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ScienceDirect

Procedia Engineering 131 (2015) 711 – 720

Procedia Engineering

www.elsevier.com/locate/procedia

World Conference: TRIZ FUTURE, TF 2011-2014

OTSM-TRIZ Games: Enhancing Creativity of Engineering Students

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Abstract

Enhancing the ability of solving non-typical problems especially in engineers is an important issue for any R&D&I department. Consequently, some initiatives have been launched recently to foster new educational approaches and methods.
The system of OTSM-TRIZ games, developed by Tatiana Sidorchuk and Nikolai Khomenko, proposes a series of games for 3-8 years old kids to lead them thinking according to the OTSM-TRIZ postulates and models, without learning TRIZ tools directly. This paper postulates that these games can be efficiently used also for stimulating creativity of engineering students, with interesting insights on their behaviors when challenged through unexpected situations and tasks. Some of these games have been tested both with 12 years old Iranian kids and with MS students in Mechanical Engineering of Politecnico di Milano. The research shows improvement in creativity indexes for MS engineering students under the condition of the proposed experiment.
First, in the paper a thorough description of the classical OTSM-TRIZ games is provided. Then, after presenting the experimental activities run with kids and university students, their behavior is discussed so as to extract some general guidelines about the implementation of these educational practices in different contexts, as well as some preliminary assessment on the resulting outcomes.

Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC

Keywords: students creativity, OTSM-TRIZ Games, imagination abilities, thinking abilities;

1. Introduction

Problem solving, especially related to non-typical problems, is one of the necessary skills and abilities for engineers in R&D&I. The literature shows that solving inventive problems and predicting future products and

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Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC
doi:10.1016/j.proeng.2015.12.360

technologies diminishes time to market in companies [1]. As well, the research has shown that TRIZ and OTSM-TRIZ methodologies are efficient methodologies for solving non-typical problems and they can be exploited efficiently for predicting future products [2]. According to the literature, non-typical problems are defined as those problems that cannot be solved just by means of known rules and procedures; their solution requires the support of knowledge provided by the problem solver and the available informational support. When the problem is non-typical, even if some solution path is provided, the solution cannot be entrusted just to the method itself. This problem solving process requires elements of knowledge that reside outside the boundaries of the method and its language [3]. Moreover, inventive problems are characterized by at least two conflicting requirements that cannot be satisfied by choosing the optimized values for system parameters, which means that it's necessary to solve a contradiction in order to produce a useful, novel and unobvious answer [3].

Indeed, promoting the capability for engineers of solving non-typical problems is a relevant research field under investigation [4]. This paper intends to study the effect of OTSM-TRIZ games on improving some necessary abilities of engineers in solving non-typical problems. Despite the proclaimed interest for this kind of abilities by engineers and R&D members, the society does not show a significant tendency to lead them to acquire such abilities. The introduction of TRIZ into academic curricula as a compulsory course for engineers is still very limited. On the other hand, engineers show marginal interest for most of the elective courses. Nevertheless, some companies show that they change the entrance mandatory skills of their employees and they are covering creativity and problem solving as part of their annual promoting courses.

The system of OTSM-TRIZ games is a series of games developed under the guidance of Nikolai Khomenko and tested in Russia with kids 3-8 years old in 12 pilot areas for 16 years, from 1990 till 2006 [5]. This system relies on TRIZ and OTSM-TRIZ applied theories on solving non-typical problems, and these games successfully increase the abilities of kids in problem definition and problem solving, especially for defining and solving creative problems [5].

The promising outcomes of OTSM-TRIZ games in increasing kids' problem solving capabilities on the one hand, and the limited acceptance by engineering students of lengthy elective courses such as those required to proficiently master TRIZ tools on the other hand, suggest the possibility of using OTSM-TRIZ games as catalysts also in engineering schools.

In this paper, first the System of OTSM-TRIZ games and the planned abilities are presented; then, the effects of some of them on two different ages, 12 years old and master engineering students around 24 is studied. Finally, some guidelines for such activity and further researches in this field are discussed.

