and on the other hand, the knowledge of analytic geometry (free vectors, the generation of cylindrical surfaces). To exemplify the above ideas, we consider the following problem:

Determine the vectorial equation of a curve located at the intersection of surfaces:

$$\begin{cases} x^2 + y^2 + z^2 = a^2, \\ x^2 + y^2 = ax. \end{cases} \text{(Viviani's curve)}$$

and write the equations of its projection on the plane (xOy).

Another example is the problem from analytic geometry where are applied notions of synthetic geometry, vectorial geometry (flexibility) and some problems solved previously (fluidity) is: The chords *[AB]* and *[CD]* of a circle with the center *O* are intersected orthogonal in the point *P*. Prove the relation: $\vec{P}A + \vec{P}B + \vec{P}C + \vec{P}D = 2\vec{P}O$.

The development of flexibility of students' thinking is realized successfully at the courses and seminars of final revision for exams or partial exams where in the solving of problems one switches from a type of reasoning to another. The same advantage is obtained during the classes from the end of the semester or at the end of a branch of mathematics e.g. ALGAD when theoretical or practical issues are solved using the information from more courses, helping the student to achieve an overview of the notions learned in time. Further for the development of this factor of creativity we could build seminars with applications that contain interdisciplinary approaches on the learning content or we could choose some problems with practical content.

Many students take it as a drudgery what is taught in faculty, as a claim of the teacher, they cannot see mostly the practical side, useful for the subjects taught and they cannot make any connection between the encountered situations in life and what was taught at university. For example, a course of analytic geometry of quadrics could be concluded with a beamer presentation of numerous buildings, bridges, railways, for the realization of which were used the learned quadrics or conics. As homework each student will bring for the next course five similar examples, motivating them indirectly for learning of the course.

Flexibility of students' thinking is cultivated when at courses or seminars are taught or solved theoretical problems or applications, algorithmic or not, whose solving requires knowledge from several chapters of the same discipline. This way more lessons are linked by solving at the blackboard, by the student, of some exercises that use information from each of them, thus helping students to overview the whole studied theory. For example, at a seminar of linear algebra, with the subject: eigenvectors and eigenvalues, the students were required to solve the following problem, using knowledge from three chapters (vectorial spaces, linear transforms, eigenvectors and eigenvalues):

Let $T : \mathrm{R}^3 \to \mathrm{R}^3$ *the endomorphism through the matrix be:*

$$A = \begin{pmatrix} 1 & 0 & 1 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{pmatrix} \textit{ in } \mathrm{B} \textit{ - canonical base of } \mathrm{R}^3 .$$

a) Determine the endomorphism $T, KerT, ImT$ *and* $T(1,2,5)$.

b) Determine the eigenvalues and the eigenvectors of the endomorphism T.

c) Compute using Hamilton-Cayley theorem A^{-1} *and the value of the matrix polynomial* $P(A) = A^4 - 6A^3 + 11A^2 - 6A + I3$ *for the matrix* A.

d) Prove that the matrix A *is diagonalized. Find the diagonal matrix, and its* *corresponding base,* B'.

e) Determine the transition matrix S from the base B *at the base* B'

Solving at seminars the exercises that use theoretical concepts from several chapters builds in students a flexible thinking, forcing them to make a strong connection between the learned knowledge during a longer time frame.

A way to follow the development of the fluidity of students' thinking is to solve as many as possible exercises of the same type. For example, at a seminar of analytic geometry, regarding the free vectors without orthonormal reference, were written on blackboards five similar mixed products, asking the students to calculate them in a limited amount of time through independent work, after previously the first product was solved on the blackboard.

Another example at a seminar of Special Mathematics is the insertion of general exercises that contain different types of differential equations, those being required to be identified by the students. The exercises with parameters are usually difficult enough for students, advanced theoretical knowledge being necessary to identify the type of equation to know what solving method is better to employ.

