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Interdisciplinary FCA- and TRIZ-Based Projects: Experience and Prospects in Training Teachers

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The paper analyzes the ways to improve the quality of engineering training in Russia. It proves the importance of using Russian experience in problem-solving and project-based learning, as well as, it necessitates introduction of training course for teachers to be involved in interdisciplinary FCA- and TRIZ-based projects.

Key words: CDIO initiative, interdisciplinary projects, thematic plans of innovative and inventive activity, experience in international training of specialists, TRIZ-FSA phenomenon, cross-professional training of teachers in Russia, prospects of TRIZ-FSA-based training of engineer-businessmen.

Due to difficult social and economic situation in the country, the representatives of science and education should actively generate ideas to eliminate the possible disproportions in economic and cultural life, and also take steps on training qualified personnel in advance.

Today, scientific and pedagogical community actively discusses the International initiative of CDIO (Conceive – Design – Implement – Operate) [1]. A number of higher education institutions of the country have already implemented this innovative educational framework. It is oriented to eliminate contradictions between the theory and practice of engineering education. A new approach implies giving greater focus to practical training and implementation of problem- and project-based education. Its purpose: as a result of training, future engineers shall be able to think out new products (new technical ideas), to design (or to give the necessary instructions to those who will be engaged in this process), and also to produce [2].

While analyzing the publications concerning the problem of CDIO initiative implementation, the desire of scholars to look at it more widely («to pass in supersystem») is noticeable. The representatives of Astrakhan State University agree on the idea to introduce cross-cultural communication in the competences of a modern engineer and even suggest developing additional 13th CDIO Standard [3, p. 87]. The scholars of Penza University of Architecture and Construction fairly believe that in order to implement CDIO standards successfully not only engineering specialists are required – managers will be also necessary. Otherwise, a great number of unnecessary products will be produced, or someone else will make profit of the proposed ideas [4, p. 42].

The need to «break» disciplinary barriers persistently leads us to training future specialists who are able to solve non-standard problems. According to G. S. Al'tshuller's classification, interdisciplinary decisions are the third level of inventions which can hardly be made without superprofessional knowledge [5].

This idea is not new, 130 years ago the president of the Yell and Town company Henry R. Towne provided the report «The engineer as an economist» at the meeting of the American society of mechanical engineers. According to his opinion, engineers of new generation should also possess the qualities of production managers. The engineer should be in charge of organizing and supervising the work, as the power of the organized efforts prevails over professionalism of a worker. "There are many good mechanical engineers: there are also many good 'entrepreneurs'; but the two are rarely combined in one person", – Towne wrote [6].

Here is an idea about the uniqueness of the past: the fact is surprising but past has everything for the future. Therefore, when searching for the models how to change the current engineering education system into the system of training specialists able to work in interdisciplinary teams and projects, it is important to consider both Russian and foreign experience.

However, at the same time the problem of subject area of these interdisciplinary projects arises [7]. The international learning standards provide educators with an effective mechanism that allows them to "grow" the graduates who meet the requirements of real workplaces – the mechanism of "workplace-related competences" [8]. Its essence is that the professional organizations representing the interests of entrepreneurship regularly publish the lists of real workplace-related tasks which graduates should be able to do. At the same time, these tasks («workplace-related competences») are rather specific and differ from the qualification requirements stated in the domestic professional standards [9].

In Soviet time, regular thematic plans (rules) of rationalization and inventive work were used as equivalents of the contemporary "workplace-related competences" lists. Sometimes, the quality of the task description left much to be desired, but they took into account numerous particularities and could form a basis to plan technical, social, and economic development of the enterprise.

The thematic plan of SPA Tsellyulozmash developed via TRIZ methodology is case in case in point of task description [10]. The proper description of the technical tasks and also organization of the system for its performance (motivational, information, consulting, legal) allowed overcoming all the challenges mentioned above. As a result, the design engineer G.I. Slugin registered 13 inventions, and the engineers I.M. Golubev and L.T. Los – 7 and 5 inventions, respectively.