2. System of OTSM-TRIZ Games

2.1. Position of system of OTSM-TRIZ games

System of OTSM-TRIZ games was proposed as a part of a new generation of education system. Modern system of education is subject centered. While learning through "constructivism learning theory" and "transformative learning theory" has being considered the ability of students of acting right in every specific situation, based on received information, knowledge and skills [6, 7], the modern system has shown low efficiency [8]. Students, as the target of this system, are able to remember and apply the information in reference conditions, but only some of them can really use what they learned in real situations [8]. Doing experiments, solving problems, raising questions are some approaches that teachers use as their style of teaching to increase comprehension of subjects, and, as a whole, as partial solutions for increasing the efficiency of subject centered education. This system prepares students for past and today problems based on ready to use solutions for typical problems [5]. Besides, with the aim of preparing students for future problems as the expected result of the learning process, problem centered education seems to be the core of a new generation of education system. Despite all efforts of human in forecasting and predicting future, nobody can be sure about the nature of future problems. Therefore, future problems can be assimilated to non-typical problems. TRIZ and OTSM-TRIZ are theories for solving non-typical problems and the system of OTSM-TRIZ games is a problem centered system for promoting the abilities of kids in working with creative activities [5].

2.2. The features of TRIZ and OTSM-TRIZ for System of OTSM-TRIZ Games

TRIZ and OTSM-TRIZ are applied scientific theories. Every applied scientific theory explains the basic fundamentals of a working system that helps human to obtain desirable results with less trial and error. Some key elements of their body of knowledge, such as "assumptions", "models" and "instruments" are summarized hereafter based on the interpretations by Nikolai Khomenko [9].

Table 1. Components of Classical TRIZ and OTSM-TRIZ theories

	Classical TRIZ	OTSM-TRIZ
Assumptions	Objective Laws of Engineering system evolution do exist and could be used for problem solving; Contradiction* shows the root of problem. It should be disclosed and resolved; Specific Situation* provides resources that should be used to solve a problem.	Axioms of Models are used during thinking process. Problem arise when typical, traditional models could not be used and should be changed: Group 1: Axioms on Thinking Process ((1) Axiom of Impossibility; (2) Axiom of root of problems; (3) Axiom of reflection; (4) Axiom of process.); Group 2: Axioms on world Vision ((1) Axiom of Unity; (2) Axiom of Disunity; (3) Axiom of Connectedness.).
Models	System Operator* model of system thinking; Classical TRIZ Models of Problem Solving Process dedicated to develop and organize other problem solving instruments into whole system efficient for solving problem and develop thinking skills further: -Tongs Model; -Hill Model*; -Funnel Model; -Parallel Model.	ENV Fractal Model* is a general and formalized language to describe problems and solutions, real and imaginary facts and objects OTSM Fractal Model of Problem Solving Process dedicated to manage a problem solving process and harmonize the application of various instruments even out of Classical TRIZ.
Instruments	For Typical Problems: -Standards; -Pointers of Effects; -Mechanism of Convergence; -… For Non-Typical Problems: -ARIZ*.	For Small Problem situation (dozen of sub-problems): -New Problem Technology; -Typical Solution Technology; -Contradiction Technology; -Problem flow Technology. For Complex Problems (hundreds sub-problems): -Problem Flow Network Approach.

Although learning TRIZ and OTSM-TRIZ is considered as the acquisition of the ability of using their instruments, for many users its ultimate goal is the improvement of people thinking processes. Those who assimilate the assumptions and models of a theory can use the instruments more effectively and even can develop new instruments for special requirements, or new specific situations [10]. Therefore, the assumptions and models of these theories were considered as the target of System of OTSM-TRIZ Games by its authors [5], [11]. Also as OTSM-TRIZ is more general than TRIZ in domain and every interdisciplinary problem can be solved by it, the games were focused on this theory more. The stars in table 1 show the components of these theories that are fully or partially covered by the games [5].

