Formation of project environmental thinking in the training of engineers

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Abstract. At transition of civilization to the sixth technological way and the Industry 4.0 the speed of new technologies emergence, which influence on the environment can be different from former, increases. The created means of environmental protection can be insufficiently effective for new technologies. In these conditions the formation of project environmental thinking is important when training engineers to fully consider ecological requirements directly during the development of new technologies. In this work the possibilities of the theory of inventive problem solving (TIPS) use as effective means of modern engineering thinking for project ecological thinking formation are considered. The theoretical analysis and systemic synthesis of the TIPS methods and the didactic system of innovative education "TIPS pedagogics" are applied. The possibilities of TIPS in innovative thinking formation and its highest form, such as sustainable thinking, including ecological project thinking, modern ecological outlook and noosphere thinking, starting since school level, are shown. The possibility of a collaborative activity in interactive training, using the method of innovative projects, allows to find new problems solutions, including in ecological education.

1. Introduction

The transition of civilization to the sixth technological way as a set of associated production which core is formed by convergent NBICS (nano - bio - info - cognitive and social) technologies, to the Industry 4.0 significantly influences both environmental problems specificity and possibilities of their solution. The development of nanotechnologies, together with breakthrough achievements in various industrial products quality indicators, can lead to environmental pollution by nanoparticles the influence of which on living organisms is difficult to predict. The same can be said about biotechnologies wastes if released into the environment. The transition of production from subtractive to additive (for example, 3D - printing) reduces but does not fix completely a problem of wastes. More and more space technologies influence the environment: an increase in missile launches number influences, for example, agricultural workers health in adjacent to the spaceports territories; accumulating "space debris" subsequently forms extensive "garbage islands" in the oceans.

In general environmental protection problems during the transition to the sixth technological way (and especially to the subsequent ways which philosophers and sociologists already speak about) gain a significantly more common, systemic character. The main systemic problem is that the acceleration of new technologies creation leads to the lag in creation of protection means against
new types of the harm from these new technologies. The solution of this common problem refers to the tasks of sustainable development (Sustainable Development).

Nowadays the relevance of sustainable development problems increases so that requires a scientific approach not only to specific areas of human activity, to specific territories and branches, but also to the concept of "sustainable development" in general. The need for a fast solution of the emerging environmental problems demands the corresponding methodology based on the common, fundamental ideas of development processes. Timely and high-quality training of future engineers in this methodology is not less important (as well as operating engineers in the form of further professional training).

2. Environmental and cognitive technologies

According to economists and sociologists forecasts, cognitive technologies will enter a core of the sixth technological way, along with new production technologies. The comprehension of cognitive technologies as technologies of computer model operation of a number of human brain functions [1] is the most widespread. Along with it, there is a comprehension of cognitive technologies as technologies of human brain functions improvement, in particular a creative function [2]. In both of these cases of comprehension, cognitive technologies are technologies of information creation (knowledge or project decisions). In this sense, cognitive technologies do not harm the environment. However, the use of cognitive technologies in the second comprehension if it is directed only to the projection of new, more economically efficient production technologies, without taking into account ecological requirements, can increase environmental damage.

The cognitive technologies having at the same time the property of creativity began to be created in ancient times: Socrates maieutics [3] and heuristics of Pappus Alexandria [4]. In the Middle Ages the philosopher Raymond Lully created "Lully's Circles" [5]. In the 20th century with the growing need for innovative ideas a number of new methods were created: brainstorming [6], lateral thinking [7], the method of focal objects [8], morphological analysis [9], sinektika [10]. The theory of inventive problem solving – TIPS [11] is considered to be the most modern and efficient, gaining more and more wide recognition in the world. TIPS has already been actively applied to innovative solutions generation by leading multinational corporations: Boeing, Kodak, Intel, Samsung [12] and, according to the growing demand for experts, is taught in a number of leading world universities of the USA, Europe, China, Southeast Asia, Australia.