Such an exercise, from the chapter of Differential equations of first degree is the following one:

Determine the general solution of the differential equation:

$$x^2 (y')^m - 4xy^{n-1} y' + 4y^n = 0, m \in \{0,1,2\}, n \in \{1,2\}.$$

The students will identify the following types of equations:

1. $m = 0, n = 1$ it is obtained the differential equation of Bernoulli type:

$$y' = \frac{x}{4} y + \frac{1}{x} y^2$$

2. $m = 0, n = 2$ it is obtained the differential equation of Bernoulli type:

$$y' = \frac{x}{4} y + \frac{1}{x} y^3$$

3. $m = 1, n = 1$ it is obtained the differential equation with separable variables:

$$y' = -\frac{4y}{x(x-4)}$$

4. $m = 1, n = 2$ it is obtained the homogeneous differential equation

$$y' = -\frac{4y^2}{x^- 4xy}$$

5. $m = 2, n = 1$ it is obtained the differential equation with parameters of Lagrange type

$$x^2 (y')^2 - 4xy' + 4y = 0$$

6. $m = 2, n = 2$ it is obtained the differential equation with separable variables:

$$x^2(y')^2 - 4xyy' + 4y^2 = 0 \Leftrightarrow (xy' - 2y)^2 = 0$$

Another exercise that stimulates the intellectual capacity of the students is found in the chapter of Complex functions and the fields theory:

Let be $Q(x,y) = (2a+2)x^3y - (6a^2-2)xy^3, a > 0$. *Find* $a \in \mathbb{R}$ *such as function* $f(z) = P(x,y) + iQ(x,y)$ *be holomorphic in* $\mathbb{C}$ *knowing that* $f(i) = 2$. *Compute the derivative of the complex function in the point* $z = i$ *and find the field lines* $P = K$ *and the equipotential lines* $Q = C$ *that pass through the point* $z_0 = i$.

Another way for increasing the fluidity of students' thinking is solving the "river" type problems - with as many as possible sob-points, for whose resolution is used only notions from the last taught course. Problems of the below type correspond to the mentioned requirements:

We consider the surface with parametrical equations:

$$(\Sigma): \begin{cases} x = u \cos v, \\ y = u \sin v, \\ z = u + v, \end{cases}$$

and is required:
a) the first fundamental form of the surface,
b) the angle of the coordinate curves,
c) the length of the bow curve $u = 1$ *between the curves* $v = 1$ *and* $v = 2$,
d) the area element of the surface, e) the angle formed by the curves: $u = v$ *and* $u = -3v$.

Or we consider the problem of analytical geometry of the conics:

We consider the conic

$$(\Gamma): 4xy + 3y^2 + 16x + 12y - 36 = 0,$$

the line $(d): x - y + 2 = 0$ *and the point* $A(0,2)$.

Are required: the center, the axes and the asymptotes; the tangent in A at conic and the parallel tangents with (d) at conic, the pole of the line (d) in report with the conic and the conjugate diameter of the direction for the (d).

Likewise, problems of differential geometry of crooked curves, where are required to be calculated all the elements of the Frenet's trihedron, the curvature and the torsion, or it is required to determine other analytic representations, are leading to the increasing of the fluidity of students' thinking.

For the development of the insight and the spontaneity of students' thinking, in seminars can be put many questions, which would cause the students to perform quick calculations and judgments. Some problems can be proposed for solving to students (not necessarily the types encountered before). For example, at differential geometry of curves in space, at the seminar regarding the curves in space, after problems relating to elliptical curves are resolved on the blackboard, we can give as independent work to students an exercise regarding the Titeica curves, exercise that by laborious calculations develops their perspicacity.

To develop students' thinking originality is indicated that the teacher aims, beside the algorithmic problems to be solved on each course or seminar, at the nonstandard problems, too. For example, at differential geometry of curves in space, after problems relating to crooked curves are resolved on the blackboard, we can give as independent work to students the following problem: *Prove that if the normal planes of a curve in space pass through a fixed, then the curve is spherical.*

Another way to stimulate students' thinking originality is solving problems with more requirements, with increasing difficulty, the last question of the problem addressing to creative students, and also having an enormous amount of knowledge in mathematics. For example, in linear algebra the originality of thinking is stimulated by the finding of a way to write a function uniquely as sum of an odd function and an even function, in the next problem: In the real vectorial space of the defined functions in a symmetric range in report with the origin, prove that the sets of even functions and the odd functions represent additional vectorial sub-spaces of the mentioned vectorial space. The cultivating of creativity of students' thinking is also fully realized through their preparation for the participation in scientific students' sessions or at professional students' contests or through the realization of their bachelor thesis.