2.3. Structure of System of OTSM-TRIZ Games

In the Context of OTSM, a problem solving process is considered as a transformation of an initial undesired situation into a satisfactory solution by disclosing and resolving contradictions [9]. The following overlapping factors were considered as OTSM-TRIZ main educational factors [12]:

- Developing sensors (Visual, Acoustics, Smell, Kinesthetic, and Taste) through an ENV model description;
- Developing creative imagination by mental manipulation of the properties of an element;
- Knowledge acquisition through identification of interconnections between diverse properties;
- Developing ability to conduct mental experiments by manipulating properties and forecasting the consequences of such manipulation according to the available knowledge;
- Developing analytical skills by analysis a problem situation and generating partial solutions;
- Developing holistic synthesis skills by gathering partial solutions and generating integrated solution;
- Developing skills to assess obtained solutions and forecast consequences of their implementation by using all OTSM-TRIZ instruments as an integrated system;
- Application of all the above issues for the generation of new knowledge by solving real life problematic situations.

In order to enhance these abilities, the System of OTSM-TRIZ Games was structured in three parts: “Imagination”, “Thinking” and “Speech”. It turn, the games focus on the improvement of mental abilities of kids in imagination and thinking, and on the development of appropriate presentation skills to talk about the results of the thinking process. Each part is mostly focused on special mental skills and abilities; besides, there are some common skills, such as expressing mental processing, reflection, tolerance and team working, appearing in all the three parts. Table 2 proposes a summary of OTSM-TRIZ games in the vision of the authors’ based on the book “Thoughtivity for Kids” [13].

Table 2. System of OTSM-TRIZ Games

Mental Process	Sub-Process	Games	Planned Abilities
Thinking	Dichotomy Thinking	Numerical Yes-No Game Spatial Yes-No Game Classification Yes-No Game Situational Yes-No Game Literary Yes-No Game	1. Ability of narrowing, quickly and accurately, the field of search for necessary information to define the model of the situation; 2. Ability of Knowledge Acquisition based on classification; 3. Ability of finding cause & effects relationships and conducting Mental Experiments; 4. Ability of defining the abstract model of objects and situations;
	Systematic Thinking	Life cycle thinking (birth, growth, exhaustion) Prognosis/ historical thinking (Concept, development, combining, removing)	1. Ability of distinguishing the function of any object and its evolution; 2. Ability of identifying relationships between any object with other systems around in different hierarchical levels and temporal sequences; 3. Ability of combining an object with other systems to extend the line of evolution and decrease the negative effect of the anti-system;
	Dialectic Thinking	Getting familiarity with contradictions Formulating contradictions Overcoming contradictions Solving inventive problems	1. Ability of defining the contradictory traits in any object; 2. Ability of defining the contradictory traits that hinder the desired evolution of an object; 3. Ability of applying the methods for resolving contradictions;

Table 2. System of OTSM-TRIZ Games (continued)

Mental Process	Sub-Process	Games	Planned Abilities
Imagination	Composing Traits	Lulio's Circles	1. Ability of describing an object by using all 5 senses and also intuitive feelings; 2. Ability of conceiving a new object with different degrees of originality Transfer of known traits and elements of an object into a novel one for improving its functionality;
		Morphological Analysis	
		Modified Morphological Analysis	
		Focal Object	
		Empathy	
	Exaggerating Traits/ Typical Techniques of Fantasizing (TTF)	Increase-Decrease Magic wand	1. Ability of Changing the value of traits, components, location and time of any object or event through ignoring fundamental laws of nature.
		Division-Unification Magic wand	
		Time Magic wand (Slow & Quick Minutes/ Scramble Minutes/ Reverse Minutes/ Faraway Minutes/ Mirror Minutes/ Freezing Minutes)	
		Animation-Petrifaction Magic wand	
		Specialization-Universalization Magic wand (One functional-Endless Multi-Functional)	
		The Opposite Magic wand	
Speech		Comparisons	1. Ability of communicating the mental processes; 2. Ability of communicating with the external world; 3. Ability of self-Regulation.
		Riddles	
		Metaphors	
		Rhymed	
		Fairy-tale	

Each game consists of two parts. The first part gets the players acquainted with some imagination or thinking clues; the second part makes the players apply the same clues in a creative (non-repetitive) situation. Teaching the kids how to use imagination and thinking clues for enhancing their mental abilities is an indirect way to make them learn TRIZ and OTSM-TRIZ problem solving processes. At the same time, these games directly invite the kids to engage themselves into real problems, so as to develop their mental attitude to problem solving.