The effectiveness of TIPS is caused by the fact that it is not just a set of divergent ("departing" from stereotypes) thinking methods, but it combines divergent and convergent ("merging" to the required decision) thinking. At the same time convergent thinking is based on the laws of technical systems development opened by the author of TIPS G.S. Altshuller and also on the principles, techniques, standards concretizing these laws. In turn, the named laws of systems development are a specification of philosophical science laws on dialectics development, therefore TIPS received one more name "applied dialectics", in particular in relation to its extension to not anthropogenic systems [13]. In this regard it is possible to predict that TIPS will become the main cognitive technology in the second comprehension (i.e. possessing creativity) which is applied in science, technique, economy of the sixth technological way [14].

Briefly the substance of TIPS can be expressed as follows:

1. Any solution of a problem task (the result of which is the innovative idea) is the act of some system development.
2. Development, according to dialectics, occurs through accumulation and overcoming (resolution, elimination) contradictions.
3. Therefore, if there is a problem, it is necessary to find a contradiction in it and to overcome it.

The external contradiction manifestation is usually the impossibility of system quality indicators improvement within its former structure. After contradiction overcoming a system performing some function better than the previous system in which there was a contradiction is formed. This new system has qualitatively different structure (qualitatively different principle of action).
To overcome contradictions in TIPS, in addition to classical dialectics, there are corresponding “intelligent tools”: laws, principles, techniques, standards, algorithm. These “intelligent tools” reflect the regularities of systems development existing in the anthropogenic and not anthropogenic world.

Currently, a new based on TIPS class of computer programs – CAI (Computer Aided Invention) supplementing the complex CAD, CAM, CAE with design tools of fundamentally new structures of technical systems is being developed in the world.

The distribution of TIPS in the world has naturally led to the application of TIPS in the solution of ecological tasks [15, 16] as well. So far there is an experience of TIPS application for the solution of specific objectives of harm decrease or prevention to the environment from specific technologies. Based on philosophical, systemic character of TIPS ("system" – one of the basic concepts of TIPS), it is important to consider the possibilities of application of this science for the solution of the above-named systemic problem: possible lag in creation of protection means from new types of the harm caused by new technologies.

3. Concept "Degree of system ideality" as tool of environmental thinking

The first law of systems development in TIPS – the law of ideality degree increase: "In the process of all systems development their degree of ideality increases, striving for infinity, but never reaching it". (In the literature on TIPS there are also other formulations which differ in separate words and their alternation, but not differing essentially) [11, 17].

The concept "ideality degree" is usually expressed with the formula which has not a strictly mathematical, but a methodical character:

\[ H = \frac{\sum \Phi_U}{\sum \Phi_P} \rightarrow \infty, \]

Where \( H \) – ideality degree, \( \Phi_U \) – useful factors, \( \Phi_P \) – reckoning factors.

The degree of system ideality is the relation of its useful factors sum to the factors of reckoning sum (with what we "pay" for the useful factors). The concept "ideality degree", in essence, is the concept "purpose function" expansion which engineers use improving the composite technical system within its former structure, especially by computer optimization. The function of purpose has a precise mathematical expression. In TIPS the concept "ideality degree" is applied to the creation of fundamentally new systems, i.e. systems with a new structure. At the same time the degree of ideality increases so significantly that it is obvious without accurate mathematical formulation.

The given above definition of ideality degree refers to anthropogenic, including technical, systems. For not anthropogenic and social systems, as G.S. Altshuller followers researches show, it has specificities. However the questions of ecologically safe technical systems creation are considered here, therefore we will further use this definition.

From the point of view of the ideality degree the question of environmental protection comes down to whether such factor of reckoning as environmental harm is considered during new equipment and technologies designing. Judging by the fact that so far no noticeable acceleration of various environmental problems solutions has been observed in the world, the corporations applying TIPS in innovation consider this factor insufficiently so far. The named factor consideration leads to the emergence of additional contradictions which it is necessary to overcome, however potent "intellectual instruments" of TIPS, including application of CAI class programs, allow to make it.

Thus, TIPS methodology possession becomes the most important new part of engineers ecological culture while this methodology is applied to such increase in the new projected systems degree of ideality when the reckoning factor in the form of environmental harm is considered in it.

