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S. Malkin's Algorithm of Inventive Problem Solving as an Instrument to Mastering Technical Systems in Supplementary Mathematical Education of School Students

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The relevance of the research is determined by the complexity that secondary school students experience when they master the regularities of development and existence of technical systems as an important link in the creation of the structured knowledge system, abilities and the correct world perception, and training to search task solutions arising in technical systems. In this regard, the goal of the conducted research is to create approaches in teaching practices that will provide learner involvement in technical systems research and, consequently, will promote conditions for the solution of mathematical inventive problems. The main approach to the training of vocational technical creativity is G.S. Altshuller's (1956) theory of inventive problem solving (TRIZ) that takes a specific place in Russia. Labor-intensiveness and complexity of application of TRIZ in the educational process determined the creation of simplified algorithms of inventive problem solving. . Malkin's (2012) algorithm of inventive problem solving "Generator of ideas" was selected, which is based on a part of algorithms of inventive problem solving (ARIZ). The pilot study conducted since 2010 has helped to develop an approach to the organization of learners' activities when working with the algorithm of inventive problem solving. Due to the approach that school students have formulated and solved tasks arising in technical systems, some solutions have been patented and certified by the Federal Service for Intellectual Property. The materials of this paper may be useful for teachers of general and supplementary mathematical education of school students,

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who are engaged in technical creativity, and for all those who study new opportunities of creative search in the sphere of mathematical apparatus of technical systems.

Keywords: algorithm of inventive problem solving, creative pedagogics, open type tasks, technical systems, algorithms of new ideas designing; supplementary mathematical education of school students

INTRODUCTION

Relevance of the study

According to A.M. Novikov (2006), for a long time the object of didactic and methodological research was the process of knowledge, abilities, and skills development and "it became the biggest error of all national pedagogics. And now we are speaking about the need of pedagogics aimed at personality development that significantly changes not only the focus and the content of pedagogical researches, but all educational practice as well" (Novikov, 2006). Therefore, the enormous growth of the number of innovations in pedagogics in the XX and XXI centuries is justified by the search of effective pedagogical technologies, forms, methods and techniques of personality development.

One of the current trends in science is the integration of various disciplines. So, basing on the regularities of development and existence of technical systems and pedagogics, the integration of mathematical knowledge, technical, and scientific creativity allows for training to solve search, creative and inventive tasks (Gin, 2005; Zinovkina, Gareev Gorev, & Utemov, 2013). The developed thinking of personality's capable of solving creative problems and the design of new ideas for their solution has the greatest value for an advanced state; it is the key to the success of scientific and technical creativity and necessary for the search for new solutions for production tasks. However, the inertia of thinking often suppresses the imagination of highly qualified experts whose scientific and technical knowledge and experience is vast; one cannot make scientific discoveries and inventions without imagination.

The development of creative technical and mathematical thinking is possible by way of a bilateral approach: first, studying creative experience of the past, and the best samples of its logic, provide engineers and scientists with inventive tasks and methods of their solution; secondly, the development of creative thinking in order to train future experts to design new solutions of creative tasks. Experts in the field of inventive problems solving realize the first approach and the results of the second approach have resulted in the accumulation of many disparate and effective methods, and have yet to be systematized (Mikhaylov, Gorev, & Utemov, 2014).

To develop creative thinking efficiently, there is an urgent need for approaches to teaching practice that will provide learners' involvement in technical systems research and, consequently, will promote conditions for learners' mathematical inventive problem solving.

At the present stage of scientific creativity, there are more than 30 techniques (principles, theories) of scientific creativity. S. Malkin's (2012) simplified algorithm of inventive problem solving may become one of the mechanisms that can adequately satisfy the needs of secondary school students mastering the regularities of development and existence as an important unit of structured system for the creation of knowledge and abilities, and for training to search for solutions arising in task-based technical systems.

