Concept of the Natural Structure of Engineering Training and the Code of Professional Ethics of an Engineer

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Abstract. The paper focuses on challenges and problems of modern engineering education. The necessity of designing and constructing a new model of the educational system related to the survival of humanity and training of engineers of a new type is substantiated. The global trends in the development of engineering education, trends and requirements for the competencies of future engineers are characterized. As one of the concepts for the development of engineering education, the concept of the natural structure of engineering training (NL) has been considered. The main innovative components of the NL concept are highlighted. Based on the code of professional ethics of an engineer, the main provisions of the Leonardo oath for engineers are formulated as a reference for curricula in engineering education.

Keywords: engineering education, engineer of a new type, concept of natural structure of engineering training, code of professional ethics of an engineer, Leonardo's oath

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Introduction

Solving of the global civilizational problems is closely connected with the development of engineering and therefore with the improvement of contents and organizational forms of higher engineering education [1–5]. At the same time, the objective and subjective challenges and risks facing the domestic engineering education are well known. Among the systemic problems, the researches distinguish the following: imperfection of the state policy in the field of education, insufficient funding, lack of long-term planning, sectoral focus of the Higher Technical Education (HTE) system, Soviet-industrial in form and unrestrainedly market in content HTE system, decline in the status of the a teacher and a student; lack of integration of education, science and production, decrease in the prestige and status of the engineer, respect for engineering work, low popularity of engineering professions, as well as insufficient funding for exploratory and basic research; low level of equipment of training and production base; reducing fall in the level of technical and methodological support; lack of work practices;

problems of introducing new educational technologies; problems of implementation of level training; reducing decrease in the level of basic fundamental training in at undergraduate level; reduced ability of future engineers to invent; lack of certification of engineering qualifications; low efficiency of postgraduate doctoral education [6–9].

Main part

To solve the problems of engineering education, it is necessary to go beyond the limits of the educational level itself sphere. But this presents a range of fundamentally new aspects at the interface of technical sphere and humanities.

Today a new type of engineer is needed – an intellectual engineer, a cultural person, who organically combines, on the one hand, multilateral reflexivity, which makes it possible to view the world holistically, as a whole in different planes; on the other hand, universal conscientiousness as a dominant motive of nature-creating activity. It is necessary to start building educational models of a new type right now, building at the first stage integrative courses in the natural science and social science directions, and then proceed to global cultural studies integrating mathematics and biology, physics and geography, geometry and music, poetry and technical creativity in organic socio-natural whole. Just such an organic fusion of all layers of culture was revealed to the world by Pythagoras and Plato, Paracelsus and Leonardo da Vinci, F. Dostoevsky and L. Tolstoy, A. Schweizer and K. Popper, V. Vernadsky and P. Florensky [10].

In the context of an ever-increasing gap between the requirements for graduates and the quality of education, among the global trends in the development of engineering education, there are: fundamentalization, innovation and informatization; technologization and practice orientation; universalization and training of generalists; greening and harmonization of relations with nature; humanization and focus on human needs; strengthening economic and legal training; managerial and psychological-pedagogical training.

The experience of engineering projects implementation has allowed creating unified approaches to support the life cycle of the designed systems from concept and development to production, operation and disposal. These approaches, called "system engineering", allow to develop complex high-tech systems with multiple constraints. Systems engineering is a holistic, product-oriented approach aimed at creating and executing processes that cover various engineering disciplines and ensure that the needs of customers and direct users of the product are met. It is implemented through the use of methods to achieve high quality and reliability, cost efficiency and compliance with the project or program schedule throughout the system's life cycle.