4. Innovative thinking and environmental thinking

Due to the accelerating process of innovations creation such term as "innovative thinking" is more often used. As the analysis shows, practically all formulations have common character and are expressed as an ability to do something (provide innovative activity; search, open, create a new; overcome stereotypes of public consciousness; call into a question effectiveness and success of
traditional concepts and approaches. For actual formation of innovative thinking, in an education system as well, such formulations are not enough. Creation and distribution of TIPS engineering projection in practice allows to define the concept "innovative thinking" as the project thinking directed to various systems of the environmental anthropogenic and not anthropogenic world improvement by searching and overcoming contradictions in these systems. This definition does not reject all above formulated, but supplements them to such a degree when creation and use of the appropriate learning tools is possible.

At the same time the concept "environmental thinking" (it is possible to take "ecological thinking" for a synonym) should be also specified as the thinking acquiring a project character and directed to overcome contradictions between economic efficiency and ecological safety of the created innovative techniques and technologies.

Working on the theme of sustainable development which includes environmental protection as the major part and also considers other factors, we formulated the concept "sustainable thinking" as the project thinking directed to overcome contradictions between economic efficiency innovative technique and technologies and preservation of resources for future generations.

Respectively, the concept "ecological outlook" so far formulated as deep awareness of vital need of the environmental life, common for all mankind, preservation [18], it is expedient to add and formulate as vision of the world around, as a system consisting of various level subsystems, developing under the laws which can be learned and used for the life environment, common for all mankind, improvement.

Finally, the concept "noosphere thinking" on the basis of which the concept of sustainable development as the global thinking in its communication and interaction with a cognitive envelope of the earth [19] assuming the ability to project and predict consequences of the interaction with the world around [20] is built, it is possible to complement with ability to see and overcome the arising development contradictions between economic and ecological expediency. Since the noosphere existence opening [21], by V.I. Vernadsky, the noosphere developing as well as all systems of the world, has undergone a certain evolution and, according to the authors, entered a quantum leap stage in the development of the first part of the word "noosphere" – a noo, in Greek mind. While the mind of people did not rely on ecological outlook in its offered modern comprehension, the world development was a resultant of various, often opposite, aspirations of people, and kept a substantially spontaneous character. The ecological outlook in the modern comprehension gives much more conscious character to the development of the world directed to its stability, preservation of resources for future generations.

5. Formation of environmental thinking in educational system

Formation of environmental (ecological) thinking is considered to be a problem of education for sustainable development (ESD) which develops in the world according to the United Nations decision by efforts of UNESCO. During 2005 - 2014 there was a Decade of education for sustainable development throughout which the Global action program (GAP) in the field of ESD started to be carried out. So far ESD was generally understood as the reflection of sustainable development questions in the form of separate training courses, separate subjects, lectures at various stages of education [22], though the task of integration of ESD into all types and stages of education was set. Creation and distribution of TIPS in the world, and together with the systems integrated with other subjects of TIPS study – the didactic TIPS pedagogics system [23], caused consideration of TIPS pedagogics use opportunities as an integrated system of ESD. First of all, it was necessary to extend the TIPS pedagogics system to all stages of an educational process as earlier there was one method of creative tasks [24] in it. A method of knowledge invention (for a stage of new material studying) and a method of innovative projects (for a project activity and scientific-technical creativity including youth intensive schools) were developed by the experts who are the authors of the present article [25-27]. In this regard it meant that before improving the development processes, making a sustainable development, it is important to have a general representation of development mechanisms. This representation is formed by the method of knowledge invention according to which each studied system on any subject, any educational program is "re-invented" by TIPS methods as a result of
contradictions in predecessor system overcoming. At the same time this promotes better assimilation of the studied material and formation of the major competences.

The method of innovative projects is, in essence, the association of Problem Based Learning (PBL) Problem Based Learning (PBL) [28] and TIPS. The method includes an option for youth intensive schools and other situations when a small number of teachers who know TIPS have to manage the creation of dozens of youth innovative projects at the same time. This option provides double or group supervision of intensive school participants' scientific works. One of heads – a methodologist of creativity who knows TIPS and raises questions to all school participants, according to TIPS, and other heads – scientists and experts in scientific and technical areas corresponding to the subject of the created projects. They provide answers to the questions of the first head.

Exactly with the method of innovative projects it is expedient to create such projects of new technique and technologies in which the contradiction between economic efficiency and ecological safety is resolved.

