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UDC 378: 37.026

CDIO: Objectives and Means of Achievement

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The system of CDIO standards in terms of implementation in Russian engineer¬ing education is analyzed. Particular attention is paid to the scientific and methodological elaboration of «Con-ceive» stage. To increase the efficiency of this stage, domestic TRIZ methodol¬ogy is considered. Relevant didactics, CAI programs and virtual environments of professional activity are proposed. It is indicated that international standards are more effective when they are imple¬mented in educational-scientific-indus¬trial (innovation) complexes.

Key words: Conceive, TRIZ, applied dialectics, knowledge invention, innovative projects, CAI programs, virtual environments, technological engineering centers.

In the era of postindustrial information society and innovative economy specific emphasis are put on the training of engineers that are able to create new technics and technologies. CDIO International Standards guide towards a complex approach for the formation of such specialists. These standards stipulate system training of engineers able to conceive ideas, design, implement, operate and utilize products of engineering activity.

De facto, by far not every staff member of scientific and development divisions of the world leading corporations possesses a full set of qualities that are proposed by CDIO Standards. As a common rule, dedication to only one or two CDIO stages takes place in practice, for instance, a "Conceive – Design" or an "Implement – Operate" stage. According to psychologists' statistics only a small percent of people are able to generate up-to-date ideas and work in design. At the same time, it is essential for any engineer to fully understand all stages of new technics and technologies' life cycle.

Equal mastering of all four stages of CDIO model by all engineering students is a great challenge even for world leading universities due to the psychological characteristics mentioned above. On a national level of engineering education system this is impeded by insufficient laboratory facilities for experiential part of the second stage and poor facilities for the third and the fourth stages.

The second stage – "Design" – usually starts with routine calculations. Numeric parameters of the technical system elements are defined. The structure of the system is normally designed on the "Conceive" stage. To a big extent most engineering universities provide infrastructure for the first (estimation) part of the "Design" stage, namely the software for automated design systems: CAE (Computer Aided Engineering) systems and, as their component, CAD (Computer Aided Design) systems. Application of PML (Product Lifecycle Management) systems used not only for the second, but for the later stages as well, is expanding. Learning of the mentioned systems (according to the industry sector) is included in programs of corresponding educational directions and majors.

Next to the calculations of the "Design" stage is the experiential part, whose infrastructure is usually developed rather weak. Systems of multidimensional simulation and, later on, relevant subsystems of virtual domain for professional activities can become an up-to-date solution to this problem [1].

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Exploitation of the industrial facilities from partner enterprises – "consumers" of engineering universities' graduates – for the third and fourth stages is available in most cases only to those students, who take part in contractual development projects on request from those enterprises. Best facilities are provided for students at Educational-Scientific-Industrial Networks and Educational-Scientific-Innovative Net-works that unite universities, research and development organizations, technological engineering centers and production enterprises, with an extensive attraction of staff and students for its work activities. However, life cycle of real products usually lasts much longer than educational process at university.

Full-scale execution of the third and fourth stages at Russian universities can be conducted with the use of professional virtual domains enabling fast-track imitation of a product life cycle. This stimulates development of these stages for different educational directions and majors.

The most troubling situation regards the "Conceive" stage. It is on this stage that the creative process of conceiving new structures for technical devises and systems is executed. With the societal transition to the fifth and sixth wave of technology, the demand for breakthrough unconventional high-tech solutions development is rising. Therefore, employers expect engineering universities' graduates to have the ability to generate innovative ideas. And students have to learn this. Current state of infrastructure for development of breakthrough solutions can be characterized as following:

Analyzing CDIO Standards, it appears that they basically represent a set of objectives specifying the main aim of CDIO: "to ensure engineering educational programs' content and effectiveness in compliance with current level of technology development and employers expectations". Stepping stones for achieving the main aim are given in a generalized manner. For instance, "Students engage in the practice of engineering through problem solving and simple design exercises, individually and in teams" (Standard 4); "The curriculum includes two or more design-implement experiences" (Standard 5); "Professional leave to work in industry, partnerships with industry colleagues in research and education projects" (Standard 9), etc. Slightly more precise methods are listed in Standard 8: "…Active learning in lecture-based courses can include such methods as partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning…".

