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Creativity Components in Engineering Education

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The article describes the conflicts in the development of engineering education, their algorithm definitions which would be eligible for engineers, researchers, instructors, and students. This, in its turn, is the result of long-term experience in the development and application of about 20 algorithms based on TIPS (Theory of Inventive Problem Solving).

Key words: engineering education, creativity algorithms, system, function, Theory of Inventive Problem Solving (TIPS / TRIZ), contradictions.

Introduction

It is a well-known fact that engineering education, comparable to Humanitarian and Natural Sciences, has its own specific features. Hand-on experience involves applying the theory of inventive problem solving (TIPS / TRIZ) in teaching some engineering disciplines in Chuvash State University n.a. I.N. Ulyanov (CSU). In the publications [1, 2] the experience in implementing practice-oriented educational technology into the engineering education was described. The existing tendencies prevailing in the transformation process of the engineering education itself (including the content and technology strategy) "block the hope" in furthering changes in the engineer training today. In [2] the experience of the Siberian Federal University (SFU) in shaping engineering competencies relevant to today's knowledge structure, skills and abilities, as well as developing those competencies to generate modern ideas has been described. Taking into account the modern approaches – Theory of Inventive Problem Solving (TIPS / TRIZ) [2-5] and the experience of SFU the up-dated learning strategies and IT have been proposed. People with creative thinking, competent to generate and develop ideas are imperative of our days when the country is entering the path of innovation development. The generation of up-dated innovative ideas is becoming more and more relevant as an aspect of human activities due to the gradual change to a well-established innovative civilization and the rapid emergence of the fifth and/or sixth technology revolution [1]. These factors highlight the role of a talented-thinking person in this process.

A knowledge database [6-10] for professionals, engineers, instructors, and students has been developed in CSU. This database involves 30 books in TIPS (TRIZ) (600 copies) and 15 manuals published in CSU (more than 100 copies) in 1976-2014. These manuals embrace different intellectually-demanding learning tasks in chemistry, environment protection, metalworking, electrical engineering, business, and IT. There are consulting programs, i.e. computer programs and videos in TIPS (TRIZ) in the CSU computer classes (Computer Information Center). The students become acquainted with the fundamental principles of TIPS (TRIZ) which include [3-13]: system approach, generalized experience of many inventors via problem-solving algorithms, as well as demonstration examples of creative patent-decision making actions in different domains of technology and science. The students study in TIPS (TRIZ) School, as well as at some advanced courses developed in the Computer Technology and Radio Engineering departments.

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Engineers should be involved in inventive problem solving based on Inventive Problem-Solving Algorithm (IPSA) projects developed in 1961-1985 (in the USSR) and being further developed today. Advanced methods and simplified approaches for beginners are being developed. It is a well-known fact that students are becoming acquainted with TIPS (TRIZ) components in more than 800 Russian engineering universities. However, TIPS (TRIZ) proficiency is practically impossible as TIPS (TRIZ) is not considered to be an essential engineering discipline, and consequently, few academic hours are included in the university curriculum.

The basic principles and methods of TIPS (TRIZ) are discussed:

1. System approach. TIPS (TRIZ) includes the examination of system organization and structure, their functions (principal, subordinate, supplementary, negative), recording of system errors (more of something desirable, also brings more of something less desirable, or less of something else also desirable). Recording predominant laws of technical systems evolution: a) ideal system (IS) or towards ideal final results (IFR); b) system improvement via IFR results in emerging technical (TC) and/ or physical (PC) contradictions which should be resolved. Conscious recording of these laws of technical systems evolution reduces lost searching time for new creative decisions, diminishes the number of decision errors (1000 to 3-7 close to implementation) and improve the quality of ready decisions.

2. Professional evaluation of creativity. According to the professional evaluation of creative technology, in cases of random search method (i.e. excluding knowledge of system evolution laws in problem-solving according to the so-called "trial-and-error method" – T&EM) only one of 3000 commercially proposed ideas are accepted; while in cases of direct search method (based on the system evolution laws) 3-7 practical ideas are found [2-13], then, after engineering-economic quantitative assessment, only 2-3 ideas are selected.

3. Description of TIPS (TRIZ) methods. Description of the tools and methods based on TIPS (TRIZ) of various complexities for both learners and professionals are depicted in Table 1. The methods differ not only in the number of included TRIZ steps, but also the applicability for different types of inventive problem solving (involving one person and/or a group of professionals; or several groups of different-employed professionals). The method types in №№ 1-5 are simple and practical for examination and application in the start-up introduction of TRIZ principles and further proficiency: they are operated by a single solver. Method types №№ 2, 10-12, 14 are based on intelligent computer-supported programs: Expert Systems-Invention Machine- IM 1.5 (Research Lab of Expert Systems, Minsk, 1989) and / or foreign analogues: TechnoOptimizer-TOP 2.5 (IMCorp, Boston, 1997), GoldFire-GF 3.5 (IMCorp, Boston, 2007) and Invention Machine-IM 2.4 (St. Petersburg, 2004). The users also developed numerous simple search-based computer programs, for example, № 1 (according to G. Altshuller 40 Principles). Method types №№ 6-9, 12-15 are considered to be complex and more complicated.