The trends and requirements for competencies include [11]: the emergence of a knowledge society (strengthening the scientific component, research skills; possessing a much wider range of key competencies than mastering highly specialized scientific, technical and engineering disciplines, readiness for learning throughout life and changing your own professional installations); the growth of man-made factors in the life of mankind, leading to the risk of mega-disasters (possession of technologies for complex expertise, integrating the technical, technological, environmental, social and humanitarian assessment of engineering projects); the rapid development of knowledge-intensive technologies, the formation of techno science (the ability to understand the nature of new complex scientific mega-problems, the possible consequences of their development and risks for modern society); increasing the share of multidisciplinary and integrated research, the interpenetration of fundamental and applied research, the emergence of new directions at the intersection of science (the ability to solve complex problems in traditional, related and new areas, creative thinking, the ability to detect potentially new in the already known, go to new paradigms of engineering); the formation of new global information paradigms, the emergence on this basis of transnational corporations (participation in the work of multidisciplinary teams, which requires an intellectual potential, possession of world-class core competencies in a wide range of science and technology areas, language skills, the ability to accept and respect other cultures); the improvement of information technologies affecting the foundations of self-organization of mental and cognitive processes that are responsible for the ability to maintain personal integrity and identity (to anticipate poorly controlled consequences of the introduction of genetic engineering, changing the life balance of the natural habitat of man and the nature of man himself).

Today, the world is making a transition to project education. Training in the process of working on certain projects becomes the main way of training. The problem-oriented approach to training in engineering specialties, along with the innovation-oriented approach, allows students to focus their attention on analyzing, researching and solving a particular problem, which becomes the starting point in the learning process. The problem for research maximally motivates students to consciously acquire the knowledge necessary to solve it, and the interdisciplinary and multidisciplinary approach allows students to teach themselves to "acquire" knowledge from different scientific fields, group them and concentrate in the context of a specific task being solved, master the world-class high-tech technologies. For the successful development of this activity, it is necessary to anticipate the acquisition and implementation of modern key competencies and technologies (primarily, computer-aided design technologies and high-tech computer engineering technologies), as well as gaining positive experience with leading global industrial firms.

According to both domestic and foreign analysts, the mutual adaptation of national education programs of engineering training and integration processes define the problems of engineering education, modern requirements for engineering training and forecasts of its further development. Instead of "informational and knowledgeable", ways are being sought to implement problem-oriented, activity-based and project-based approaches to engineering training. Despite the persistence, in general, of the cyclic structure with integrated groups of disciplines (humanitarian and socio-economic, natural science, general professional and special), their content is being continuously updated under the influence of socio-economic factors, new results of fundamental and applied sciences, innovative engineering practice. The assertion about the need to ensure the fundamental nature of training as a guarantee of professional mobility and the prerequisites for the formation of an appropriate general culture of engineering personnel retain their significance. However, new elements and trends, as a rule, concern substantive, methodical, technological and rarely structural aspects, remaining, essentially, within the framework of typical structures of basic vocational educational programs (BVEP). But any updated or innovative paradigm can be effectively and fully implemented when it is specified in the form of an adequate structure of interdisciplinary connections throughout the entire educational program.

In general, the traditional structure of engineering training is initially aimed at synthesis, ignoring the stage of analysis that is obligatory for the cognitive process. The existing structures focus on synthesis because engineering training begins with the natural science cycle – theoretical disciplines operating with abstract high-level models, and not with the decomposition of the whole. It is well known that at the stage of general technical and, especially, special training, it is necessary to re-learn, using the applied material, the methods and principles of the previously studied fundamental disciplines, especially higher mathematics, physics, mechanics, etc. This is a direct consequence of their formalized study, without the constant support of applied needs (*Fig. 1*).

One of the promising concepts of engineering education is the *natural structure of engineering training* (Natural occurring Learning, NL) [12; 13]. The basis for designing the natural structure of engineering training is *determined by the following theses*.

1. The logic of any human activity can be represented by a generalized structure that is invariant to the form and sphere of human activity, including in engineering. Any activity at first