The most specific means of CDIO elaboration are stated in Standard 2 "Learning outcomes" as the CDIO Syllabus [3]. A set of achievement methods for the listed outcomes, both for the reduced (three decomposition levels) and for the full (four decomposition levels) versions, can be found in the academic literature as well as in the articles on CDIO experience of different universities from various counties. The expansion of the university society implementing CDIO Initiative enables gaining valuable experience, selecting best practices and exchanging them within the network. It is worthwhile to create a constantly evolving database of such practices.

At the same time, there are some learning outcomes among the CDIO Syllabus that imply controversial opinions within scientific, pedagogical and engineering communities. In particular, this refers to the addressed "Conceive" stage, to which the Syllabus 2 is dedicated: Personal and Professional Skills and Attributes including 2.1. Analytic Reasoning and Problem Solving; 2.4. Attitudes, Thought and Learning. Most of the subparagraphs of the 2.1. Syllabus are dedicated to problem solving (although there is an opinion that this could be done in a different manner). Some of subparagraphs are devoted to learning outcomes; and only one subparagraph covers the solution itself. Many agree that problem solving is a creative artistic act usually leading to tailor-made ideas, however, the essence of creativity and possibility of its algorithmization evoke controversial opinions. From one common point of view, it is impossible to teach creative thinking; it comes as an insight, an epiphany. Such attitude logically leads to inability of the majority of students to successfully elaborate the "Conceive" stage, and, inevitably, all of the later stages.

Along with that, an opposite point of view has existed since the ancient times underlining the possibility and feasibility of creative thinking formation. It is becoming more and more fortified with help of methodological and, in the past decades, programming tools. Nowadays, the widest recognition as a biggest achievement in methodology of inventive solutions generation has been given to internationally acknowledged Theory of Inventive Problem Solving (TIPS, TRIZ), created by Soviet scientist Genrich Altshuller (1926-1998) and, later on, developed by his students and followers. TRIZ theory is highly effective, since it is not just a set of methods, but a "development philosophy" setting equivalence between innovation creation and development of anthropogenic world under the laws of didactics incorporating constructive methods of overcoming development contradictions, which results in inventive solutions generation.

It is notable that TRIZ is not only a complex of methods corresponding with fundamental laws of didactics, but a constantly evolving and specifically structured database of various laws of nature – funds of phenomena: physical, chemical, geometrical, etc. Database of biological phenomena has been growing rapidly for the past few years. Development of psychological, social and other databases has started recently. It is not only the set of phenomena that makes databases valuable and significant, but the principles of its structuring that allow for its efficient use in inventive solutions development. These principles can and should be used when structuring new knowledge.

Nowadays, TRIZ is widely used by many leading transnational corporation for inventive solutions development. For instance, Intel Corporation, that has an Intel TRIZ Chapter division, states on its website that TRIZ technologies are "tracking millions of dollars saved". Samsung also has a similar division. The same methodology is actively applied by Boeing, Kodak, Procter&Gamble, LG, Western Digital, Motorola, Siemens and other companies.

Following CAD and CAM programs, CAE program class has been enriched by CAI (Computer Aided Invention) programs such as «Innovation Workbench», «Invention Machine Goldfire», «InnoKraft» and others, containing TRIZ methods, as well as phenomena databases. These programs are almost unknown in Russia, even though their predecessor, "Invention Machine", was created in former Soviet Union.

A number of universities using TRIZ in their educational practice for the purpose of updating students' ability to generate ideas is rising. Among such universities are: University of Oxford, Massachusetts University of Technology, Stanford University, universities from Europe, South-East Asia, South Africa, China, etc. Generally TRIZ distribution in different countries is initiated by expatriated or temporarily migrated specialists from Russia and other countries of the former Soviet territory.