4. TRIZ and Instructions. What has been accomplished in TRIZ instructions for students and professionals? A. Gin reported about the 15-year experience results of the Laboratory of Educational Technology [12,14] at TRIZ-conferences. More than 30 manuals have been published in different disciplines which include the introduction and training of modern approaches to open problems (numerous possible correct solutions). These manuals and books have been published in many languages. Students should understand that they would have to encounter different open problems and it is the TRIZ methods which could help solving them. New numerous manuals to assimilate TRIZ

Table 1. Methods of inventive problem solving based on TRIZ [15]

№	Methods types	Number of steps	Problem type	References
1	2	3	4	5
1	ARIZ and 40 principles: Atlshuller table (1972)	5+	simple	[3, 8, 13]
2	Brainstorming technique (software based) – S. Malkin "Guided Brainstorming LLC" (2012)	6+	simple	[14]
3	A. Podkatilin 5-20 steps (2008) TRIZ-1 – theory of inventive problem solving (level 1)	5-10	simple	[13, 15]
4	Algorithm SIE (ARIZ-77 – part 1 and Atlshuller table, CSU)	15-20	simple	[10, 13]
5	ARIZ-76 Atlshuller table (1985)	1-10	simple	[3, 4, 13]
6	Algorithms for inventive problem solving ARIZ-85v (1985)	>100	complex	[3, 4, 13]
7	Algorithms for selecting engineering problem solving – ARIP (G.I. Ivanova, 2010)	>32	simple-complex	[15]
8	TRIZ-3 – A. Podkatilin, advanced level including application steps (2015)	>>10	complex	[20]
9	Algorithm G3-ID (GEN3-Partner Inc., US) and Algorithm (S. Litvin, St. Petersburg, 2000)	>>100	more compli-cated	[15]
10	Algorithms of Idealization TRIZ, Direct Evolution (B. Zlotin, US, 2006)	>>100	complex	[15]
11	Invention Machine Program IM- 1.5 (V. Tsrikov Research Lab. Of Expert Systems, 1989 Minsk	5-100	simple-complex	[10, 15]
12	TechnoOptimizer Program TOP-2.5 (IMCorp, US, 1997): TC-algorithm, ARIZ and 40 principles, contradictions (PC, AC, TC), standards and final results	5-100	simple-complex	[8, 13, 15]
13	GoldFire-3.5 – decison-engine platform (IMCorp, US, 2007)	5-100	simple-complex	[15]
14	Theory of Evolution of Matter and Models-algorithms for IT problems (M.S. Rubin et al., 2012	5-100	simple-complex	[15]
15	Algoritm MO-2.4 (V.V. Mitrofanov, 2004)	>7	science-based	[15]
16	ARIZ-2010 (S. Litbin, C. M. Rubin, V. Petrov et al., TRIZ- Conference Meetings 2005-2013)	>100	simple-complex	[15]
17	Subversion analysis (B. Zlotin et al., 1989)	5-100	simple-complex	[15]
18	Future evolution of systems (B. Zlotin, S. Litvin)	>100	complex	[3, 5, 15]

in solving technical, chemical, business and ecological problems are being published [5-16] in CSU, TSU, and TSUAB.

5. Simple algorithm to analyze the problem. One of the simplest and most effective TRIZ methods is Brainstorming algorithm. A summary of this algorithm [14] is formulated in the following example which includes 5 steps (note: empty pair of parentheses with dots embraces specific content for this or that problem).

The main purpose is the transition from an indefinite initial problem situation to the clearly formulated and extremely simplified description (model).

Problem Model:

Step 1. Mini-problem conditions: (state the purpose of the system in economy, technology or human relations; list the main parts of the system introducing such requirements as: current level and future required level, what is impossible to change? how to determine the progress? minimum level? what required result (…) what contradictions? (…) (…).

Step 2. IFR (ideal final result): state the **required result** (…) under conditions (…), where (…) and when (…).

Step 3. Transition to problem situation: includes 5 questions denoting the technical parts of the system (Technical Contradictions) – a) introduction (improvement) b) elimination (reduction), c, d, e) identifying contradictions (changing action / substance / parameter (…) improving useful action (…), or eliminating a harmful action (…)).