If we turn to the classification of innovation process models by Roy Rothwell [11], it is easy to notice teamwork of different professional (designers, technologists, economists, marketing specialists) within the fourth integrated model (referred to as Japanese or best practices). According to this model, the task can be solved more efficiently by teams rather individual engineers.

This model is applied in Japan and the USA [12]. At the Texas University, a prominent American scientist of the Russian origin George Kozmetsky revealed inefficiency of the existing system of engineers training and developed the system which strongly reminded the technology and organization of work of the Soviet military establishments, where the groups of experts developed the best World War II military technologies in the shortest possible time.

The results of G. Kozmetsky's system are impressive. Thus, the contribution to the regional economy made by the entrepreneurship incubator for technology commercialization of Texas university, Austin, which works with the companies at primary stages, accounts for one billion US dollars over 25 years [13, p.51].

According to I. Kant, "there is nothing more practical than a good theory", the idea which was also supported by G. Kirchhoff and L. Boltzmann. It is fully applicable to the national theoretic and technological developments which are generally referred to as the theory of inventive problem solving (TIPS or TRIZ). Though the invention technique originated from G.S. Al'tshuller's works in the late forties, the development TRIZ theory is supposed to begin with the publication "About Psychology of Inventive Creativity". It declared that "any technical task can only be solved in accordance with the laws of science, which is conditioned by current technology advances" [14]. This article became a manifesto of TRIZ. 25 years after, the publication of the book "Creativity as Exact Science" gave the status of "exact science" to TRIZ [5].

In the 70-80s, the techniques of the functional and cost analysis (FCA) were united with TRIZ at leading Leningrad enterprises (ETL "Elektrosila", PA "Izhorskii zavod", etc.) based on the works by experts in TRIZ V.M. Gerasimov, A.N. Zakharov, B.L. Zlotin, S.S. Litvin, A.L. Lyubomirsky, and others. By the 80s, there were a lot of enthusiasts nurtured by G.S. Al'tshuller's training seminars, who developed the ideas of TRIZ-FCA and applied them for new technical inventive solutions funded by the commercial agreement and state budget Researches and Development. They also provided students, graduate students, and academic staff with the basic TRIZ tools.

Modern theoretic and technological approaches of TRIZ and FCA allow making a "set" of tasks, a comlex of problems to be solved in the course of professional training and prospective professional activities [15]. Any practical challenge is a problem situations (PS or «putanka»), overlapping technical, social, and economic issues taken as undesirable effects (UE) (Tab. 1).

Non-inventive and inventive tasks correspond to standard and non-standard ones. In the first case (routine tasks), the reasons are not expressed – these tasks

Table 1. Task system classification

Characteristics		Components (information about the models)						
Type	in terms of TRIZ, FCA	IC "Given"					FC "Needed"	Pr "Procedure"
		Reasons type			Transfor-mation means (MFIR)	Opera-tion mode (OM)	Purpose of transfor-mation and its orientation (I = F/C)	Ways of MFIR involve-ment – system develop-ment laws (SDL)
		Contr	UE	A group of UE				
Routine	Non-inventive	Not expressed			+	+	+	–
Non-routine (with difficu-lties))	Non-inventive	Not expressed			–	+	+	–
Educa-tional (IT)	Inventive	+			+	+	+	–
Transi-tional (IS)	Inventive		+		+	+	+	–
Real PS – "putanki"	Inventive			+	–	+	–	–

describe an equilibrium condition of a system. When training, any procedures (formulas) are usually fulfilled. To create complicated situations, teachers «hide» the means of transformation – resources from the trained (see non-routine tasks).