As the approbation of the method of innovative projects which was carried out more than 15 years during its development, pupils and students created dozens of innovative projects – winners and prize-winners of All-Russian forums, patents for inventions were obtained, the Big scientific Russian Cup was won. Among them, a number of innovative projects on environmental protection is created: a high-capacity tanker not collapsing on storm waves (the patent of the Russian Federation), mutual neutralization of various harmful wastage, economic technology of utilization of "garbage islands" (the victory in the competition "SHUSTRIK" of innovative regions of Russia Association), the economic "cleaner of space debris", etc.

The possibility of TIPS assimilation and creation of projects on the basis of TIPS by school pupils of various stages checked by authors and their colleagues from various cities and countries in practice allowed the authors to create the concept "New polytechnical school" offering a new system of pre-university engineering and engineering-ecological education: in specialized classes, studios of supplementary education, in youth intensive schools, in Children's science and technology parks. The concept assumes application of the method of knowledge invention when studying new material and application of the method of innovative projects in project activity, scientific and technical creativity.

Recently, methods of interactive learning have been widely developed. Interactive learning is the learning with well-organized feedback of subjects and objects of learning, with a two-way exchange of information between them.

Interactive training allows you to form the active-cognitive and intellectual activity of students, increase the motivation to study the subject, develop in various forms the communicative competencies of students [29, 30]. The possibility of joint activities in interactive training, using the innovative projects method, allows to find new solutions to problems, including in environmental education, and this contributes to the development of education for sustainable development (Education for Sustainable Development) in accordance with the plans of UNESCO.

The main requirement of educational programs in the field of "Engineering, technology and technical sciences" becomes a practice-oriented as the ability to form a certain set of professional and over professional competencies that allow the graduate to quickly join the production chain. In the undergraduate program, the focus is on the implementation of applied engineering competencies and basic soft skills, work in team engineering projects in competition formats and the introduction of the mandatory end-to-end module "Project Activities". Master programs focus on specialized engineering competence and soft skills in project management, end-to-end qualifying work in the form of a real engineering project. Engineering master programs aimed at training engineering teams in order business and the implementation of real engineering projects [31].

6. Conclusion
The possibilities of the theory of inventive problem solving (TIPS) use as an effective tool of modern engineering thinking for project ecological thinking formation are shown. The acceleration of scientific and technical progress rate causes new environmental problems, but due to the presence of cognitive technologies at the same time contains efficient means of these problems. Solutions It is
important to make full use of these means. The use of interactive technologies in the organization of training opens the opportunity to consider the issues of individual educational strategies defining the direction vector and content of future engineers education, to improve the quality of their training and creates opportunities for self-realization.

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References

[1] Dror I E 2007 Gold Mines and Land Mines in Cognitive Technology. Cognitive Technologies and Pragmatic of Cognition. Edited by Itiel E. Dror. University of Southampton. (Amsterdam / Philadelfia: John Benjamins Publishing Company) 1-7

[2] Finansovyy slovar [Financial dictionary] 2017 Cognitive Technologies Access 06.12.2017, available at: https://dic.academic.ru/dic.nsf/fin_enc/23874

[3] IEP – Internet Encyclopedia of Philosophy (2017). Socrates. Access 05.12.2017, available at: http://www.iep.utm.edu/socrates/#SH3b

[4] Encyclopaedia Britannica 2017 Pappus of Alexandria. Access 05.12.2017, available at: https://www.britannica.com/biography/Pappus-of-Alexandria.

[5] Stanford Encyclopedia of Philosophy 2017 Ramon Llull Access 07.12.2017, available at: https://plato.stanford.edu/entries/llull/.