Step 4. Analyzing the problem model: The following list (Table 2) of 30 interrelated abstract inventive resources [3, 14] is intended for identifying available potential that may be useful for solving the problem.

To identify the idea in the first group "resources" a new operation (or their combination) is applied as a hint for further identification of new ideas via the transition of an element or function, action, interaction, environment or another system. Could such an operation develop a new resource and / or change the result? It is recommended to consider the remaining operations to eliminate the contradictions and conflicts with respect to defining the resource.

When considering the operations it is necessary to remember that there

Table 2. Abstract inventive resources

	AVAILABLE RESOURCES					
Operations	RESOURCES	TIME	SPACE	STRUCTURE	CONDITIONS & PARAMETERS	
	Energy	Ahead	Alternative dimension	Elimination	Partial	Inoculation
	Substance	After	Asymmetry	Degradation	Redundant	Isolation
	Information	Gap	"Russian Doll" principle	Consoli-dation	Consistent	Counter-measures
	Derivatives	Accelerate	Exportation	Mediator	Dynamic	One-time
	Concent-ration	Decelerate	Localization	Copy	Controlled	Inversion

are 300 inventive operation application examples for different problems: technical, economic, or human relations.

Step 5. Formulating problem model: estimate the utility and/or harmfulness of proposed ideas as a complementary solution mode, identify new possible problems, and, if necessary, repeat the search for other ideas and develop an implementation plan.

6. Problem example: Hydrated dust cloud in a workshop

Problem: In a workshop (Perm R&D Instrument Engineering Co.) there is a deactivation unit for acid waste solution HF + HNO3. The process is as follows: 1) a sack of crushed caustic limestone is emptied into a tank (with water and mixer); 2) pressurized oxygen absorbs the finest CaO particles; 3) this hydrated cloud spreads throughout the workshop; 4) there is an outlet ventilation with hood above the tank. The worker is dressed in a PE and respirator. However, the workers from other workshops complain of this situation. All complaints are sent to the Health & Safety Department.

Step 1. Stated problem: technical and personal interrelations. What should be changed and what cannot be changed? – acid waste water should be completely neutralized. Why? – cheap caustic limestone (CaO) is suitable in this case. What conflicts? – when dispensing powdered CaO, hydrated dust cloud is formed. Stated task – to cut-off the formation of hydrated dust cloud in the workshop air.

Step 2. IFR: in the process of dispensing powdered caustic limestone CaO into the neutralization tank, the CaO dust cloud itself does not enter the atmosphere.

Step 3. Substance-Field Resources (SFR) 1: 3.1 Clear up the dusty air in the workshop. 3.2 Eliminate the dust cloud path in the workshop. 3.3 TC-1: powdered CaO is necessary to neutralize the waste solution; however, in the process of CaO dispensing, a dust cloud forms in the tank hood due to emitted pressurized oxygen from the tank itself. 3.4 TC-2: dispensing powder is necessary to neutralize the waste water; however, a bad result is the formation of a harmful dust cloud due to the aerodynamic flow in the hood itself (i.e. powder contains dust particles, and it is this dust that forms the harmful cloud in the air).

Substance-Field Resources (SFR) 2: all operations are necessary.

Step 4. Analyzing the problem model (30 operations are applied: Energy (E) = Mechanics - Acoustics - Surface Radiation - Electricity - Electro - Magnetic Waves - Chemistry - Biochemistry - Nuclear Physics; (S) = Substance; (I) = Information; Time; Space; Structure; Conditions and Parameters). Operation groups are applied (Table 2).

4.1. Resources: 4.1.1. Mechanical – dynamic (E) dispensing powder forms aerodynamic flow. 4.1.2. Substance (S = solid - liquid - gas - plasma) powder flow + gas current → capture zone. 4.1.3. Information (I): explanation that the neutralization of waste water is conducted once a week – rarely; major ecological problem – complete neutralization, but no rush. A sack – 20kg. CaO, CaO capacity – 7 liters and pressurized 7 liter of air (from the tank). 4.1.4. Derivative (from E/S/I): neutralize slowly, but accurately excluding harmful dust cloud. 4.1.5. Concentration (E/S/I): premixed concentrated caustic limestone solution, but this is an unwanted operation, as the solution cannot be stored over a long period – sediments accumulate in storage.

4.2. Time: 4.2.5. Slowed down operation – in the process of slow CaO powder delivery, the dust cloud formation is less.

4.3. Space: 4.3.2. Asymmetry – assuming, powder flow embraces only 0.1 portion of the hood area, then the sack is opened partially, scissor off sack corner and thinly pouring out; 4.3.3 "Russian Doll" – jet-flow of powder into a pipe, not contacting with air current; 4.3.5. Localization – powder in the pipe.