Inventive tasks, on the contrary, are the models to describe unstable, developing real systems. In terms of information completeness, there are different types of models given in Tab. 1. PSs are characterized by the highest uncertainty. The abbreviations are used: UE – undesirable effect; Contr. – contradiction; OM – operation mode(s); I – ideality; F and C – sets of functions and costs; SDL – system development laws; PS and IS – production and inventive situations; IT – an inventive task; MFIR – material and field information resources. The names of task system components (initial (IC) and final conditions (FC) describing the task in terms of statics and also procedure (Pr) of change from IC to FC that makes the task dynamic) correspond to the terminology accepted in the literature on task systems.

The thin arrows in Tab. 1 describe the procedure of problem solving in production, while the thick ones illustrate educational tasks. The "educational" inventive problem solving (IPS) have the characteristics as follows: 1) contradiction; 2) the described principle of a problem component operation (UE); 3) the conversion purpose («a decision portrait»); 4) the means of communication conversion determined by the solver (first of all, «cheap» intrasystem MFIR). After the correct description of the inventive problem solution (IPS), the solver should choose the transition procedure from IC to FC – an algorithm of resources involvement depending on their accessibility and contradiction type (SDL). Therefore, IPS is a final model of task description to separate the task from the problem situation (PS).

The case in point is the activities performed by the academic staff of Chelyabinsk higher education institutions to promote TRIZ-FCA. Institute of Mechanization (later Institute of Mechanization and Electrification of Agriculture) is the first technical college in South Ural (1930). The authoritative scientific schools appeared there as a result of tractor industry development. In 1937 Ya.V. Mamin (the pioneer of national tractor industry) came to the Chelyabinsk Tractor Plant (CTP); he actively worked at the department of tractors and cars.

In October, 1941, CTP turned into Tankograd where the outstanding tank designers worked (N.L. Dukhov, Zh.Ya. Kotin, etc.), later the nuclear and thermonuclear weapon and missile systems were produced in the region (N.L. Dukhov, E.I. Zababakhin, V.P. Makeev, K.I. Shchyolkin, etc.). In 1944 N.L. Dukhov headed the department of tank construction (track laying vehicles) at the Chelyabinsk Mechanical Engineering Institute (later ChPI).

In 1960-1981 V.P. Makeev, the founder of the Soviet scientific design school of sea strategic rocket production, was a professor of the department "Flight vehicles" in the polytechnic institute.

Over the post war years, the technical higher education institutions of Chelyabinsk – ChPI and Chelyabinsk Institute of Mechanization and Electrification of Agriculture (ChIMEA) turned into powerful vocational schools of the country with a strong scientific and educational potential. In the late 1970s, 21 thousand students studied in ChPI, 2.3 thousand educators and scholars worked there. There were many inventions designed and patented and the roll scientific school was intensively developing (V.N. Vydrin, L.M. Ageev, etc.) is known. More than 500 inventor's certificates of USSR and more than 120 foreign patents prove the novelty of engineering procedures and milling equipment developed by this school. The Chelyabinsk rolling school sold two licenses to the leading firms – "Schloemann-Siemag" (Germany) and IHI Corporation (Japan) for 3 million US dollars. Thus, figuratively speaking the "seeds" of

TRIZ and FCA fell on well fertilized soil in Chelyabinsk.

By the beginning of the 80s, a set of TRIZ-based educational and methodical guidebooks was published (from 300 to 1000 copies), which was resulted from TRIZ-based academic activities of ChPI and ChIMEA faculty staff who had participated in G.S. Al'tshuller's seminars [16–21]. The TRIZ and FCA tools were provided for students, young academic staff at the Public Institute of Patent Science (PIPS) of All-Union Society of Inventors and Rationalizers and Ratsio club in ChPI.