[6] Osborn A F 1963 Applied Imagination: Principles and Procedures of Creative Problem-Solving 3rd Edition (N.Y.: C. Scribner)

[7] De Bono Edward 1970 Lateral thinking: creativity step by step (N.Y.: Harper & Row)

[8] Whiting C H S 1958 Creative Thinking (N.Y.: Reinhold)

[9] Zwicky F 1957 Morphological astronomical. Springer-Verlag

[10] Gordon W J J 1961 Synectics: the development of creative capacity (N.Y.: Harper & Row)

[11] Altshuller G S 2007 The Innovation Algorithm: TRIZ Systematic Innovation and Technical Creativity Worcester (MA: Technical Innovation Center)

[12] Shaughnessy H 2013 What Makes Samsung Such An Innovative Company? Forbes Access 07.12.2017, available at: https://www.forbes.com/sites/haydnshaughnessy/2013/03/07/why-samsung-such-an-innovative-company/?utm_referrer=https%

[13] Pogrebnaia T V, Kozlov A V, Sidorkina O V and Pogrebnaia T V 2017 TRIZ and applied dialectics, available at: http://www.metodolog.ru/01108/01108.html (access: 06.12.2017)

[14] Kozlov A V 2016 Thought Process of Engineering “Elite Force” Russian Development Technologies. Engineering Education 19 14-18 Access 07.12.2017, available at: http://www.aeer.ru/filesen/io/m19/art_2.pdf.

[15] Yang M and Guo M 2011 Application and analysis of TRIZ in man-made environment. In Proceedings of 2011 IEEE 18th International Conference on Industrial Engineering and Management (Changchun, China)

[16] Serban D, Man E, Lonescu N and Roche T A 2003 TRIZ Approach to Design for Environment Product Engineering pp 89-100

[17] Orloff M A 2003 Inventive Thinking Through TRIZ: A Practical Guide

[18] Ecology. Directory 2017 Access 07.12.2017, available at: http://ru-ecology.info/term/13769

[19] Noospheric Thinking 2017 National encyclopedic service Access 07.12.2017, available at: http://didacts.ru/termin/noosfernnoe-myshlenie.html.

[20] The concept of celebrating the 150th anniversary of the birth of V.I. Vernadsky "Noospheric Thinking - Thinking XXI" 2013 Access 07.12.2017, available at: http://www.vernadsky.ru/files/o_vernadskom/150/Koncepciya%20150-letiya.pdf

[21] Vernadsky V I 1989 Biosphere and noosphere (Moscow: Nauka) p 261

[22] Hopkins C 2013 The Future of ESD. In Proceedings of International conference on education for sustainable development 18 (Khanty-Mansiysk, UNESCO Vestnik) pp 358 – 363
[23] Vikentiev I L, Gin A A and Kozlov A V 1998 TRIZ-pedagogy. In the Book of Creative Problems in Biology, Ecology (St. Petersburg: Akcident) pp 162–165
[24] Gin A A and Andrzheyevskaya I Yu 2010 150 tvorcheskikh zadach o tom, chto nas okruzhaty [150 creative tasks about what surrounds us] (Moscow: Vita-Press)
[25] Lepeshev A A, Podlesnyi S A, Pogrebnaya T V, Kozlov A V and Sidorkina O V 2013 TRIZ-based Engineering Education for Sustainable Development. In Proceedings of IEEE International Conference on Interactive Collaborative Learning (ICL) (Kazan, Russia) pp 489-493
[26] Lepeshev A A, Podlesnyi S A, Pogrebnaya T V, Kozlov A V and Sidorkina O V 2013 Development of creativity in engineering education using TRIZ. In Proceedings of IEEE Interdisciplinary Engineering Design Education Conference (IEDEC) (Santa Clara, USA) pp 6-9
[27] Kozlov A V, Pogrebnaya T V and Sidorkina O V 2013 ESD in UNESCO Associated schools. Didactics of sustainable development. In Proceedings of International conference on education for sustainable development 18 (Khanty-Mansiysk, Russia, UNESCO Vestnik) pp 228-237
[28] Boud D and Feletti G 1998 The Challenge of Problem-based Learning. Milton: Routledge
[29] Loginova I O and Chupina V B 2011 Technology of interactive learning in the university (Krasnoyarsk: KrasGMU)
[30] Yakovleva N O and Yakovlev E V 2014 Interactive teaching methods in contemporary higher education. Pacific Science Review 16 75–80
[31] Kovalev I, Loginov Y and Zelenkov P 2015 An integrated system of training engineers for aerospace industry in Siberia using innovative technology of the student project-and-team work. Procedia – Social and Behavioral Sciences 174 pp 537-543