4.4. Structure: 4.4.1. Elimination – powder - air contact flow; 4.4.2. Degradation – pouring out partially, while 1/20 portion by a bucket; 4.4.4. Mediator – bucket + funneled pipe to provide precise dosage, as well as separate powder and pressurized air flows from the tank.

4.5. Conditions: 4.5.3. Matching – portion volume (bucket) is matched to required precise dosage; 4.5.5. Controlled – bucket is regulated manually.

4.6. Parameters: 4.6.2. Isolation – mainly isolate the flows.

Step 5. Model: 5.1) (based on operations 4.1.3 + 4.2.5 + 4.3.2) – thinly empty CaO from the sack (scissor off sack corner), then the dust would be less; 5.2) (add operations 4.3.3 + 4.3.5 + 4.4.1) – empty through a pipe funnel, then dust formation would be completely excluded; 5.3) (add operations 4.4.2 + 4.4.4 + 4.5.3 + 4.5.5) – empty partially the sack, where CaO dosage is performed by a bucket (at 0.5-1 kg.), then two problems will be solved; major – precise dosage (100-110%) CaO, excluding dust formation. The Customer suggests a set of 3 proposals.

7. Practical application of TRIZ. Three factors proved the effectiveness of professional TRIZ application within developing innovative enterprises and companies [5-8, 13-16, 20]: 1) a 20-year application of TRIZ in technical problem solving of varying complexity within hundreds of USSR enterprises (followers of G. Altshuller, S. Litvin, B. Zlotin, A. Podkatilin, G. Ivanov, and others); 2) 20-year experience of integrated TRIZ application based on the TIPS supporting-based programs (such as TechnoOptimizer and GoldFire); and 3) personal engineering experience of professionals from transnational companies and corporations of USA, Western Europe, South Korea and other countries.

To introduce, train, and further apply TRIZ in the research of students and CSU teaching staff, TRIZ training programs [4, 7, 15, 17] were proposed within the framework of Innovatik School, Computer Technology Department and CSU Education Center (Table 3). These programs include an introduction into the basic TRIZ principles and problem solving of about 30 drilling problems in technology and business management. During the classes (practicum) methodological, technical and science-based failures, inaccuracies and errors are discussed and corrected and/or improved. It should be noted that not only executives of academic and R&D organizations, but also students propose their own practical problems. To extend knowledge and enhance the understanding of the basic TRIZ principles and its components, it is recommended to develop supplementary materials, additional guidelines, and problem books.

The 40-year experience results in training TRIZ and its practical application has been described in the book "Basic Fundamentals of the Theory of Inventive Problem Solving" [13]. For example, comments of A. Pizhenkov (PhD in Chemistry) (2013): "How did your book help me? Solving 20 problems I used the database www.dace.ru, where I sometimes found the answers. I also applied ARIZ-85v, platform technology evolution, system operator, algorithm SIE (ARIZ-77), my personal knowledge in chemistry and physics. Your book [13] is simple and understandable. You can learn independently. Although there are some specific problem examples, but they are "stand-alone". Earlier, I read books in TRIZ which were "blurry" and rather difficult to understand". Based on ARIZ and 40 principles; and algorithm SIE [13 - pp. 118 and 253] the following problems were solved: technogenic load decrease on environment during petroleum development via oilfield pipe protection from pitting erosion (patent RU 2534134, published 27.11.2014); eliminate four technical contradictions (TC) typical of modern individual transportation; proposed universal pneumatic transport system (patent application RU 2011149865, published 27.06.2013). The following achievements should be mentioned: e-learning in TRIZ, 30 published manuals

Table 3. Student Course schedule (TRIZ School)

№	Lecture topics	hours	Practicum topics	hours
1	TIPS – Theory of Inventive Problem Solving (in Russian TRIZ) – basic principles. Video	2	Presentation – TRIZ, different problems	4
2	Stated problem. Problem example	2	Example problems	4
3	Ideal final result (IFR). SFR-concept (technosystems)	2	Example problem – its presentation	4
4	Substance-field resources (SFR): provided and derivatives	2	Example problem – its presentation	4
5	TRIZ and three different models	2	Example problem – its presentation	4
6	ARIZ algorithm – 30 principles: 6 steps	2	Example problem – its presentation	4
7	Mini-problem conditions, transition to problem situation, and analyzing problem model	2	Example problem – its presentation	4
8	Formulating problem model and practical application	2	Summary – test	4
	Total:	16		32

for colleges of Russian-American A. Gin group, inventive stories of M. Shusterman [18] and V. Galetov [19].

Conclusion. The authors described 18 TRIZ methods of different complexity, which are available for innovator-users. A training program of TRIZ-method for beginners and instructors was proposed. TRIZ-method is applicable in solving practical problems. Students-engineers should be acquainted with TRIZ components in their futureinnovation activities.

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