The faculty of ChPI (then ChSTU and SUSU) and ChIMEA (then ChSAU), most of them being graduates from the state advanced training courses in patent science and invention and also mastering TRIZ techniques (E.G. Shchepetov, B.V. Shmakov, N.I. Gorbunov, V.A. Kislyuk, V.V. Likholetov, Yu.F. Prokhorov, S.V. Strizhak, B.V. Barichko, B.M. Berezovsky, Yu.P. Galishnikov, etc.), began to introduce TRIZ in educational and research work in the 1980-90s years. It brought good results: 15 students of B.V. Shmakov became coauthors of the USSR inventor's certificates. 12 students of V.V. Likholetov from ChPI were the coauthors of the inventions which were defended with the USSR inventor's certificates and GDR patents.

In 1982, in collaboration with the regional technical creativity center, B.V. Shmakov and E.G. Shchepetov initiated the regional Olympiad on technical creativity for students of secondary vocational schools that existed till 2013. TRIZ and FCA tools were also effective in academic activity of vocational schools. As a result, in the 1980-90s, several students from vocational schools lyceums of Zlatoust, Magnitogorsk, Chelyabinsk registered the patents for inventions and useful models.

The dissemination of TRIZ and FCA ideas throughout the country was triggered by the international project "Inventing Machine" (IM) in 1989 in Minsk. Since 1991, the Ural office of research laboratory of the Inventing Machine (URLIM) was in charge of staff retraining and professional development (both for industry and professional education, first of all, for high school).

Our experience show (in Moscow, Kiev, Irbit, Ivanovo, Tolyatti, Orsk, and other cities) that, when using TRIZ, FCA, IM in educational and research process, people involved in these activities tend to change their way of thinking and become organizers of innovative activities rather than their users.

By the middle of the 1990s, the project was almost closed in Russia due to social and economic reasons. However, the project "appeared" de facto in the companies and universities of the USA, the countries of Europe and Asia where innovative activity is supported.

Since 1994, some faculty of URALNILIM introduce TRIZ experience to advance analytical training at the faculty "Economy and entrepreneurship" of ChSTU. At that time (before the introduction of State Education Standard), they developed a model to combine methodological and information and analytical subjects with economical and managerial ones (Tab. 2). The professional development course was designed for engineering experts and leaders and provided the specialization "Analysis and problem solving in social and technical and economic systems (STES)" of the specialty 071930 "Management".

8 groups of "analysts" or 39 specialists graduated from the courses. They became top managers of the largest regional and national companies, commercial banks, regional ministries. It led to development of original and adapted TRIZ FCA, IM – based methodical support for different university courses including non-engineering ones [22].

Since the end of the 1990s, these practices have been used for professional development of faculty of all SUSU departments [23]. Since 2008 (by the order of Federal Agency for Education No. 2270 adopted on 12/10/2007 via Institute of additional education of SUSU (as basic

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Table 2. Training model of manager-analysts

Subject areas					
Content					Technology
ECONOMICAL AND ADMINISTRATIVE					
Levels of functioning and management					Technologies
National economy			Enterprise	Person	Methods and technics of specific economical and managerial disciplines (EMD)
Abstraction levels	High	Macroeconomics	Microeconomics	Praxeology	
		Economic theory			
		Management theory			
	Low	Finances	Economic analysis and account	Entrepreneurship fundamentals	
		Money and credit			
		Insurance	Financial and economic activities analysis (controlling)		
		Statistics			Computer technologies (CT) of documents electronic control
		Stock-exchange industry	Management	Labour	
		Branch economies	Marketing		
LAW					
Constitutional and tax law					Protection of right and intellectual property (IP)
			Economic, labor, administrative law		
Financial law			Social development, author's and patent law		CT of economic activity and IP protection
INFORMATION AND ANALYTICAL					
Logic (logical laws of correct thinking)					Uses of logic laws
System modelling					Modelling
Systems functional and cost analysis (FCA)					Structurally functional modelling
				CID	Development of Creative imagination (DCI)
Theory of inventive problem solving (TRIZ)					Description and solution of tasks
Theoretical bases of computer systems to support thought process					Analysis of task systems and its solution
SOCIAL AND PSYCHOLOGICAL					
			Theories of team formation and development		Technology of team designing
			Conflict management		Technology of businessman self-survival
			Communication psychology		
				Information culture	Technology of a manager's personal work
			Information influence on demand (advertizing)		Technologies of advertizing

higher education institution), the author's program of professional development of PTS of linear higher education institutions "A possibility of potential use of TRIZ and theory of creative person development (TCPD) for modernization of higher education institutions disciplines" has been implemented for some years (see: http://www.susu.ru) in the profile "Innovative Activity" (72 hour). The summary of the program is given in Tab. 3.

