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The Development of Approaches to Engineer Training Improvement in the Research University in Compliance with the International Standard

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The article deals with the problem of practical implementation of CDIO international standard approaches to the engineering training of bachelors in the research university. The purpose to implement the CDIO concept is to improve the engineering education up to the level of leading world technical universities. The use of method of group project training is considered by the example of solution of urgent engineering tasks of the project "Proryv" ("The Break"). The number of accomplished students' projects presents the results of this method implementation.

Key words: Engineering education, CDIO Standard, Group project training.

At present, there is a strong deficit of skilled engineering staff at the labor market (36% of the market gross share). Insufficient quantity of specialists in the engineering sphere is conditioned by the loss of prestige values of the relevant specialties in the 1990, lower level of engineer's income, as compared with economic, juridical and other specialties and general demographic decline (Fedorov I.B., Medvedev V.E., 2011).

Because of traditional system based training, when the students get non-utilitarian knowledge, with the lack of current knowledge and practical experience, the labor market become full of graduates, the competencies of whom are out of keeping with the employer's requests (Vladimirov A.I., 2011). The interested plants prefer to hire the experienced specialist, or, in case of personnel at labor market, are to train the new employee at their own expense (Podlesny S.A. and Masalsky G.B., 2014).

Thus, at present, an urgent task is to create the skilled engineering personnel, who, by the close of educational institution, possess not only fundamental background, but also the skills of practical project activity (Alykova O.M. and Smirnov V.V., 2013), having the experience of team work, able to analyze and solve problems in the course of project development (Minin M.G. and Vyuzhanina N.Yu., 2013). To solve this task, a pilot project for bachelors' training, in compliance with the principles of international CDIO standard, was developed at the "Construction of Instruments and Units" Department of the National Research Nuclear University MEPhI (CDIO, 2014).

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CDIO (Conceive – Design – Implement – Operate**)** presents a large international project on reforming of engineering education, which was started in 2000 (Crawley, E. F., 2001). This project, named "The World Initiative of CDIO", includes technical programs of the leading engineering schools and technical universities of the USA, Canada, Europe, Russia, Africa and New Zealand. The purpose of this project is to provide students with the education, which underlines the engineering bases, set out in the context of life cycle of real systems, processes and products (The World Initiative of CDIO. Standards: Informational-Methodological Publication, 2011).

MATERIALS AND METHODS

The purpose of the CDIO Initiative is to bring the content and effectiveness of engineering educational programs into the compliance with the development level of modern technologies and employee's expectations. The CDIO Standards (12 CDIO Standards) determine special requirements to the CDIO programs, which can be the guidance to reform and evaluate the educational programs in the sphere of processes and technologies, as well as to create the conditions of their continuous improvement.

12 CDIO Standards determine the requirements to the following:

a) The concept of engineering educational programs (Standard 1);
b) The formation of curriculum (Standards 2, 3);
c) The practice-oriented educational environment (Standards 4, 5, 6);
d) The educational methods and qualification of teachers (Standards 7, 8, 9,10);
-e) The methods to evaluate the students' training results and the program in whole (Standards 11 and 12).

The Standard CDIO 1 formulates the concept of CDIO and presupposes, that the content of engineering education is determined by the complex character of the engineering activity under the model "to plan - to design - to produce - to use".

The Standard CDIO 2 determined and specifies the requirements to the educational results and bachelors' training for complex engineering activity.

CDIO Syllabus (Planned educational results) are the competencies of the present bachelors' in the sphere of processes and technologies; they are classified as per four main sections:

1. Disciplinary knowledge and Engineering bases;
2. Professional competencies and personal qualities;
3. Interpersonal competencies: team work and communication;
4. Planning, design, production and use of products (systems) in the context of enterprise, society and environment.

As per the Standard CDIO 3, the developed educational plan is integrated, i.e. it contains the interconnected disciplines and a strict plan on integration of personal and interpersonal skills, as well as the skills to create products, processes and systems.

The Standard CDIO 4 determines the presence of introductory course "The Introduction to Engineering Activity" in the educational program, creating the basis for engineering practice when producing the products, processes and systems and formation of main personal and interpersonal competencies of the program graduates.

As per the Standard CDIO 5, the curriculum of the educational program shall include two or more projects, providing the student with the experience of project-implementation activity: one is one the basic level, the other one is on the advanced level.

The Standard CDIO 6 determines the necessity to create the working space, enough for the student to get the skills of practical engineering activity, social interaction, team and individual work.

The Standard CDIO 7 prescribes the educational institution to use the methods of integrative education, when implementing the educational programs.

The integrated education involves pedagogical approaches, which promote the acquisition of skills simultaneously with the development of personal and interpersonal skills, skills of engineering activity.