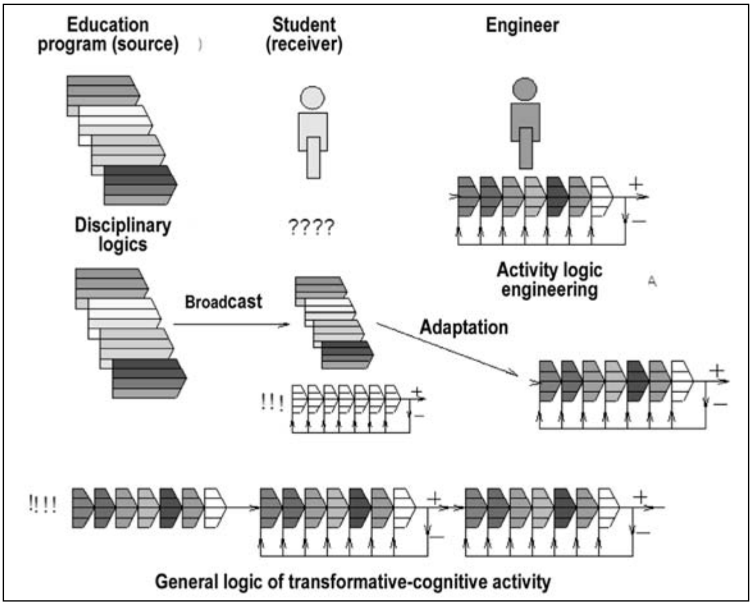


Fig. 1. Towards a Consistency of Information Structures in BVEP, Engineering and Training Activities

seems to be some kind of thinking or material model, i.e. projected. Therefore, the structure of the activity stages practically coincides with the structure of the design and is supplemented only by the implementation stage.

2. The educational process is the activity of transforming the initial level of student's knowledge, skills and abilities to the composition and level necessary and sufficient for the implementation of a certain type of activity in engineering.

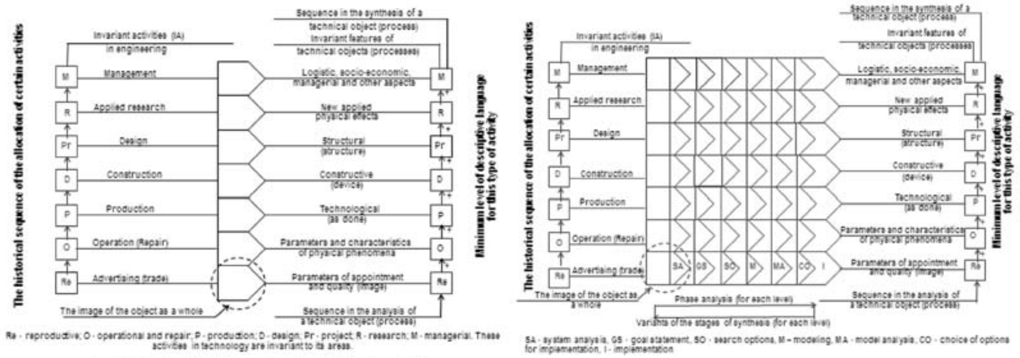
3. The structure of the educational process as an activity should coincide with the generalized structure of activity.

The natural structure of engineering training (NL) in the logics of the formation of activities and engineering is illustrated in *Figure 2* [13].

In most countries with an Anglo-Saxon education system (two- and three-level) under the Washington Accords (WA), the requirements for graduates enrolled in engineering education programs imply knowledge in the engineering sciences, including: fundamentals of engineering analysis, design methods and complex engineering solutions, applied research, project management and finance, etc. All this knowledge is an invariant base for activities in the field of engineering [13].

A conceptual CDIO initiative (Conceive, Design, Implement, Operate) undertaken by the world leader in engineering training – Massachusetts Institute of Technology (MIT) (USA) with the participation of scientists, industry representatives, engineers and students in the late 1990s, suggests that graduates of universities, trained for the creation of new systems and technical facilities, within the framework of engineering training programs, should be able to "understand-design-implement-operate" modern integrated engineering systems in team-based environment. This MIT initiative is a concept of practice-oriented engineering education aimed at developing the basic skills of integrated engineering activity at bachelor's level as the main qualification degree giving the right to practical work. The master's degree in WA member countries is not considered to be fundamentally important in practical engineering activities and is viewed as evidence of specialization and higher qualification.

In contrast to the Russian system of higher technical education, which is characterized by



a) the logic of the formation of activities in technique

b) the natural invariant structure of BVEP based on the logic of engineering

Fig.2. Natural structure of engineering training (Natural occurring Learning):

multidisciplinary, many courses in US universities are integrated (an example is “Mechatronics”, which has already been introduced in some universities in Russia), have an applied character (bachelor’s level) and are studied comprehensively. A significant amount of teaching material is mastered in laboratories and research and educational centers.