The trainees were from all over the country: Moscow and St. Petersburg, Barnaul and Yuzhno-Sakhalinsk. Their feedback is available in the Internet [24].

While defining the prospects of faculty retraining for interdisciplinary projects, it is necessary to overcome negative tendencies «flourishing» in modern national education. It is obvious that graduates of economical and managerial specialties do not know engineering and technology, while prospect engineers are not competent in promoting technical solutions to the market. Neither of them developed such professional skills at universities. It means that the teams of future innovative enterprises should be "cultivated" since student years in the mode of multi-level extra training and joint activities. All departments of a university should be involved in joint efforts to train prospect leaders of high technology industries. It implies training engineers-entrepreneurs who would be able both generate technical and technological innovations and assess the market potential of the product.

The faculty trained within the framework of TRIZ and FCA techniques, in collaboration with business community represented by the regional office "Opora Rossii" (Support of Russia), can facilitate training such kind of engineers-entrepreneurs.

Table 3. Content of the program "TRIZ and TCPD to improve academic subjects"

№	Content
1	The general review of TRIZ practices and their importance in the modern world
2	Characteristic of the theoretic and methodological block: 2.1. Empirical basis of the theory. 2.2. Initial theoretical basis. 2.3. Logic and heuristic tools of the theory. 2.4. Logic and heuristic rules for revealing consequences (methodologies).
3	Characteristic of the technological block: 3.1. Modifications of the inventive problem solving algorithm (IPSA) with fight of a task solver against psychological inertia. 3.2. Technologies of problem identification in production situations. 3.3. A technique of research task solution (including diversionary approach). 3.4. Techniques for forecasting system development. 3.5. Technology of social problem solving by a creative person ("Life strategy of a creative person").
4	Characteristic of the social and cultural block of TRIZ: 4.1. Register of Science fiction Ideas (RSFI) and G. Altov, V. Zhuravleva, P. Amnuel's science-fiction works, etc. 4.2. Works in TRIZ pedagogics. 4.3. Research results of TRIZ approach in different areas (science, technology, economy, ecology, medicine, visual art, and music).
5	TRIZ-FCA-based software products: 5.1. Logic of software products and their trends.

We have offered "The concept of engineering entrepreneurship support in South Ural State University (SUSU)" to the administration of the university. It is based on the experience of the leading higher education institutions and provides a number of organizational steps (Tab. 4).

As the first step, the subject "Engineering entrepreneurship" is offered to be introduced to the engineering education programs, which will allow disguising engineering students who would like and be able to develop business skills. The second step implies launching the system of additional training and motivation on the basis of innovative structures of higher education institution to train engineers-entrepreneurs. Higher education institutions, including SUSU can establish structures like "Test site for engineering entrepreneurship" based on the experience of Institute of engineering entrepreneurship of Tomsk Polytechnic University. Nowadays, the term "engineering entrepreneurship" is widely spread in different subject areas and structural divisions of some Russian and foreign higher education institutions and has positive public image.

The developed concept is based on the experience of training engineers-entrepreneurs in Tomsk Polytechnic University, TUSUR University, Bauman Moscow State Technical University, and other technical universities. The systems of cross-cutting activity in engineering entrepreneurship are developed on their base (from pre-university to postgraduate spheres).