As per the Standard CDIO 8, the education in the higher educational institution shall be based on the use of active and effective practice-oriented methods, including:

a) Modeling of engineering practice;

b) Encouragement of analysis, reflection, expression of personal opinion;

c) Aimed at the increase of students' motivation.

CDIO presupposes the necessity of systematic increase of university teachers' qualification in the sphere of personal, interpersonal and professional competencies (Standard 9), the use of active and integrated methods of education and evaluation of its results (Standard 10).

The Standard CDIO 11 determines the necessity to use, when implementing the educational programs, the adequate methods to evaluate the results of education, forming professional, personal and interpersonal competencies of the graduates.

The Standard CDIO 12 provides the higher educational institute with the system to evaluate the correspondence of educational program to the CDIO concept and to provide the feedback with students, teachers and other related parties for continuous improvement of educational programs.

RESULTS

The Implementation of the CDIO concept in the National Research Nuclear University MEPhI implies the improvement of engineering education up to the international level, underlying the engineering bases, provided in the context of life circle of real systems of atomic, space and other high-technology industries.

The first step in concept implementation was done at the "Construction of Instruments and Units" Department for the Bachelor Degree Program 140800 "Nuclear physics and Technologies", the specialty is the "Information-Measuring Systems of Nuclear Power Units and the Procedure of Radiation Experiment"). The educational process of the Department was reorganized in such a way, that the graduates, in compliance with the international standard CDIO, would be able to demonstrate the following:

a) Deep theoretical knowledge of engineering bases and practical skills of engineering work;

b) Practical skills to implement all stages of life cycle of products, processes, systems, which are in demand by Russian and world market of nuclear industry;

c) The understanding of importance and strategic significance of scientific-technical development of the society and implementation of large innovative engineering projects.

The abovementioned approaches to the engineering education are implemented on the basis of the developed "road map", structurally uniting the purposes, tasks, project performance indicators, time horizon and required resources throughout the whole project implementation period. The first (approbatory) stage was successfully implemented; it has the following results:

a) A list of professional, personal and interpersonal competences was developed taking into consideration the CDIO Syllabus. It reflects the level of graduate's training in creation of new products, processes and systems;

b) There was developed and approved the curriculum, where the CDIO skills are integrated with the technical content of disciplines and the corresponding interdisciplinary links are provided; it also includes the discipline, providing the basic knowledge and skills in the spheres of project management;

c) The programs of basic educational disciplines were corrected in compliance with the development trend of practice-oriented approaches in education;

d) The training process was integrated with the scientific-research activity of laboratories, research centers, small innovative enterprises;

e) A program of basic introductory course "The Bases of Design, Construction and Engineering" was developed and approved; it is aimed at the stimulation of students' interest to the engineering activity (Surin V.I. and others, 2013);

f) A program of the discipline "Project Management Practice" was developed; it is aimed at students' knowledge acquisition and formation of skills in the sphere of project management.

g) A system for educational results evaluation was developed and approved; it includes oral and written examinations, tests, evaluation of projects and presentations of the educatee by the other students, self-judgment, compilation of personal student's portfolio, expert evaluation of competence development, the results of students engineering project contests;

h) A feedback with students, graduates, employers was organized using the network technologies;

i) A number of seminars and practical courses was held for the academic teaching staff of the Department on the use of active educational methods in training process;

j) A special training of teachers-tutors was held to provide the group project students training;

k) There was developed and implemented a methodology of group project training, in the course of which the students try themselves in roles, similar to real engineering practice;

l) Active training methods were implemented to the disciplines of the curriculum; they include inquiries, business games, modeling, solution of tasks from real practice etc (Fig.1).

Fig. 1. Tutor Baryshev G.K. holds a business game

m) The evaluation and analysis methods for the educational program were developed and approved.

The Standard 5 plays a special role in implementation of the CDIO concept; it implies, that the curriculum of the educational program shall include two or more projects, providing the students with the experience of project-implementation activity. The project is understood as the training-practical task on design and creation of products that is implemented by means of the engineering discipline complex. The students develop the skills to design and create new products and systems, and also to apply the theoretical knowledge in real engineering practice, solving training-practical tasks on design and creation of products and systems, integrated to the curriculum. The tasks on design and creation of new products and systems can be basic and advanced, depending on their profundity, complexity and sequence in program. For instance, the tasks on design and creation of simpler products and systems are executed at earlier program stages, meanwhile more complex engineering-technical tasks are suggested at later training stages for the students to be able to apply the acquired theoretical knowledge in practice. The tasks on planning, design, implementation and management of products and systems can be included as the extracurricular tasks, for instance, as term practice or production practice. Gradual increase of complexity level promotes deeper acquisition of basis, required for precise and profound understanding of technical disciplines. The development and creation of products and systems in conditions of real engineering practical context provide the students with the opportunity to come up with their future professional interests (The World Initiative CDIO. Standards: Information-Methodological Issue, 2011).