The sequence of mastering the disciplines according to the curriculum is given in the form of charts or tables in university electronic environment – using graphic presentation. The detailed information about them can be seen in textual descriptions including information on previous courses (input parameters for the discipline being studied) and descriptors of the discipline. All training material is presented in the form of modules having an alphanumeric code in accordance with their belonging to a specific field of activity and the year of study. Special mathematics modules, for example, are studied as they are needed when studying general technical disciplines and disciplines related to a particular type of activity. With the automated formation of general and individual curricula (with personal trajectories), these modules are placed in the appropriate place in terms of time and relevance in the university’s education program. Such modulation is less systemic, but similar to the cells of the generalized NL structure. With such provision of information, students are acquainted with the strategy of their training.

Designing ET within the NL concept framework requires rethinking of traditional didactics. Within the NL framework, the main role should be played by project didactics with its methodology for generating new ideas. The didactics of educational and informational interaction is also changing in order to increase the efficiency of the educational process, which will enable the formation of the necessary skills, relevant educational contents and assessment technologies for a new generation of university graduates.

The main innovative components of the NL concept are as follows [12; 13]:

- the presence of a clear and natural backbone idea;
- objectivity of its generating structural core;
- consistency with the structure of natural stages and the logic of the cognitive-transformative function of human activity;
- consistency to the natural processes of human perception and cognition of the surrounding world;
- the supranational character of the NL basic principles as a prerequisite for the simplification of communications in the field of technical education;
- the end-to-end fractal nature of the NL structure, including the structures for solving particular learning tasks that coincide with the structure of student's life activity;
- algorithmicity as a basis for comprehensive informatization of the educational process;

• the organic nature of the formation of any range of competencies including general cultural competencies.

The Code of Russian engineer [14; 15] defines the basic principles of professional ethics.

Russian engineer shall:

• act for each employer or client in a polite, fair and faithful manner, as well as maintain confidentiality and avoid conflicts,

• provide moral incentives to colleagues and handle any fair criticism in a positive way,

• have an unbiased attitude to all clients and colleagues irrespective of their ethnic belonging, religious views, age, mental and physical abilities, marital status and nationality.

• publish the outcomes of their work, as well let their subordinates and colleagues do so.

Russian engineer shall not:

• display his experience in order to undermine public trust in the engineer's profession or shatter its reputation,

• issue public statements concerning an engineering project until full factual information on the latter is obtained,

• attempt to injure, maliciously or falsely, directly or indirectly, the professional reputation, prospects, practice, or employment of other Russian APEC Engineers,

• use engineering products or processes for commercial publicity,

• accept remuneration for the services rendered without consent of the employer,

• accept commissions, discounts, direct or indirect payments or any other remuneration in connection with the work for which they are responsible,

• use confidential information for obtaining profit,

• take part in the engineering project implementation or solve a technical task which might do harm to the society and /or environment (even if this meets customer and employer requirements and is approved by colleagues).

Professional engineer should [15; 16]:

• continuously search for reliable facts to find and protect the truth, being the main goal of cognition, regardless all the difficulties that might arise,

• respect creative worky of his/her colleagues,

• critically assess his/her own results and achievements and stop any attempts of appropriating other people's achievements,

• use a prospective approach when considering any problem or situation with the account to all the social, environmental and other consequences for the society,

• be able to point out civil and ethical aspects of a problem in the process of searching for new engineering knowledge and solutions, which might at first seem to be purely technical,

• be prepared for a constructive dialogue with representatives of related industries,

• try to minimize the negative consequences of specialized equipment usage for individuals, society and environment,

• deny conservatism and stagnation in creative activity,

• enhance the reputation of the Russian APEC Engineer.

The Code of the Russian engineer defines the key moral values [14; 15] (*Fig. 3*).

Looking to the UNESCO millennium goals, the idea of creating a "Leonardo's Oath for engineers" (by analogy with the "Oath of Hippocrates" in medicine) as the main goal of engineering education requires that engineers perform their work based on the categories "sustainability", "capacity building" and "society faced". The "Leonardo's Oath" was developed as benchmark for engineering curricula by understanding that engineering work is more than a process to transfer technology in products and solutions. It is an act of design with the aim to create the technical requirements for a world without famine and epidemics but with open access to fresh water and information, to education for all and more equality and sustainable development. Engineering work should be oriented and pledged towards two guiding principles:

• the "transfer competence" to realize a solution;

• the "responsible competence" to be aware of the effect of this solution for the problem itself as well as for the social, ecological and economic environment.