3. The Cultivating of the Creativity of Students through Teaching and Learning used Methods

Effective learning requires involvement, engaging of the learners in the act of learning; the method playing here a fundamental role (Valcan, 2013). Besides the ways of cultivating the creativity presented above, it follows that we have not neglect the teaching and learning used methods, which also lead to its development. Among them a significant role in the cultivating of students' creativity was held by the active-participative and interactive methods. We refer to those methods such as: problem solving, discovery learning, heuristic conversation, teaching math game, Brainstorming, RAI method, Cube, Jigsaw, Starbursting, etc. For example at analytical geometry, at the seminar referring to the plane and the line in space, after some problems regarding this subject were solved on the blackboard, the teacher proposed to the students the following problem using the Brainstorming method:

Determine the equations of the line contained by the plane

$$(P): x + 3y - 2z - 2 = 0,$$

having the support on the line

$$(D): x = y = z$$

and which is parallel with the plane

$(Q): 4x - y - z - 3 = 0$.

After the expiration of the thinking time, were written on the blackboards the solutions proposed by the students, and after discussing them, were found five correct solutions of this problem, different totally or partially and even for the solutions that had the same way of solving, the mathematical language used in wording them was different.

Certainly, the solving of this problem with the help of this interactive method, by which the students were allowed to consult each other, brought a small contribution to the development of flexibility and originality of their thinking. Another example from linear algebra, the seminar referring to the reducing of quadratic forms to the canonical form, also for the development of flexibility of students' thinking was used the interactive Jigsaw method. The group was divided into three subgroups, each receiving the same quadratic form to reduce it at the canonical form through another method: the orthogonal transformation, Gauss or Jacobi. The students of each subgroup prepared at home the given exercise and in class they have consulted between them and they sent a representative of the group to explain and write on the blackboard. Besides the prize mentioned above, this method of learning also led to the increasing of students' interest towards this discipline.

Composing questions by students for their colleagues contribute greatly to the development of their thinking fluidity. For example, at a seminar of analytical geometry referring at sphere was used the interactive method RAI in the following way: on the blackboard were written four points of known Cartesian coordinates and it was required that each student asks a colleague a question that will use for solving only the four given points. The student whom the question was asked had to solve on the blackboard (if necessary, the colleague who asked the question, or other colleagues or teacher could intervene), and at the end he was invited to pose a question to another colleague. This method certainly contributed to the increase of the fluidity of students' thinking, because by the questions asked were solved easier or more complicated exercises from many chapters of analytical geometry: the free vectors, the plane and the line and quadrics.

From the specific methods of teaching and learning of mathematics, the generalization of some theoretical concepts, some problems or some categories of problem, will also lead to the cultivation of creativity of students' thinking. For example, at the seminar of analytical geometry of quadrics it could be required to students to reduce at canonical form the equation of quadrics without being taught in class the related theory, but just asking them to apply the acquired knowledge to solve a similar problem at conics.

4. Cultivating Students' Creativity through the Used Methods and Assessment Tools

Besides the traditional methods of assessment (oral or written exam), the use of alternative methods for continuous assessment can contribute successfully to the development of creativity students' thinking. The finding of some methods to evaluate students on the way, to write down their outstanding answers, will motivate them, as well as their satisfaction to have solved themselves difficult problems, or noticing an artifice to a demonstration of a theorem, finding an example, or a counter-example, or a practical application of a mathematical theory, or discovering an error. These motivations, in time will implicitly lead to the increasing of creativity of their thinking.

Continuous assessment is realized based on portfolio, in which students are asked to submit theoretical homework complementary to the theory taught at class, leaving under their responsibility the realization of the essay structure as well as the modality of its presentation (oral, poster, based on questions). Portfolio may contain also all problems left as homework during the entire semester. The grade given to student for the realized portfolio will be a percentage of the final grade at the evaluated discipline, which will motivate him to work with more interest throughout the semester. Documentation work, the effort of the student in searching the bibliography, in its understanding, in the design and implementation of the essay, would broaden its creativity thinking, the formation of the skills for future research.

Also in order to increase interest and, implicitly, the students' creativity in the context of continuous assessment we can use the role playing: "Teacher for 20 minutes", where the student is asked, sometime ahead, to present in front of his colleagues new problems, or even parts of theory. Their choosing and understanding will contribute to the development of student's logical thinking, to the increasing of his interest and creativity. Using this method over several years we found an improvement in the degree of satisfaction in class and in the interest in mathematics not only of the student "teacher" but also of the other colleagues. The obtained grade under these alternative methods of assessment represented a percentage of the final grade in the evaluated discipline.

