Elements of the Foresight Technology in Design Project-Oriented Training of Prospective Engineers

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Abstract

The article is devoted to one of the most important problems regarding the results of technical innovations implementation in people's life and to training future specialists to uncover those consequences during the preparation stage of technical projects. The objective of this paper is to analyze the problems of design project-oriented training of engineering students in Russia and find ways for its improvement. Methodology: Universal scientific research methods were used such as the methods of idealization and formalization. The experimental research methods of observation, modeling, abstraction, comparison, the analysis of students' educational activity results were also employed. Results: 1. The experience of some well-known organizations that use foresight technologies for predicting the consequences of innovative engineering and technical decisions implementation is analyzed. 2. The methodology of students training in forecasting skills making use of foresight technologies is developed. 3. The educational and expert procedure content is described. The results obtained are novel as for the first time foresight technologies are applied to the process of training of engineers. Previously the foresight technologies were used for elaborating large social and

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economic projects directed on the large territories development. The findings obtained comply with well-known technologies with similar focus, e.g. CDIO. This research contributes to the theory and methodology of professional education of engineers as it develops the understanding of their training content. Recommendations: The findings obtained can be useful for specialists of training and methodological associations, technical universities curricular designers and educators, specialists of various design organizations.

Key words foresight technology, project-oriented training, engineers, foresight, project-based learning.

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1. Introduction

Project-based learning is a core, systemically important component of educational process at a higher technical school because it integrates all the knowledge in humanities and sciences as well as social, mathematical, technical and other subjects learnt before. It is also the backbone and a guideline of all the future professional activities of an engineer because it defines his position as a designer and producer of new real products and systems (from the emergence of an idea to finished goods).

The importance of project-based learning in undergraduate education of engineers and other specialists is underlined by many Russian and foreign scientists (Lehmann et al., 2008), (Von Grabe et al., 2010), (Zamyatina et al., 2013) and (Shekar, 2014).

The objective of this paper is to analyze the problems of design project-oriented training of engineering students in Russia and find ways for its improvement.

2. Background and Methodology

The following methods were employed: universal scientific methods, including methods of idealization and formalization. The experimental research methods of observation, modeling, abstraction, comparison, the analysis of students’ educational activity results were also used.

Currently in Russia students are exposed to specific elements of project activities mainly through the study of unrelated subjects by solving physical, chemical, technical and other problems. Even an undergraduate degree paper cannot replace a full-fledged multidisciplinary project since the paper contains only some particular elements of a graduation paper: review of literature on the problem set by the teacher, choosing the way of solving the task and elaborating on its solution (doing some calculations, carrying out experiments). As a result, Bachelor of “Methods and technologies”, being a graduate of the first tier of higher engineering education, cannot fully master the procedures and an entire array of engineering methods; consequently, it does not make it possible to qualify him as an engineer in the common sense of the word; it rather makes regard him as a vocational school graduate (Ministry of Labor and Social Protection of the Russian Federation, 2013).

It should be noted that the problems of the quality of engineering education are not specifically Russian. Thus, in accordance with the study conducted by Australian researchers Chenicheri Sid Nair, Arun Patil and Patricie Mertova (2009),

Research on student-learning outcomes indicates that university graduates do not possess important skills required by employers, such as communication, decision-making, problem-solving, leadership, emotional intelligence, social ethics skills as well as the ability to work with people of different backgrounds.

At the 2014 Indianapolis Third International Forum for Engineering Education the problem of the dissatisfaction of employers with the quality of training of technical university graduates was also discussed: university graduates are not ready to work in modern environment and do not possess the required skills and knowledge (Ivanov and Zijatdinova, 2014). With this, it was noted that employers demand very much of young specialists: manufacturing companies need a graduate possessing the skills of a project manager, a specialist in a specific field, a researcher, a designer and a talented manager with communication and leadership skills. Those findings comply with the earlier research conducted by A.J. Hesketh (2000), who has found out that:

Employers no longer seek graduates with the ‘hard’ technical or vocational skills required for the job… the ‘softer’ or interpersonal skills are the new vogue.

Manufacturing companies need a full-fledged specialist with all the necessary competences, including design skills, who is capable of getting down to work at once and making money for the company.