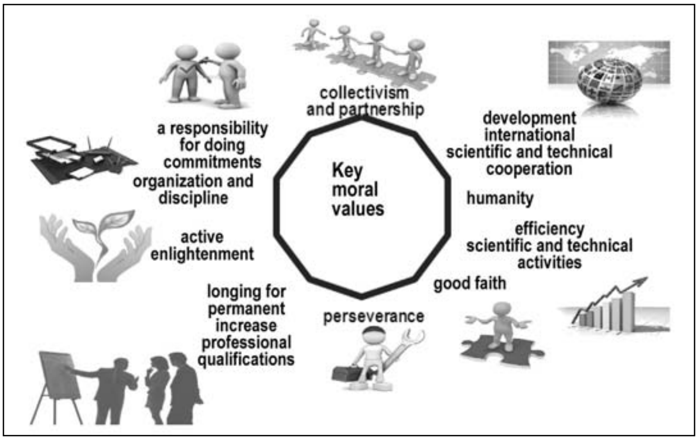


Fig. 3. The key moral values

With regard to engineering educators, this idea implies that engineering education should aim at designing and realizing curricula, which will enable to develop both "transfer" and "responsible" competences on the basis of defining goals, learning outcomes and systematically structured and linked contents of the study programmes, as well as at creating teaching and learning styles, in all their diversity, which facilitate students to develop their qualification in transferring and designing [17].

The actual form of the "Leonardo's Oath" reads as follows:

Each engineering course should be based on the idea that engineer will be prepared to use his technical knowledge, with his responsibility for design, focused on the principles of:

- ethical justification;
- sustainability;
- social assessment.

The curricula in engineering education must give more space in the study courses for action-oriented learning [18]. A typical structure of such a course shows (*Fig. 4*) [17] that academic courses in the case of developing design competence must follow the principle of a fulfilled action with the steps Inform, Plan (Decide), Do, Control and Reflect, which correlates with the concept of CDIO.

Conclusion

The proposed concept of the natural structure of engineering training (NL) [12; 13] based on the Code of a professional engineer [14–16] and "Leonardo's oath for engineers" [17; 18], in our opinion, will make a worthy contribution to the formation of the engineer of a new type.

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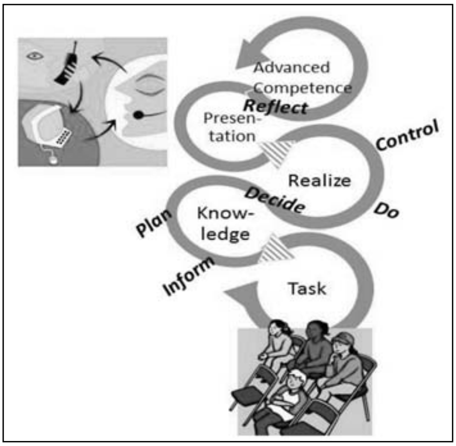

Fig. 4. Typical structure of practice-oriented course

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Концепция естественной структуры инженерной подготовки и кодекс профессиональной этики инженера

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Аннотация. *Актуализированы вызовы и проблемы современного инженерного образования. Обоснована необходимость проектирования и конструирования новой модели образовательной системы, связанной с выживанием человечества, подготовки инженера нового типа. Охарактеризованы мировые тенденции развития инженерного образования, тренды и требования к компетенциям будущих инженеров. В качестве концептуальной основы развития инженерного образования рассмотрена концепция естественной структуры инженерной подготовки (NL), выделены её основные инновационные составляющие. На основе кодекса профессиональной этики инженера сформулированы основные положения «Клятвы Леонардо» для инженеров как эталона для формирования учебных планов в инженерном образовании.*

Ключевые слова: *инженерное образование, инженер нового типа, концепция естественной структуры инженерной подготовки, кодекс профессиональной этики инженера, Клятва Леонардо*

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