The algorithm also requires such pedagogical conditions, which would not simply satisfy the purposes of student achievement at a certain level of mathematical inventive problem solving and which would lead them to good results; the assessment of which is carried out by external experts.

MATERIALS AND METHODS

Methods of the study

In the course of the research the following methods were applied: the analysis of psychological-pedagogical and methodological literature, literature on scientific creativity and methodology of mathematics; the analysis of various algorithms of inventive problem solving; the analysis of educational activity products; the method of mental experiment; forecasting; systematization and generalization of facts and concepts; modeling; design; the method of expert evaluations; the analysis of educational activity results; studying and synthesis of the experience of mathematical inventive problem solving; diagnostic techniques; and, pedagogical experiment.

Experimental base of the study

The experimental work was carried out by testing of S. Malkin’s (2012) algorithm as an instrument for the development of teenage student’ mastering of technical systems in supplementary mathematical education and their mathematical inventive problem solving:

1. Participation of school students (grades 7-11) in the intensive Olympiad of scientific creativity “Breakthrough” (2010 - 935 learners, 2011 - 1210 learners, 2012 - 1105 learners, 2013 - 1189 learners, 2014 - 1278 learners, 2015 - 1731 learners);
2. Participation of school students (grades 7-11) in the intensive school of scientific creativity “Breakthrough: science, creativity, success”, based in a country camp (2010 - 98 learners, 2011 - 102 learners, 2012 - 130 learners, 2013 - 142 learners, 2014 - 196 learners);
3. Participation of school students (grades 5-9) studying at Lyceum No. 21 (Kirov, Russia) in their summer educational camp “Mathematics. Creativity. Intelligence” (2010 - 78 learners, 2011 - 121 learners, 2012 - 114 learners, 2013 - 135 learners, 2014 - 141 learners; 2015 - 172 learners);

The experimental work involved pupils of all age groups from secondary schools across all regions of the Russian Federation and some neighboring countries.

Stages of the study

The research was conducted in three stages:

1. The “preparatory” stage. The analysis of the current state of the investigated problem in pedagogical theory and practice, and development of the research methodology.
2. The “main” stage. Development and implementation of S. Malkin’s (2012) algorithm of inventive problems solving; the systematic analysis of large samples of experimental data; verification of the effectiveness of the methodology by means of state registration of copyrights in the Federal service of intellectual property (learners had the copyrights to their databases presented as a result of mathematical inventive problem solving).
3. The “final” stage. Systematization, interpretation and synthesis of the research results; refinement of theoretical conclusions; processing and registration of the obtained results.

RESULTS

The theory of inventive problem solving as the basis of technical systems mastering in the supplementary mathematical education of school students

The theory of inventive problem solving (TRIZ) takes a specific place in the professional creativity training in the Russian Federation. The engineer-inventor and science fiction writer G.S. Altshuller was actively engaged in its development and distribution (Altshuller, 1979). TRIZ is a scientific and practical direction in the development and application of effective methods used for inventive problem solving, and the generation of new ideas and solutions in science, engineering and other areas of human activity. The development of TRIZ started in 1946 and it still continues today. The fundamental theoretical provision of TRIZ is the statement that technical systems are developed according to objective, cognizable laws, which come to light by studying a large amount of scientific and technical information (including patents) and engineering history (Altshuller & Zlotin, 1989). These laws are used to improve the existing systems and to develop new ones. Unlike the majority of methods applied for inventive problem solving, the techniques based on TRIZ are now widely used in the world in the XXI century (Mikhailov, 2012; Mikhailov & Mikhailov, 2013; Zinovkina et al., 2013; Utemov et al., 2013). Currently, about 20 algorithms of different degrees of complexity, based on the application of TRIZ elements used, the conscious aspiration to an ideal final result, and the identification and resolution of conflicts (see Table 1) (Mikhailov, 1992).

It is worth noting that techniques 1-4 are for beginners' mastering TRIZ; techniques 5-7 and 10-14 are for TRIZ experts who have good knowledge of TRIZ; techniques 8, 9 and 15-18 are for complex groups of solvers including TRIZ experts of the highest qualification, having experience in the solution of many tasks.