The same benefits can be obtained if for the summative assessment of a learning unit are used interactive methods like Cube or Jigsaw. For example, to assess the unit: The plane and the line in space, at analytic geometry we can used the Jigsaw method, whose expert sheet is: Subtopic 1: The plane equations; Subtopic 2: Equations of lines; Subtopic 3: Relative positions for lines and planes, Subtopic 4: Angles and distances. Because the fact that the four subgroups in which was divided the group of students are not homogeneous, and on the sheet of each subtopic the exercises are given with increasing difficulty, containing some exercises that verify only the knowledge of theoretical concepts, and thinking exercises. Interaction between students during solving the exercises help to increase the interest in analytic geometry, and the percentage of the final grade assigned to this type of assessment helps to increase the student motivation. Collaboratively solving difficult problem helps to increase student creativity.

5. Cultivating Teacher's Creativity

Teachers must be able to design and implement learning environments that support the development of mathematical creativity (Shriki, 2010). Teachers must be fluent in lesson management, flexible in reacting to students' unexpected responses, and original in using surprising teaching ideas (Panaoura & Panaoura, 2014). Removing the admission exam to most universities generated situations in which at classes are met different types of students from art graduates to winners of Olympiads at Math. Presenting attractive courses in these conditions is a higher challenge than the scientific research (Caus, 2015).

An important role in cultivating students' creativity is played by the teacher's creativity, because we cannot talk about the development of students' creative thinking, without the teacher being creative, too. Didactic mastery of the teacher will lead to arousing the curiosity of students.

The attitude of the teacher during the class can enhance students' thinking fluidity. Thus, it should not suggest immediately the solving of a problem by using a specific method, but discuss with the group some ideas of solving that problem and analyze the advantages and disadvantages of each method, establishing the simplest way that lead to the result, highlighting the students that found the most interesting solutions.

Teacher's creativity arises from the approach of solving exercises. For example, in differential geometry course, after the second fundamental form of a surface was taught, students are required as homework to calculate the coefficients of the two fundamental forms for sphere without drawing their attention on their proportionality. In this way, some of the students have the chance to discover for themselves this property, developing their observation, forming them in this way for future research. Teacher's creativity also arises from the way he approaches differentiated training strategies in the seminars, strategies that will lead to the cultivation of creativity of students regardless of their level of preparation in math. Some problems that are difficult for some students are simple for others and for this reason, to give chances to all to become more creative, is indicated the approach of differentiated or individualized work. Teacher's creativity emerges from the way in which he knows in which courses to distill without sacrificing rigor and in which to detail the concepts taught, as from the way he finds in the area of preparation of students who he addresses, practical applications of the notions just taught. The teacher who quickly succeeds to demonstrate to the students the usefulness of mathematics in their field of study, motivates them for a systematic learning of mathematics, with seriousness and joy.

Creative, is that teacher who knows how to motivate students so they want to solve new math problems, to treat analyzing a new theory as a challenge.

One way to motivate students is how the teacher chooses exercises that combine the theory with practice. In this situation in the chapter of differential equations of second degree with variable coefficients it is required the form of differential equation and of the general solution for the equation:

$$y'' - \frac{2}{x} y' + a_2(x) y = 0$$

where

$$y_2 = y_1^2, y(1) = 1, y_1'(1) = 1.$$

For this type of exercise the students should use the Liouville theorem to find the coefficient $a_2(x)$ based on the Wronski determinant.

Is also related to the creativity of a teacher the way he knows how to avoid or not some demonstrations of the taught theorems in math courses. In order for some elegant and beautiful demonstrations not be considered useless by the students, the teacher should use his entire teaching skills in approaching them as problems and not as a theory in order to increase the students' interest and their creativity.

6. Conclusions

If the teacher is concerned about how to proceed so that all students, regardless of their level of preparation in math, acquire passion for it, then surely it will come to cultivation their creativity. We noted that the interest arises when we find the most productive teaching strategies, for students to participate consciously and actively at the discovery of solutions so that to achieve the purpose and objectives in each course or seminar.

Math passion is the engine of the activity. An important role of the teacher is to guide the work of the learners so that they feel the charm, specific attraction to this activity; not only to help him to understand, but to help him feel (Rusu, 1965).

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