The systems include the elements as follows: 1) work with seniors high school students [25]; 2) multi-level work with students when studying at higher education institution (including the Olympiads on engineering entrepreneurship [26], summer schools of engineering business in BMSTU [27] and summer Lean schools "Economical Production" in TPU, club activity like "Kaizen" club in Tomsk or "KLIP" club in BMSTU); 3) interactions with the graduates who have become entrepreneurs and able to act as experts, consultants, and also business angels of the students' entrepreneurial projects.

The "Test site of engineering entrepreneurship" was opened as educational and scientific laboratory of Institute of engineering entrepreneurship of TPU in 2010 [28, 29], and became an efficient element for the training systems of engineers-entrepreneurs.

The concept of engineering entrepreneurship support in SUSU offers the similar steps (see Tab. 4). However, as distinct from the models developed in the above mentioned universities, our model contain the following ideas: 1) support from TRIZ-FCA-trained faculties from the different departments; 2) closer interrelation of innovation idea search technology with technology of problem identification and solution in the existing systems based on TRIZ and FCA; 3) application of technologies of parametrical optimization of the TRIZ-FCA devices based on planning extreme experiments; 4) application of theory of creative person development (TCPD) for teambuilding in small innovative enterprises (SIE), which involves laws of team development and TRIZ ideas; 5) long experience of holding the training, consulting seminars, innovative designing, innovation commercialization, and complex engineering based on TRIZ and FCA under the conditions of market formation at national enterprises and also effective consulting activity of TRIZ experts at leading companies of Europe, America, and Asia [9, 30].

Table 4. Stages of the concept-project implementation to support engineering entrepreneurship in SUSU

№	Actions (steps)	Realized functions (F)	Expected results (R)
1	Introduction of the subject "Engineering entrepreneurship" into engineering education programst	F1. To introduce the bases of innovative business to students. F2. To encourage students to work in high tech industry. F3. To select students for innovative structures of higher education institution.	R1. Identification of students interested and able to be engaged in business. R2. Employment of motivated staff for innovative structures of higher education institution.
2	The launch of additional training, foundation of the educational and scientific laboratory "Test site of engineering entrepreneurship"	F2. To motivate students to work in the high technology business F4. To provide additional. knowledge and skills necessary for engineering business activity. F5. To involve students in innovative activities of the "Test site" and other innovative structures of higher education institution F6. To involve faculty of the university in the "Test site" activities.	R3. Improved status of the engineering education. R4. Presentation of the projects which are brought closer to reality on Olympiads and exhibitions held in higher education institution with R5. Increase in the number of small businesses (SIE) established while and after training. R6. Extent the scope of Research and Development of higher education institution.
3	Organization of summer and winter schools of engineering entrepreneurship	F2. To give greater focus to motivation of students for high tech industry. F7. To develop a number of practical skills of innovative activities. F8. To encourage students to develop innovative products and open small enterprises for their implementation.	R7. Improved status of the engineering education provided institution. R8. Organizations and people interested in innovative projects. R9. Stable performance of small businesses.
4	Organization of trainings on team building for engineering entrepreneurship	F9. To develop team work skills the sphere of high tech. industry. F10. To build teams for innovative business. F11. To develop business for a team F6. to involve more faculty in the activities of the "Test site".	R10. Increased number of SIE established while and after training. R11. Increased number of active young engineers with developed leadership skills. R12. Increased number of faculty involved in innovative entrepreneurs.
5	Organization of consulting support for opened enterprises of small business	F12. To ensure support for young businessmen within the project framework. F6. To involve more faculty in the activities of the "Test site".	R13. Developed strategy to regulate small business enterprises involvement in the project (as well as designing them out). R14. Intensive Research and Development at higher education institution. R15. Phase of system sustainability.
6	Development of the system to train regional small innovative business	F13. to develop key competencies used in the sphere of the national innovative economy.	R16. Community of business angels, system of crowd funding and charity performed by successful entrepreneurs.

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