Altshuller selected forty thousand inventions out of more than one million based on "technical contradictions solution". He singled out 40 standard techniques applied by engineers in order to solve contradictions. He specified the laws that set tendencies in technology development and created the algorithm of inventive problem solving (ARIZ). The algorithm sets the sequence of TRIZ tools actions for a task solver. So, for the first time, there was a system of solutions production and their evaluation in the intellectual sphere, based on system development laws. It is similar to material

Table 1. Inventive problem solving techniques (methods of complexity and task types)

No.	Technique name	Steps	Task type
1	The system of 40 techniques to solve technical contradictions (Altshuller, 1972)	5+	Simple
2	Software "Generation of ideas" (Malkin, 2012)	6+	Simple
3	Five / ten-steps (Podkatilin, 2009)	5–10	Simple
4	AlgMCM (Mikhailov, 1992)	15–20	Simple
5	76 standards of ITS (Altshuller, 1984)	1–10	Simple
6	Algorithm of invention AITS-85v (Bush, 1985)	>100	Difficult
7	Algorithm of engineering problems solving (Ivanov, 2009)	>32	Simple-difficult
8	Algorithm of G3-ID (Malkin, 2012)	>>100	Very difficult
9	Algorithm Ideation TITS (Zlotin & Zusman, 2006)	>>100	Very difficult
10	Program "Inventing Machine IM-1.5" (Tsurikov, 1989)	5–100	Simple-difficult
11	Program "Technooptimaizer TOP-2.5" (Tsurikov, 1997)	5–100	Simple-difficult
12	Program of engineer's intellectual support GoldFire-3.5 (Tsurikov, Voronov, & Pronin, 2007)	5–100	Simple-difficult
13	Algorithm of discoveries DM-2.4 (Mitrofanov, 2004)	>7	Scientific
14	Algorithms for tasks of information technology (Rubin, 2012)	5–100	Simple-difficult
15	AITS-2010 (Petrov, 2010)	>100	Simple-difficult
16	Diversionary analysis (Zlotin & Zusman, 1991)	5–100	Simple-difficult

production systems. The principles and technologies verified in the sphere of material production were brought into use in solution production. ARIZ includes 9 large parts, 40 steps, 44 notes and 11 rules. It is a grand tool which has been repeatedly tested in order to solve technical tasks of any complexity. Traditional ARIZ-85 is intended for engineers who know TRIZ and the laws of natural-science and mathematical disciplines. Many scientists develop ARIZ applications for the solution of nontechnical problem situations (in pedagogics, business, human relationships, etc.). The mastering of ARIZ may be considered as the highest step of TRIZ application in practice. On the other hand, profound mastering of ARIZ and TRIZ demands a lot of training (it is comparable with the transition from arithmetic, elementary mathematics to the mastering of the highest mathematics). In school practice, ARIZ and TRIZ are studied in supplementary education due to their complexity.

At the Azerbaijan Public Institute of Inventive Creativity, future inventors have two year courses with a 500-hour program. Nowadays, experts are not yet ready to invest so much time on the studying and mastering of TRIZ and ARIZ. Besides, TRIZ experts, who have been applying it for 10-40 years, divide inventive problems into those that are difficult or simple ones. For example, sometimes it is sufficient to work out a correct and accurate final result to search for an acceptable solution idea, whereas other problems require the formulation of a technical contradiction or even to reveal its reason – physical contradiction. Cases that are more complicated demand identifying tendencies of the object development, both real, and following general regularities of systems development, and the deep consideration of all resources of the object and its environment.