To implement the Standard 5, the "Construction of Instruments and Units" Department developed a methodology of group project training, which was successfully tested on the Department bachelors.

Group design is a practical training, the essence of which is to develop the engineering, construction, technological and other types of projects in actual practice (Bokov L.A. and others, 2013). The advantages of the method are the following:

a) Combination of individual and team work of students;

b) The method stimulates the development of creative skills and critical thinking (Yarvilyanina E.V., 2011);

c) The creation of project, general for the group, requires knowledge from each participant of the design process technology;

d) Group work forms the skills of interpersonal relations in order to solve the professional problems (Frolov S.E., 2012).

Thus, the curriculum of bachelors has the term paper “Group Design”. The work on each project presupposes the simultaneous participation of the students of third and fourth courses.

The students of the third course, starting from the fifth term, get the knowledge on special disciplines, under which they carry out the practical tasks, got from the students of the fourth course. The solutions are used in the group projects.

The students of the fourth term are divided into groups based on the following principle:

1. The project bureau involves several groups on the number of projects, each group has two people: the first is appointed as the chief constructor, the second in the project manager. Each group gets the task to implement the technical project, involving all stages of life cycle - from technical design assignment up to the pilot-line production.
2. The construction bureau involves the groups of 2-3 people, each group is responsible for the solution of tasks in definite sphere. For instance, “Electronics”, “Automation”, “Construction”, “Programming”. The construction bureau gets the tasks from the project bureau, distributes the part of works between the students of the third course and controls the execution process, lending assistance, if necessary.

Thus, the students of the fourth course get the skills of decision-making and real project and team management, and the students of the third course get the practical skills of problem solving under the subject matter (ZAmyatina O.M. and others, 2013).

The Department also developed a program of basic introductory course, which is one of the obligatory courses of the program, as it provides the key theoretical-practical basis. This basis involves the list of tasks and responsibilities of the engineer, and the use of disciplinary knowledge in practice. The students are involved into practical engineering, solving simple tasks on development of products, individually or in groups. The course also teaches the main personal and interpersonal competencies, provides theoretical and practical knowledge, required for the students to study at more profound stages of products and systems program. For instance, the students can participate in solution of practical engineering tasks in small groups, in order to solve more complex engineering tasks later in more numerous groups (The World Initiative CDIO. Standards: Information-Methodological Issue, 2011).

The program of basic introductory course, developed at the “Construction of Instruments and Units” Department, provides the students with the main competencies in development of real devices, units and systems; it is planned in such a way as to arise the students’ interest to the engineering activity, to describe it in best manifestations and then to develop the engineering way of thinking and to teach the engineering language.

The task to develop in students the system engineering thinking, to teach the main design approaches, construction and engineering is gradually implemented in the several modules of the training course.

The first module is motivational. This module includes a number of lectures, seminars, business games, master-classes and trainings, aimed at the formation in students a concept of the engineering current state. Usually, a brief historical journey to the engineering history is held, the attention is focused on the greatest engineering achievements of the XX century in the human history. The motivational part consists in perception of problematics of the activity by the students, development of communication and thinking of the present-day engineer and the engineer of future (“Competing Higher Education Futures in a Globalizing World”, 2007). A good practice is when the students write an essay about their idea of the future engineer (individual work) or mutual discussion of the future engineer image (group work). A good source of knowledge for such work format is presented by the pieces of American and Soviet science fiction of the second half of the XX century, where the engineering scenarios of the future are quite thoroughly described, and the role of engineers in these scenarios is emphasized. Such approach provides the students with the opportunity to form the associations between their present-day state and the desired image of activity, implemented as engineering practice. The students' questions about philosophical substantiations of the engineering can become a by-product of such creative tasks (Pereslegin S.B., 2006).

This module also involves the master-classes on communication, development of logical, engineering and creative thinking. A number of business games are aimed at practical teaching of students to the work in group, with the client, the representatives of business, science, the attention is focused on the importance of engineering results presentation in the media-sphere (Pereslegin S.B. and others, 2013).

A motivational block is also presented by lectures and master-classes of the top managers of different projects, who share with students their practical experience of engineering tasks implementation, help to form the image of engineering activity, describe the future engineers' perspectives and possibilities.