The Association for Engineering Education of Russia (AEER) held an international conference “Management of multidisciplinary projects in engineering education: planning and implementation” in the cities of Lisbon and Porto in Portugal in May 2014. The conference was aimed at the analysis of the best results in the organization and management of multidisciplinary projects which are undoubtedly implemented in Russian universities too.

Such matters as the methodology of planning and implementation of multidisciplinary projects, basic tendencies in and approaches to multidisciplinary aspects of engineering education as well as successful practices in the implementation of multidisciplinary projects, including the ones with the participation of undergraduates, were discussed (AEER , 2015).

3. Discussion and Results

3.1 The CDIO Initiative and Instructional Engineering Design

The involvement of students in project activities requires new approaches to the project training of Bachelors of “Methods and technologies”. The concept of project training, developed within the CDIO (Conceive, Design, Implement, Operate) Initiative international project, can be used as a guideline. Project competences, which are to be studied by undergraduates within educational programs in methods and technology, were included in the requirements of CDIO

Syllabus (Crawley et al., 2007). The CDIO Standards, which have been developed, specify requirements to the Syllabus of Bachelors of “Methods and Technology” in the field of design education and stipulate the following:

- to introduce into an undergraduate curriculum an engineering orientation course which sets the basics to form relevant professional, personal and interpersonal competences of prospective bachelors;
- to introduce in the curriculum two or more projects to master practical design skills (one project is for a basic level, another is for an advanced level);
- to form working environment for practical engineering practice in order to create products and systems and to improve professional and social skills of students;
- to provide for an integrated education based on the use of active and effective practically targeted methods (CDIO Standards 2.0.).

A full-fledged instructional engineering design requires a revision of the entire philosophy of instructional engineering and the introduction of modern innovative approaches to the content of educational projects; the content shall be consistent both with the current technical practice and the requirements of international standards.

First of all, it is necessary to reconsider the content of the major subject which prepares an undergraduate for practical design work and, to a large extent, helps integrate the knowledge of various subjects into the entire “body” of the educational project. This subject, which gives an understanding of the principles of coordination and integration of various fields of engineering knowledge, has a multidisciplinary character and has the respective name – ‘Fundamentals of Design …’.