The simplified algorithms of inventive problem solving were developed for the solution of simple problems, including mathematical ones. They include 5-20 steps; the experience of their application shows that they can be applied for the solution of simple inventive problems. They make it possible to increase the creative level of engineers and workers, to show that even elements of TRIZ may improve systems and promote the profound mastering of ARIZ. About 20 techniques of inventive problem solving of different complexity (including computer programs of intellectual support) for different types of problems are listed above. S. Malkin's group came to the same conclusion after 20 years of training beginners (since 1985) in the USSR and the USA (Malkin, 2012).

The simplified algorithm of inventive problem solving and the technique of work

S. Malkin's algorithm "Generator of Ideas" (Malkin, 2012) includes the definition of the solution purpose and ideal final result (IFR), the selection of three search directions, search of solution ideas by means of 30 techniques (one or several, or their combinations), drawing up both 2–5 concepts of the solution and the new task (subtask) to continue the solution search. To expand the sphere of application, to solve not only engineering and mathematical problems, but also business and human relationships issues, Altshuller's system of 40 inventive techniques was reworked and a system of 30 abstract inventive techniques was created. It is possible to present the flowchart of problem solving according to S. Malkin's algorithm in the form of 6 steps (See Figure 1) (Gorev & Utemov, 2014).

At Stage Zero, Problem Description, the task is formulated in the way it is understood by the user, the expert. Next, the solution goal is set (Stage One: Goal Setting) (i.e. what should be obtained in economy, engineering or human relationships; description of the present level and the way it should be; what is impossible to change? How to measure the success? What is the minimum level? Why is it necessary? What impedes it? etc.). At Stage Two (IFR Statement), the IFR is

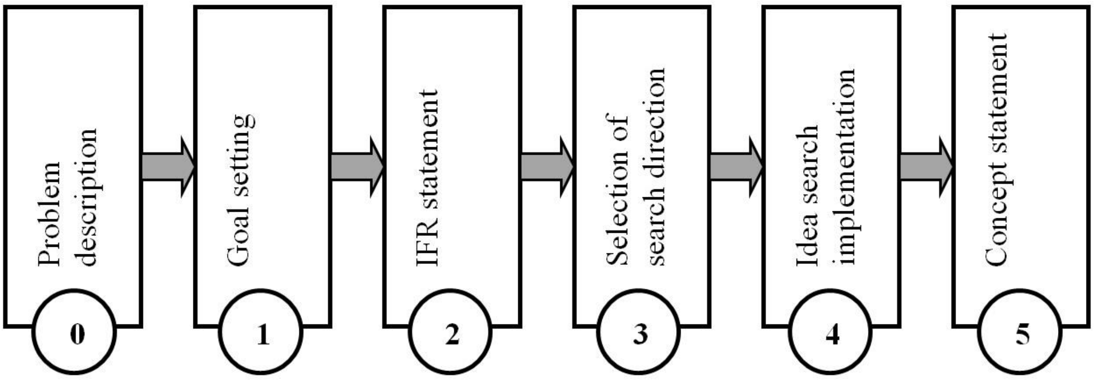

Figure 1. Flowchart of S. Malkin's algorithm

Table 2. Abstract inventive techniques of S. Malkin's algorithm

	Groups of methods		
	Time	**Space**	**Space**
Methods	Energy	Prior to	Different measure
	Substances	After	Asymmetry
	Information	Pause	Matryoshka
	Derivative	Accelerate	Removal
	Concentration	Slow down	Localization
	Structure	**Conditions and Parameters**	
	Exception	Partially	Vaccination
	Crushing	Excessively	Isolation
	Association	Agreed	Resistance
	Intermediary	Dynamically	Expendability
	Copy	Managed	Inversion

formulated: the goal is achieved by itself (…) under conditions (…), where (…) and when (…). Then comes Stage Three, the Selection of the Search Direction, where three types of questions concerning the change of technical system function takes place: "What should be increased, improved? What should be eliminated, reduced? What contradiction should be resolved: the change of function/substance/parameter (…) improves the useful function (…), but inadmissibly worsens (…)".

At Stage Four of the algorithm (Idea Search Implementation), the search for the solution idea is carried out. The following list of 30 complementary abstract inventive techniques is proposed (see Table 2).