3. Assessing the effects of OTSM-TRIZ Game on engineering students

3.1. Scope of the experiment

As stated above, the aim of this research is to assess the possibility of increasing the ability of engineering students in solving non-typical problems by exploiting OTSM-TRIZ games. According to this objective, the experiment has been defined and planned taking into account the following resources and concerns:

- Target group: the first implementation was made with MS students in mechanical engineering attending the course “Methods and tools for systematic innovation” at Politecnico di Milano;
- Time planning: the games were planned so as to not interfere with the syllabus of the course; for the same reason, it was decided to select only a subset of games;
- Object of the experiment: OTSM-TRIZ games are domain independent, so they can be easily adapted to any field; on the other hand, they have been conceived as an integrated system, therefore a selection of a subset of them (for organizational issues) needs special attention;
- Criteria for assessing the results: Several creativity indexes are known in literature, while there are no specific metrics for assessing problem solving skills. Therefore it was decided to use both creativity indexes and some special indexes that the authors consider meaningful for this study;
- Reference sample for the experiment: Comparing the selected indexes before and after the introduction of the games shows the changes occurring (in this case to MS engineering students), Besides, since there are no published experiences about the impact of these games on adults, it is interesting to compare the same indexes related to a similar experience with kids, in order to have a reference behavior to interpret the results. Indeed, the largest majority of researches in this field are in Russian and, according to the authors’ knowledge, there are no publications revealing the effect of the games on kids taken individually. As well, the previous experiences of the authors are related to long-term courses. Therefore, it was decided to repeat the same experiment on another sample of kids;

3.2. Implementation of the Experiment

According to the initial resources and concerns, the experiment was carried out as follows:

- The samples: thirty MS mechanical engineering students of Politecnico di Milano were selected as the main sample and thirty 12 years Old Iranian students of Roshangar Secondary School were selected as the reference sample. Besides, writing up the questionnaires of the test (see below) was considered as voluntary duty for students of both samples. So it was predicted that the amount of filled questionnaires would be smaller than the overall amount of students.
- The games: OTSM-TRIZ games involve either speech interaction, or vision-based games based on matrixes, tables and circles. It was decided to limit the experiment to speech-based games, since tables and matrixes are too close to standard engineering tools and could condition the behavior of the engineering students. Moreover, mentioned above, OTSM-TRIZ games are an integrated system of complementary games: some games are to be considered as prerequisites for the others, as for instance the role of “Mixing Circles (Lulio’s Circles)” for all other imagination games dedicated to 3 to 4 years old games. According to the prerequisite relationships of the games, “Comparison” and “Riddle” were selected for enhancing imagination and thinking abilities respectively.
- Game sessions: According to the time limitation, two game sessions were planned 90 minutes each: one for Comparison and the other for Riddle.
- Target abilities:
    - Comparison: “Ability of describing the objects by using all five senses” and “Ability of comparing two objects based on their similarities, differences and opposites in different time”;
    - Riddle: “Ability of quickly and accurately narrowing information searches for highlighting the important information in every situation” and “Ability of building an abstract model of objects and situations”;
    - Structure of tests: Pair of tests was prepared in the form of questionnaires to be delivered before and after the games sessions. Each questionnaire contains two groups of questions. The first group is directly related to the abilities solicited by the games. The second group is related to an overall imagination ability of students in proposing a new object (considered as a general skill needed for non-typical problem solving). As a general example of what is meant with testing imagination abilities, the students were requested to suggest a new type of fruit for kids (pre-test), and a new type of toothpaste for kids (post-test), also respecting some specific expectations (e.g. parents desires, kids behaviours etc.);