The major part of this module is held in the playing form. The game, as an educational instrument, has ultimately different methodological paradigm, as compared to the traditional form of lectures and seminars: it allows changing in students' consciousness the idea of educational process as it is, helping to find such individual educational path, which will provide an opportunity to form their engineering and creative competencies. The obtaining of competences in the playing form is the most effective training method. Such method also allows forming the worldview (ontology), solving the problems of communication and group conflict management.

The second module is the project one. One of the most important competencies, which the engineers shall possess, is the competence of interaction with the client. The top experts present such ones in the training process; they are the owners of real engineering projects, implemented at the "Construction of Instruments and Units" Department. They have the great experience of practical activity; they can teach the students and clients at their own example to formulate the problems, purposes and tasks in a correct way. A co-work product of students and clients in the form of master-classes is the formulation of the technical design assignment - an important document, determining the progress of the engineering project implementation.

The students face a number of extraordinary, sophisticated problems, the straightforward solution of which is frequently absent - the majority of tasks in modern world refer to this class. There is a number of procedures, aimed at the solution of such tasks. The most well-known one involves the algorithm for inventive problem solving (AIPS), being the part of the theory of inventive problem solving (TIPS) (Altshuller G.S. and Shapiro R.B., 1956).

The theory of inventive problem solving was developed by the Soviet engineer Altshuller G.S. and his colleagues in 1946. It is a field of knowledge, studying the mechanisms of engineering system development in order to create practical methods for inventive problem solution.

TIPS procedure became a frequent practice still in Soviet era; it is being actively used not only in modern engineering education, but also in the work of the largest world corporations. The use of TIPS instruments and devices in terms of practice-oriented education of students is a key element for successful development of engineering thinking (Altshuller G.S., 1991).

An important stage to pass to the third module is the road map of project implementation, formed by students together with the experts. In the situation, when the solution approach for the engineering problem is determined by means of the TIPS methods, the technical design assignment is formulated, the predicted technical requirements to the development object are formulated, the students shall solve a number of communicative and forecasting problems:

a) To choose the team leader (if it was not done before);
b) To determine the competencies of each team member;
c) To divide the engineering task into the sub-tasks in compliance with the principles of project management;
d) To determine key resources, required for each sub-task solution (firstly, the temporal

ones);

e) To determine the sphere of responsibility of each team member, correlating previously specified personal competencies and sub-task solution stages;

f) To organize the work on solution of each sub-task together with the expert (to form a road map for engineering project implementation).

A third module of educational program is aimed at the experts' provision of students with knowledge and competences, connected directly with the solution of specific sub-tasks, required to implement the project. The knowledge and competencies are subdivided into the following blocks:

g) The execution of the required engineering calculations, connected with the selection of materials, strength predictions, calculations of dismountable and permanent connections, engineering kinematics etc. Methodical support of this block is implemented in the required bulk of reference and educational materials, prepared by the "Construction of Instruments and Units" Department of the National Research Nuclear University MEPhI;

h) The development of the 3D model for the object, prototype production;

i) The development of the whole construction documentation;

j) The solution of automation task (in case it is present in the technical design assignment);

k) The production of the prototype of the device with the help of experts and instrumental means (intelligent machines with NC etc.).

The use of the abovementioned approaches to the engineering education results in the number of accomplished students' projects on thematic directions of "Proryv" ("The Break") project implementation in nuclear technologies, for instance:

a) The development of automated unit of nondestructive control of fuel pellets (Baryshev G.K. and others, 2014);

b) The development of robot unit for nondestructive control sensor moving along the magnetic surface with negative grade (Baryshev G.K., Ermakova N.S. and others, 2014).

DISCUSSION

Further stages of "route map" implementation are aimed at the updating of training and evaluating procedures, modernization of educational spaces in the university for successful students studying, distribution of the suggested approaches to the other university departments, implementing the students' education as per Bachelor's, Specialist's and Mater's Programs.

CONCLUSION

a) The "Construction of Instruments and Units" Department of the National Research Nuclear University MEPhI developed a number of educational programs, courses, technologies and procedures, making the process of Bachelors' engineering training to transfer to active and project educational forms in compliance with the principles of international CDIO standard;

b) Engineering and infrastructural maintenance of the Bachelors' training process was updated in order to implement the innovation-oriented engineering projects in compliance with the CDIO ideology and standards;

c) The training of skilled engineering staff is carried out; they possess not only fundamental background, but also have the skills of practical project activity, having the experience of team work in solution of modern engineering, technical and innovative tasks.

d) On accomplishment of testing of the abovementioned approaches to engineering education at the "Construction of Instruments and Units" Department, their further implementation is planned at the majority of the Departments of the National Research Nuclear University MEPhI, in compliance with the purposes and tasks of the Implementation Plan of National Research Nuclear University MEPhI competitiveness improving.

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