

The Technology of Forming of Innovative Content for Engineering Education

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ABSTRACT

The relevance of the study is conditioned by the modernization of engineering education aimed at specialists' training to solve engineering and economic problems effectively. The goal of the paper is to develop the technology of the innovative content's formation for engineering education. The leading method to the study of this problem is a method of quantization that allows compressing of the information to be studied and to create training modules and taxa. The study involved 430 teachers, 410 students who expressed their requirements for the content of engineering education, participated in the development and evaluation of training modules and taxa. Main results of the research consist in identifying of the stages for selection and structuring of the content for engineering education, requirements for the content (compliance with the invariant structure of professional activities; the system integrity of knowledge, abilities, skills, competences; taking into account of innovative educational, scientific and industrial developments) and defining of the rules for structuring (the compliance with professional functions; the identification of invariant and variant components; development of training modules; taxonomic representation of interdisciplinary relations; system integrity of structure-forming components). The significance of the findings is that the identified stages of selection and structuring of the content for engineering education provide extensive use of technology (controllability) of its formation; content requirements - selection of knowledge, abilities, skills, competences at the level of specific academic disciplines and their systematization; the proposed rules for structuring - integration of educational and vocational activities of students and research and teaching activities of teachers. The developed technology contributes to the relevance and accessibility of the content for engineering education, reliability of future engineers' vocational training, which is manifested in their readiness for multi-functional engineering and technical activities.

KEYWORDS

Engineering education, training module, selection and structuring of educational content

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Introduction

The relevance of the study is conditioned by the modernization of engineering education and the development of innovative technologies of future specialists' training and education. In the modern world the national security and independence of States cannot be separated from the level of their technological development. The level of development of high technologies nowadays is a description of the economic status and the scientific-industrial potential of the country. The role and importance of each country in the world economy are in direct dependence on how much it owns high technology (Tagay, 2015). The transition of the economy of industrially developed countries on the path of technological development, the dominance of science - and knowledge-based economies determine the key role of highly qualified personnel of an engineering profile in socio-economic sphere of society and have a significant impact on the formation of a new content for training of future engineers to multi-functional engineering activities (Subetto, 2002). The rapid development of science and technology, the rapid change of certain technologies with some other ones, the growth of innovative processes in the sphere of industry and business result in the need to continuous updating of engineers' knowledge and the continuous improvement of the quality of their training. Engineering education is becoming the leading factor of social and economic development and powerful intellectual and spiritual resource of the state (Zhurakovskiy, 1997; Shaidullina et al., 2015a).

The rapidly changing conditions of life make seeking of new approaches to qualitative change in engineering education. It is found that engineering education is developing as a link in the system of continuous education and is intended to meet the needs of the individual, society and state in the training of specialists with high level of professional competence and mobility, a broad Outlook, which is based on knowledge in related to primary specialty fields, high creative potential, which is realized in technical creative thinking to solve complex engineering and economic challenges in the increasingly complicated information environment. The development of engineering education is influenced by many factors as changing of the technical level of the economy and its restructuring, and the development of market mechanisms, and creation of branch educational clusters (Shaidullina et al., 2015b; Lunev et al., 2016; Koyunlu, Dokme & Unlu, 2016). The most important factor, reflecting the global economic development is the transition from technical to technological or post-industrial modernization, development of high-tech industry based on automation and information (Kirsanov, 2001; Zaripova et al., 2014; Kayumova & Zakirova, 2016, Masalimova, Sadovaya & Flores, 2016). It defines the fundamental novelty of modern engineering education by its place in the economy, by profile structure and by the content of educational curricula. The development of innovative paradigm in engineering education has led to the rethinking of its content, forms, methods of training and education, that is, in fact, makes urgent the challenge to develop new educational curricula and technologies focused on engineers' training to work in the conditions of dynamically changing external and internal economic environment. It is found that innovative paradigm for engineering education provides: 1) the dominance of non-classical type of scientific rationality that includes cognizing and acting entity, integration of scientific knowledge with social reality; 2) interdisciplinary organization of learning content; 3) the creation of a culture of system thinking; worldviews, aiming at the harmonization of

relations "man-society-nature"; 4) the formation and development of social responsibility as a component of professionalism; 5) the development of engineering pedagogy, the subject of which is all that is aimed at improvement of technical disciplines' teaching and all activities of the teacher concerning the goals, content and forms of training (Meletsinek, 2007). The aim of the research is to develop a technology for the formation of innovative content of engineering education. The term "technology" has received in the pedagogical literature for more than three hundred definitions depending on how the authors understand the structure and components of the educational process. The educational technology is considered as a purposeful process carried out on the basis of specially assigned tasks. The purpose of this study led to the formulation of the following objectives: to clarify current requirements for the content of engineering education; to define the rules for structuring of the content of engineering education.

Methodological Framework

The leading approach to research has become a systematic approach. According to this approaches the entire continuum of mental activities of a man, the dominant motivation of which is the formulation and solution of personal important problems can be divided into system quanta. It is known that any system of interacting particles can form a stable state for certain values, this is the principle of quantization. Quantization allows dividing of the range of values for a certain number. There is the principle of system quantization in pedagogy that "relies" on the modular organization of the cortex of the human brain and is the basis of the functional systems of human mental activities which is displayed in different symbolic systems (linguistic, symbolic, graphical, etc.). The principle of system quantization allows compressing of educational information on the basis of the content's summarizing and create integrated didactic units – modules, taxa (Oleshkov & Uvarov, 2006). Various types of models of knowledge representation in a compressed compact form correspond to a property of man to think with images. In the study, assimilation and thinking about new learning material the coding of material, making of schemes in mind take place. Compression of educational material and presenting it in four codes: symbolic, verbal, graphical, and numerical contributes to the quality of mastering of engineering educational content. During research the following methods were used: a synthesis of pedagogical experience, systematization and generalization of facts and concepts, action research (AR), expert evaluation method, observation, questionnaire survey, pedagogical experiment.