- Assessment criteria: some evaluation criteria have been taken from the field of creativity assessment, such as: "Variety of ideas", "Consideration of Details (object of the idea)", "Width of imagination (in target)", "Width of imagination (in time)", "Originality" and "Appropriateness" are well known criteria for assessing a creative work. "Acceptance of working on creative activities", "Effective time for modeling" and "Tolerance in critique" are some of the criteria for the person engaged in the creative activity [11]. So in the scope of the research the following indexes are measured:
  - In the scope of creativity indexes for the new proposed object:
    1. Variety (Number of different concepts in performing the function);
    2. Consideration of Details (Number of components of object/ Number of traits of object);
    3. Width of imagination in target (Number of directions of thought);
    4. Width of imagination in time (Number of time frames);
    6. Originality (Unusualness with respect to reality/ Uniqueness with respect to the class);
    7. Appropriateness (relevance and feasibility);
  - In the scope of the direct abilities affected by games:
    1. Number of elements in the model of given situation;
    2. Number of relationships in the model of given situation;
    3. Number of hypotheses for given situation;
    4. Number of relationships between two different objects.
- The action plan of each session: The game sessions were performed as game sessions without any direct explanation about the logic behind the games. Besides, the games were organized as set of games from the simplest, to the most articulated one, so as to help the students to get acquainted with the structure of the games step by step. The games were proposed as a sort of competition among teams of students in order to increase their motivation and focus. Also according to the possibility of decrease the amount of filled questionnaires, it was planned to gather some information about the abilities directed affected by games during the game sessions.

4. Results of the Experiment

Overall, 13 engineering students out of 30 filled the pre-test questionnaire and 13 of them filled the post-test questionnaire, but only 5 of them (38, 5%) were common and can be directly compared on an individual basis. Similarly, 14 secondary school students out of 30 filled pre-test and post-test separately, and only 6 (42,9%) of them were common and can be directly compared.

4.1. Information gathered during game sessions

The first session was dedicated to the "Comparison" game, with three subsequent rounds. In each game, the students were requested to play with properties of objects that were suggested by the teacher through some pictorial cards. In the first round, the students had to think about the traits of the object. In the second round, the focus was on the relationships (similarities, differences, opposites) of two given objects. Eventually, in the third round the students had to propose relationships between six objects also considering different time windows (past, present, future). The second session was dedicated to "Riddle" game. After solving a given riddle proposed by the teacher, the students divided in three teams made up their own riddles. In three subsequent rounds two teams contended to solve the riddle through the well-known mechanism of yes-no questions. Table 3 shows the average time and the average item or questions proposed by the students. As there was no limitation for time duration of each game, the average time shows the time spent by each team. According to the rules of the games, high average number of items is the best result in Comparison, while low average number of questions is the best outcome in Riddle.

Table 3. Average time of games and items

Game			**Master Students**	**Secondary Students**
Comparison	One Object (9 Round)	Time (Min)	2.4	5
		Number of items	30	54
	Two Objects (3 Round)	Time (Min)	3.5	1.13
		Number of items	12	6
	Six Objects (1 Round)	Time (Min)	8.3	2
		Number of items	34	4.5
Riddle	(3 Round)	Time (Min)	9	7.5
		Number of questions	14	18.5

The analysis of the games outcomes shows that the engineering students achieved better results except in round one of Comparison. In the simplest game, the secondary school students proposed more items, thus revealing a higher imagination ability, while in more complicated games, MS students were more successful in identifying connections between objects (presumably due to their larger knowledge).

4.2. Results of questionnaires

Table 4 shows the selected indexes for abilities directly related to the games, while table 5 shows the creativity indexes indirectly linked to the games activity.

The ranges of the tables were produced by authors of the papers according the received information in the filled questionnaires. For example, numbers of components of the fruits proposed by students in pre-test of comparison session were counted as a reference for the detail level of the description.

According to the table 4 and table 5, the results of experiment can be summarized as below:

1. Both engineering students and secondary school students show improvements in both indexes directly and indirectly affected by the games;
2. The results of MS students are better than secondary school students in indexes related to the abilities directly affected by the games;
3. The results of MS students are weaker than secondary students in creativity indexes indirectly affected by the games before the game session, but after the game practice the engineering students show better results;
4. The results of MS engineering students show a larger improvement compared with the secondary school students in both directly and indirectly –related indexes.