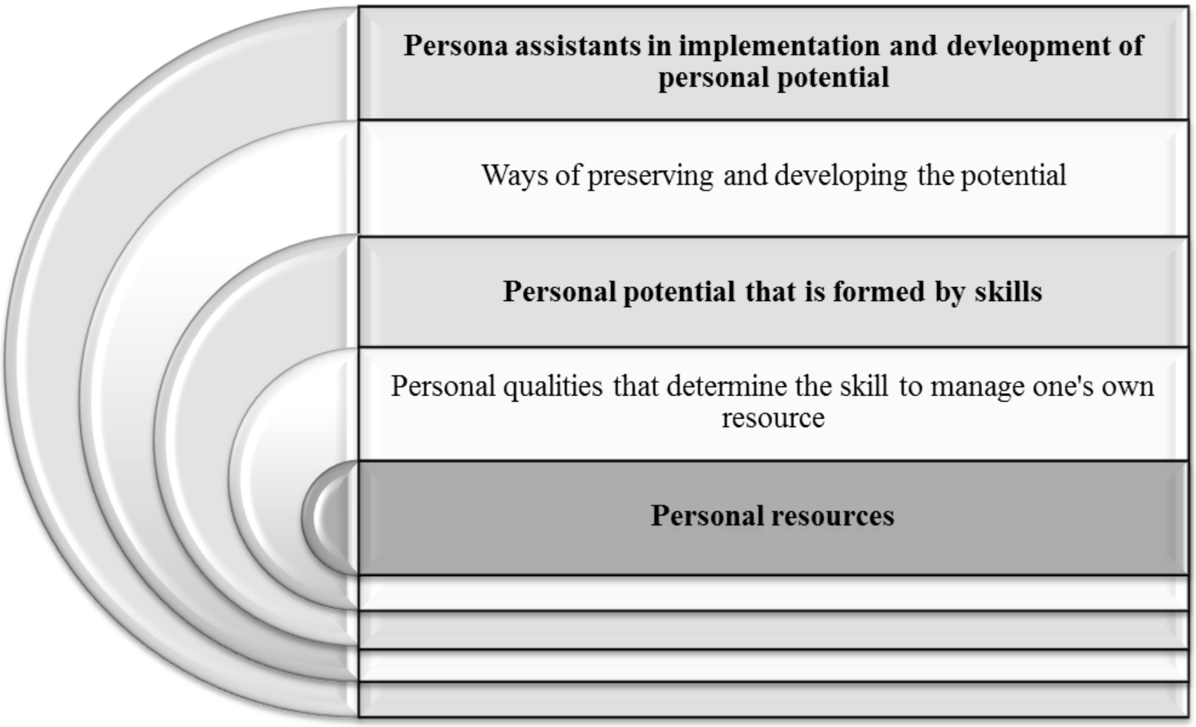

Figure 1. Components of personal management of an industrial company

The major element of educational engineering design process is the stage of the analysis and choice of a new technical decision which will be implemented in the project later. It is at this stage that a designer student can reveal all his professional knowledge and public stance.

The essential element of this stage should be the analysis and anticipatory estimates of mid-term and long-term risks and hazards for man and mankind. These risks and hazards arise due to the implementation of a complete life cycle of a technical product starting from its design and production and ending with its operation and disposal.

Any of the above stages can involve some hazards which can be critical, though they can be delayed in time and space. With this, these consequences can definitely be generated by technology, on the one hand, and caused by social and humane factors, on the other hand. This is due to the fact that in the modern global world a merge of technical, social and biological systems is observed, and the scope of a technical project has achieved royal dimensions never seen before. Nowadays mankind is in a fundamentally new social and cultural situation which can threaten mankind a real global ecological catastrophe should these consequences be neglected. Thus, a major task of a designer is to identify such consequences to society in the technological, social and humanitarian fields after the technical novelty has been implemented.

3.2 The Foresight Technology in Design Project-oriented Training of Engineering Students

This forecast is impossible without using multidiscipline knowledge. The famous Russian engineer and philosopher P. Engelmeyer believed that an engineer had to rise above his creation and analyze related knowledge to understand the essence of the invention. Due to the tunnel vision of engineering or any other professional education a specialist cannot give an unbiased look at the results of his work and assess them objectively. In this situation a possible way out might be to bring in specialists (experts) from different (non-engineering) fields to engineering when analyzing and choosing the design concept (1898).

The idea of foresight might be very fruitful in this context; foresight is essentially a set of technologies which use expert reviews to determine some possible options in the future (Limonova, 2015). The foresight technology implies the involvement of many experts from different walks of life who are related to this or that degree to the area of a particular project.

The idea of foresight is based on the assumption that the coming of the “desired” variant of the future heavily depends on today’s activities. Hence, the choice of decision options is related to the choice of technologies which make it possible to minimize possible negative consequences of the project and foresee the most unexpected ways of the development of events as well as possible pitfalls. The work of experts is aimed not only at identifying possible options but at choosing the most advantageous ones in compliance with certain acceptability criteria.

Table 1. Selected statistical information on R&D and innovative activities in Russia in 2016

Indicator	2012	2013	2014	2015	2016	2016/201

Number of Ph.D.'s	33,082	35,162	34,733	28,273	25,826	0.78
Number of doctors of science	1,321	1,371	1,356	1,359	1,386	1.04
Number of R&D organizations	3,566	3,492	3,566	3,605	3,604	1.01
Number of personnel of R&D organizations	813,200	736,500	726,300	727,000	732,300	0.90
Average number of personnel in R&D organization	228.043	210.911	203.674	201.664	203.191	0.89
Number of R&D teams five people each	46	42	41	40	41	0.89
Number of potentially created innovations by R&D organizations	162,640	147,300	145,260	145,400	146,460	0.90
Number of developed leading production technologies	1,138	1,323	1,429	1,409	1,398	1.23
Number of patent applications	32,254	44,211	44,914	40,308	45,517	1.41
Number of used leading production technologies	191,650	191,372	193,830	204,546	218,018	1.14
Number of used leading production technologies of Russian origin	117,697	110,037	109,424	116,002	122,583	1.04

Source: compiled by the authors on the basis of: (Federal State Statistics Service, 2016).

In practice, work on a multidiscipline project can be organized in the form of students' expert board in the following way. A student designer receives a design engineering assignment and generates input data to choose the way to fulfill the project task.