It is recommended to begin the search for the idea with the first group, "Resources", using each technique (or a combination of) to aid finding a new idea through the transformation of an element or function, action, interaction, process, environment or neighboring system. Could the application of the technique help to create a new resource or change the result? Further, it is necessary to consider all other techniques to search opportunities to eliminate the drawback, to settle the contradiction due to the resource identification. The consideration of techniques should take into account 300 examples of their applications for different types of problems in the database: engineering, mathematical, economic or human relationships as models of inventive technique application.

The algorithm is accomplished with the formulation of summary concepts of decisions: to estimate the usefulness or harmfulness of ideas found, the concept combined from complementary solution ideas, to reveal possible new problems and if necessary, to repeat the search for ideas, and to develop the plan of the obtained concept introduction.

The example of a mathematical problem solved by means of the proposed technique

Below we give an example of problem solving: the measurement of a river width.

Task. A mushroom picker was out gathering mushrooms and happened to come across a river. Offer him two or three ways to measure the river width only by means of makeshifts (provisional). But, the measurements have to be as exact as possible.

Decision purpose: to measure the river width.

Why it is necessary: it will give the opportunity for the mushroom picker to estimate the reality of any potential crossing, or a way to search more river bottlenecks in search of a ford.

What disturbs him: lack of possibility of direct measurement?

IFR: the river width is measured without direct application of any measuring instruments, under static conditions, and only by means of makeshifts.

Direction choice: to eliminate action "impossibility of direct measurement".

The technique "Structure" by means of "Intermediary" and "Exception" give us the ideas: 1) to tie some thread around a stone and throw it across the river, then to learn thread length by means of length of step; 2) to take a fishing rod and to cast it as far as possible in order to measure the river.

The technique "Space" by means of "Another dimension" gives us the idea: to search the width on the map or on the cell phone.

The technique "Structure" by means of "Intermediary" and "Copy" give us the ideas: 1) to take sticks, connect them together, measure the river width, and then, to mark lengths on the sticks and thereby to calculate the length; 2) to take a selfie with a tree, then measure the tree height, and then to throw it across the river; 3) to break a thin tree, measure its length, and then to measure river width by means of this tree.

The general concept of the decision: to achieve the purpose of the decision, it is mentioned to note object A on the opposite bank. Standing opposite it, turn 90 degrees and proceed *n* steps along the bank, and place a stick. Then, proceeding in the same direction, we go *n* steps and place a second stick. Then we turn 90 degrees and walk away from the bank until we appear on a straight line with the chosen object and the first stick. *M* is the required point. The length from the second stick to M will be the width of the river (see Figure 2).

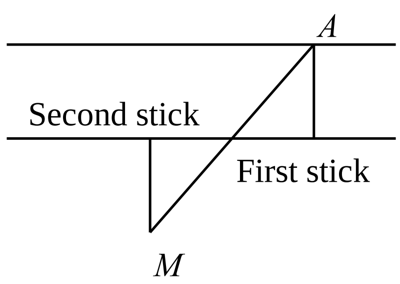

Figure 2. The scheme of solving the problem about crossing the river

The description of pedagogical effect of the proposed technique in supplementary mathematical education

The simplified algorithm based on the minimum number (3-5) of TRIZ concepts in the context of the task (IFR, selection of the direction to eliminate drawbacks of the system or contradiction resolution, application of 30 abstract techniques of changes in the system to search for prompts of resources and use of mathematics and natural sciences knowledge) allows for the solving of inventive problems, forming the correct search thinking and developing the personality at the same time.

The simplified algorithm is focused on the extension of application spheres both in engineering and mathematical systems, and in solving business and human relationships issues. When the problem is more complicated, it allows for multifaceted use by searching for solution ideas of intermediate or additional tasks. In systems and problems that are more complex, the application of more complicated TRIZ and ARIZ tools and the involvement of versatile expert groups from different areas of science and engineering may be required.