Expanding implementation of CDIO system in universities of Russia – the motherland of TRIZ (together with other former Soviet Union countries) – creates new opportunities for TRIZ integration to CDIO. First of all, in order to comply with Standard 4, it is essential to develop a radically new course "Introduction to engineering" that would demonstrate essence of engineering, its scientific content, resource limitations (financial, ecological, social, technological, etc.), engineering problems on all stages from conceiving to utilizing, and levels of inventiveness in problem solutions (for example, based on Altshuller's 5-level scale). During the course conduction and its workshops and design projects, at least some students will have an opportunity to carry out the "Conceive" stage.

Russian universities have a significant advantage – existence of TRIZ pedagogy didactics invented in Russia that allows structuring scientific knowledge and learning of TRIZ methods in compliance with Standards 3, 7 and 8, and in integration with other disciplines: not only technical, but scientific and humanitarian. Engineering developments, namely the method of knowledge invention and the method of innovative projects [6, 7] conducted at Siberian Federal University and its partner educational establishments have disseminated this system to all stages of educational process. TRIZ pedagogy deepens understanding of disciplines, forms creator mindset, and complies with new ecological paradigm "Synergy with Nature". That is the reason why TRIZ pedagogy serves as basis for elaboration of educational technology in the context of sustainable development corresponding to the aims and objectives of the United Nations Decade of Education for Sustainable Development (2005-2014), supported by UNESCO, and the activities following the Decade [7].

Potential competitive advantage of CDIO introduction to the native engineering education mostly refers to the "Conceive" stage and incorporates availability of TRIZ specialists and didactic system of TRIZ pedagogy. This advantage does not only permit the development of a new "Introduction to Engineering" course, but provides teaching of various disciplines on different study years by method of knowledge invention ("reinventing" explored technical and other systems with the use of TRIZ methods), conceiving innovative ideas and inventions by inventive projects method of knowledge structuring within internships, design projects, scientific research projects and thesis projects, and effective application of CAI computer programs.

Aiming to comply with Standards 1, 2 and 4, regarding teamwork, it is essential to form project teams that include students with various skills, who would be able to: generate ideas, design, implement, operate project's life cycle, manage the project, provide marketing, etc.

Up to this date, Siberian Federal University (SFU), and former Krasnoyarsk State Technical University that is now a part of SFU, has gained sufficient experience in inventive solutions creation (conceiving) not only on the later years of study, but on the early stage of university education and pre-university education. Starting from 1994, high school students have been placing high or winning National Youth Scientific Forums on a regular basis. And they continue developing their projects and successfully present them on international forums once they enter the university. SFU students and university applicants team won a Big Science Cup of Russia in the "Step forward" program. Some of the latest achievements are: SFU future applicants' first place in the «Shustrik» competition organized by the Association of Innovative Regions of Russia (AIRR), second place diploma in "Baby Farm" competition of Skolkovo International Conference "Startup Village", "Best Invention of the Year" regional award-winning joint patent of SFU and its basic school – Krasnoyarsk school □10 named after academician Yu.A. Ovchinnikov – piloting the described methods. Numerous intensive summer schools of inventive-innovative profile in Krasnoyarsk Kray, as well as innovators clubs in national child centres «Orlyonok» and «Ocean», have been held according to the developed curriculum. A set of professional development courses for teachers of different educational levels and specialties, teaching them the knowledge invention and innovative projects methods, has been conducted at SFU. These courses were partly organized with support of grants from the Ministry of Education and Science of the Russian Federation and All-

Russian Fund "National Perspectives".

Thorough implementation of the CDIO system at Russian universities (and many foreign universities as well) takes time, therefore, it is viable to develop "road maps". Common features of such "road maps" can be as follows:

- Creation of Educational-Scientific-Industrial Networks, Educational-Scientific-Innovative Network, including technological engineering centers.
- Development of virtual environments for professional activity including subsystems similar to modern CAI class programs and in cooperation with PLM systems.
- Introduction of various disciplines on knowledge invention methods to the teaching process, and of innovative projects methods – to internships, design projects, scientific research projects and thesis projects.

Pursuit of these "road maps" shall lead to the development of innovative project model of the university that includes profound practice-oriented student training.

A full-scale implementation of CDIO International Standards permits development of engineers' systems thinking that is indispensable for innovative economy.

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