Table 4. Indexes related to the abilities directly affected by the games

Indexes		Master Students				Secondary Students			
		0-3	4-7	8-10	10-15	0-3	4-7	8-10	10-15
Number of elements in the model of given situation	Before	0	4	1	0	5	1	0	0
	After	0	1	1	3	1	3	2	0
Number of relationships in the model of given situation	Before	0	4	0	1	5	1	0	0
	After	0	2	0	3	1	4	1	0
Number of hypothesis for given situation	Before	4	1	0	0	6	0	0	0
	After	4	1	0	0	5	1	0	0
Number of relationship between two different objects	Before	2	2	1	0	6	0	0	0
	After	0	1	1	3	5	0	1	0

Table 5. Creativity Indexes indirectly affected by the games

Indexes		Master Students				Secondary Students			
		0	1-2	3-4	5-6	0	1-2	3-4	5-6
Variety (Number of different concepts in performing the function)	Before	2	3	0	0	0	6	0	0
	After	0	3	2	0	0	5	1	0
Consideration of Details (Number of components of object/ Number of traits of object)	Before	0	3	2	0	0	5	1	0
	After	0	2	3	0	0	0	6	0
	Before	0	2	2	1	0	5	1	0
	After	0	2	3	0	0	1	4	1
Width of imagination in target (Number of directions of thought)	Before	1	4	0	0	0	6	0	0
	After	0	2	3	0	0	2	3	1
Width of imagination in time (Number of time frames)	Before	2	3	0	0	0	6	0	0
	After	0	3	2	0	0	5	1	0
Originality (Unusualness with respect to reality/ Uniqueness with respect to the class)	Before	2	2	0	1	0	5	1	0
	After	0	2	0	3	0	4	2	0
	Before	2	2	1	0	0	6	0	0
	After	0	3	2	0	0	4	2	0
Appropriateness (relevance and feasibility)	Before	2	3	0	0	0	6	0	0
	After	0	5	0	0	0	4	2	0

5. Discussion

The results of experiment were affected by the following factors and cannot be generalized without properly taking into account these aspects:

1. The games were presented within the course of Methods and tools for systematic innovation for MS engineering students. The questions of pre-test and post-test were very far from the engineering domain, so as to decrease the impact of the course on the results, but it is not fare to ignore the effect of the course on the achieved results;
2. The games were selected from the subset of OTSM-TRIZ games involving only speech. Besides, vision-based games are considered very important to make the students realize the structure of the games. Indeed, the comparison of the results of secondary and master students and also their behavior during game sessions, show the possibility of realizing and using the logic of games by engineering students even without vision-based games;
3. The paper does not compare the results to the average of indexes in kids. The authors did not find any information about similar ranges for kids for a more thorough discussion;
4. The experiment was performed near the time of evaluation tests of both master and secondary students, therefore it is possible that the condition has affected the results of pre-test and post-test.
5. Some changes in the pre-test and post-test such as tendency to "integration of contrary properties", "bias to micro level (in object of the idea)" and "bias to higher level (in target)" were not evaluated in the scope of experiment. The initial results show improvements in them too. These indexes are important in the scope of non-typical problem solving. Lack of special system of evaluation for non-typical problem solving is obvious.

6. Conclusions and future researches

The research was performed to assess the possibility of improving the abilities of engineers in solving non-typical problems. System of OTSM-TRIZ games were developed and applied successfully for kids 3-8 in some countries.

The research shows that also MS engineering students can benefit of these games, as exemplarily demonstrated with 2 games out of the complete set of 27 games. The creativity indexes show significant improvements, as well as some indexes related to the mental abilities directly affected by games.

The results need a rigorous generalization due to the mentioned limitations of the experiment. Nevertheless, the results can be enforced by replicating the experiments on a larger scale and/or adding new games to the test. Similarly, further assessment indexes can be taken into account for a finer analysis of the outcomes.

Acknowledgements

The authors would like to acknowledge the Roshangar Iranian School and its contact teachers Ms. Minoo Gharaie and Siba Malek and also Ms. Leila Ghalamkar and Ms. Maryam Farmahini as the teacher of the games from IIITS and the Department of Mechanical Engineering of Politecnico di Milano that provided the opportunity of performing the experiment.

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