DISCUSSIONS

At the present stage, there are more than 30 techniques (principles, theories) of scientific creativity development. The following are only some of the best known: the algorithm of inventive problem solving (Altshuller & Shapiro, 1956); the method of focused thinking (Sereda, 1961); the method of sevenfold search (Bush, 1974); the method of the heuristic techniques library (Polovinkin, 1976); the method of garlands of accidents and associations (Bush, 1985); the method of decimal matrixes of search (Povileyko, 1972); the method of organizing concepts (Hansen, 1966); the method of conference of ideas (Gilde & Starke, 1973); the method of systematic heuristics (Koch & Müller, 1974); the method of morphological box (Zwicky, 1969); the synectic method (Gordon, 1961); the method of control questions (Polya, 1961); and the brainstorming method (Osborn, 1953) among others.

Based on these theories, the techniques for designing new ideas while solving creative and technical tasks were created: the system of 40 techniques to resolve technical contradictions (Altshuller, 1972); software "Generation of ideas" (Malkin, 2012); Five/Ten-steps procedure (Podkatilin, 2009); 76 standards of RIZ (Altshuller, 1984); algorithm of engineering problems solution (Ivanov, 2009); algorithm Ideation TRIZ (Zlotin & Zusman, 2006); Inventing IM-1.5 program (Tsurikov, 1989); Tekhnooptimaizer TOP-2.5 program (Tsurikov, 1997); algorithm of discovery MD 2.4 (Mitrofanov, 2004) and others. Some of them, such as the algorithm "Generation of ideas" by S. Malkin (2012), may be successfully implemented in supplementary mathematical education of school students.

CONCLUSION

The pilot study, which has been ongoing since 2010 (using the S. Malkin's 2012 flowchart "Generator of Ideas", based on the theory of inventive problem solving), proved that the new approach to the organization of learners' activities to work with the algorithm of inventive problem solving was formed in supplementary mathematical education. Based on that approach, school students formulated and solved tasks arising in technical systems. Some solutions have been patented and certified by the Federal Service for Intellectual Property (e.g. certificates of state registration: BD No. 2013621432, dated 4.11.2013; BD No. 2013621449, dated 20.11.2013; BD No. 2013621438, dated 18.11.2013; and BD No. 2013621458, dated 25.11.2013, etc.). This testifies to the efficiency of the proposed technique of learners' work with the algorithm of inventive problem solving while studying regularities of development and existence of technical systems. This allows not only to develop high school students' creative technical and mathematical thinking, but also to create conditions for their further vocational scientific and technical activity, as required by the national economy.

The first steps were to create a school students training technique in order to work with the algorithm of inventive problem solving. The creation of the technique required to carry out the analysis of the existing techniques and technologies of obtaining new results in scientific and technical creativity. The analysis of this registry allowed for the formulation of recommendations for using Malkin's 2012 algorithm; its application gives the possibility to define the guidelines to a new discovery. The main task of the developed technique is the creation of predictive hypotheses, the experimental or theoretical verification of which may open the way to a discovery. Training of school students in this direction is the major task and one of the main guidelines of further research. Thus, the above technique should be definitely supplemented with methods to overcome psychological inertia. All this in total will promote the cognitive potential of researcher(s); will reduce time and costs of resources to make discoveries.

RECOMMENDATIONS

The materials of the paper may be useful for teachers of general and supplementary mathematical education of school students, those engaged in technical creativity, and for the assessment and further correction of learners' individual educational trajectories at the level of mastering scientific creativity.

The obtained results make it possible to single out a number of scientific issues and perspective directions that require further consideration: deepening and extension of some provisions stated in the paper and connected with the accumulation of psychological-pedagogic potential of algorithm of inventive problem solving in training mathematics; creation of scientific methodological support to apply the algorithm of inventive problem solving for supplementary mathematical education, developing high school students creative and technical thinking.

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