The designer uses their knowledge of social sciences, humanities, natural and technical sciences as well as personal experience to formulate a hypothesis of possible man-induced, social and humanitarian consequences of the implementation of the proposed technical solution. On its basis the designer student makes up a list of alternatives to be studied. With this aim he or she forms, upon a project advisor's review, a group of experts. Each expert is assigned the task to scrutinize one of the alternatives and provide a scientifically grounded conclusion. The group of experts is formed of peer designer students. Each of them can act for their peers as an expert in a particular field. A number of experts can be invited to consider all possible options, scenarios of the development of events as well as to obtain a complete picture (Petruneva and Vasilyeva, 2010; Petruneva et al., 2016).

The pattern of a future technical solution develops from the information which the experts share with the designer. Both traditional and comparatively novel expert methods are used during the discussion. With this, discussion methods are being constantly improved, procedures and practices are being perfected; generally, all this increases the validity of the scenario of the development of a man-induced situation.

The main aim of inviting experts is to use their knowledge in a specific scientific and applied field in order to resolve the engineering task assigned. An expert cannot rely only on common sense; they should make their judgment on the basis of scientifically grounded facts, opinions of respected authorities on the matter, results of additional investigations, including social studies, etc.

With this, experts should give answers to the following questions set by the chief performer of the project.

The proposed project is discussed by a board of experts. During the discussion various decision-taking methods can be used, including the well-known brain storming, scenario-building technique, expert panels, the Delphi method (when questionnaires are answered in two rounds by experts) and other modern technologies such as road maps, relevance trees, SWOT analysis, mutual influence analysis and others. Some of these methods require mathematical tools for data processing.

As a result, the board decides what physical, social and humanitarian consequences of various magnitude might follow the implementation of the proposed technical solution, and either recommends the design for the subsequent engineering implementation or suggests a further study of the problem with an appropriate technical solution in mind.

The necessity to assess prospective mid-term scenarios of the development of man-induced events is a necessity which has already been recognized by specialists. In this context foresight technologies are a fairly reliable and promising tool which is already being used for long-term forecasts of social and economic development of countries and regions, and an enormous number of experts, up to dozens of thousands, may be involved in the process (Stanovlenie Forsajta, 2016).

In the countries, which are the most advanced ones in this aspect, there function and operate state institutions and organizations which carry out a comprehensive expert evaluation of technical objects which includes social and humanitarian aspects. In the USA, for example, Office of Technology Assessment was set up in 1972 which task is to provide senators and congressmen with objective information in this field.

At the same time Technology Assessment Board (TAB) was set up in the Congress with the main task to develop at the earliest stage guidelines for possible positive or negative consequences of technical projects as well as to provide the Congress with information required for making decisions (Stepin et al, 1999).

In German Bundestag in 1986 a similar board was set up (Enquete-Komission "Technikfolgenabschtzung"), which was later used as a basis for the Technology Assessment Bureau; the Bureau incorporates a group of multidiscipline scientists representing natural, social and technical sciences there. The initiatives of the German engineers' union which adopted the guidelines "Technology assessment: concepts and grounds" in 1991 are of particular interest to us. According to the guidelines, technical activities always necessarily assess technology, and not everything that is technically feasible must necessarily be created. Thus, technology should meet a number of requirements – not only technical expedience, functionality and cost effectiveness, but it should also improve the living standards, safety and health of people, the quality of natural and social environment and so on. Technology assessment means a systematic and orderly activity which assesses direct and indirect technological, ecological, humanitarian, social and other consequences of this technology and its possible alternatives; with this aim it works out pragmatic and creative possibilities to make justified decisions (Ibid.).

Thus, the assessment of technology and, respectively, technological processes, has become an indispensable part of engineering. Sometimes this assessment is also called social and humanitarian (social and economic, social and ecological, etc.) expert evaluation of technical projects. It goes without saying that this work is a multidiscipline task and requires training experts with encyclopedic knowledge both in technical and scientific fields, on the one hand, and social and humanitarian competences, on the other hand. Such responsibility means that it is necessary to build up the self-consciousness of engineers in terms of understanding the necessity of social, ecological etc. assessment of technology and technological processes.

4. Conclusions

In our opinion, good opportunities in engineering and design activities are provided by the implementation of the CDIO (Conceive, Design, Implement, Operate) ideas in technical universities. Those ideas form a basis for the implementation of new approaches in teaching and learning activities to designing technical objects, including the ones which require expert opinion technologies. Moreover, the CDIO ideas induce undergraduates to implement their first projects.

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