Results

The main results of this study are: 1) current requirements for the content of engineering education; 2) rules for structuring of the content of engineering education; 3) pilot testing of the effectiveness of the rules for structuring of the contents for engineering education.

Modern requirements to the content of engineering education

It is found that current requirements to the content of engineering education are conditioned by its integration with science and industry (Kamasheva et al., 2016). The first requirement is that the content of education must correspond to the invariant structure of professional activities, including cognitive,



communicative, value-orientation, transforming (labor), aesthetic, physical and other functions, that is a lot of actions and relatively complete elements aimed at the achievement of certain intermediate perceived goals, forming certain integrity, unity. Therefore, the content of education should be selected not only in the logic of science, but also through the model of a specialist, in the logic of professional activities (Lednyov, 1989). Modern requirements to the content of engineering education involve the inclusion in its structure of knowledge, abilities, skills, competencies, and apparatus for their learning and formation.

The second requirement is the system integrity of knowledge, abilities, skills, competencies. In the educational content intended for assimilation, must be allocated the creative source of all knowledge relating to the holistically perceived surrounding world with its regularities, problems, relations and prospects of development. Processes of projecting, modeling, constructing and studying of objects of the integral surrounding world, search the relationship between them should be put forward on the first place. First, the abilities, skills, competencies should be determined. Then the necessary knowledge for them is to be selected. To this knowledge the knowledge about the activities is added – about the methods and techniques for problems' solving. Both types of knowledge constitute the scientific content of the discipline. Knowledge in this approach is systematized and structured in accordance with the hierarchy of knowable objects. The student must have a public availability (via the database or the tutorial) and learn in the context of the process of projecting, modeling, constructing or research. Knowledge should not be the object but means for development. Knowledge and skills are not neighboring but subordinated ones. Knowledge serves skills (as means serve the purpose) (Chernilevskiy, 2002). The selection of the content for engineering education should be performed according to the criterion of completeness and consistency of activities required for the future engineer to perform professional activities at different levels of its complexity. Students have to be taught not the subject matter, but specialty. This causes the attraction to the process for selection and structuring of the content for engineering education of employers and public engineering organizations (Pugacheva et al., 2016).

The third requirement is that, the content of education is a means of educational technology, systemically oriented on the formation of students' engineering competence. The content of education should possess degrees of freedom, providing the ability for dynamic self-development and bridge the gap between education, research and industrial developments. The content of education necessary to train modern engineer needs to be an open system that contains as the invariant fundamental component so the variable components - the result of network integration of the latest achievements of various educational, scientific and industrial organizations' entities (including those which are received in educational-research and production environment of industry) (Akhmetov et al., 2016). Fragmented and hard-formalized technical and technological information should be systematized and presented in the form that allows implementing of interdisciplinary and intra-disciplinary communications in the process of future engineers' performance of system tasks with professional content.

The rules for structuring of the contents for engineering education. It is found that the structuring of the content for engineering education is based on the totality of the following rules

The first rule is embedding of mechanisms of its integration with science and industry in the content of education. It is established that the process of integration is characterized by the following parameters: 1) dynamism – the vision of contemporary and emerging trends and perspectives of development of science, technology, industry and education; 2) consistency that allows imagining of planned and constructed technical object, seeing of its connection with other objects, environment and even in the projecting stage eliminating of possible negative effects and their consequences; 3) integrity is the reflection in the content and process of engineers' training of their future professional activities' specifics; 4) professional direction is the orientation of educational content, methods and forms of education on the ultimate goal of specialists' training; 5) continuity is the reflection of the past, present and future in the content of education, the relationship of educational process with future professional activities; 6) "mini-max" – the achievement of the possible maximum in the given conditions at minimal financial, material and other costs; 7) selective parameters – optimizing for specific social parameters, which are the most significant (dominant) in the current situation (Kirsanov, 2001) Professional activities of the modern engineer is a certain integrity which is integrative in nature. The content's integrative system of interdisciplinary multi-functional activities of an engineer is the basis for the development of his professional competence, functional literacy, general and professional culture and skills to navigate in related fields of activities. To ensure the students' readiness to engineering activities in modern conditions it is necessary to reflect its forms and methods in all components of the content for engineering education. At the same time as the integrating factor must be allocated a model complex professional task. This will allow orienting of the content of engineering education on the formation of the integral properties and characteristics of the personality, reflecting the essence, qualitative singularity and professional competence (Petrova et al., 2016).

The second rule is the identification of invariant and variable components in the content of education. Invariant component is determined by the state educational standards including the statutory prerequisites to achieve the required levels of graduates' competencies and to assess their qualifications. Variable component is conditioned by the gradual formation of students' engineering competence, in multifactor professionally oriented academic tasks' solving, and by the characteristics of the regional labor market.

The identification of invariant and variant components provides a transition to the modular structure of the content of education, which consists of discrete and independent holistic units. As the main characteristics of the module can be taken: 1) independence - module as a structural unit has its own, distinct content; 2) the limited time for the implementation of the goals and objectives of the module; 3) dynamism, ability to change quickly the content of the component parts of the module in accordance with the target objectives of the educational material; 4) differentiation and integration of the components of the module – components that perform their own effective functions. Features of the formation of the module are the following: 1) the educational content is submitted in the form of complete independent teaching and methodical complexes, development of which is carried out in accordance with the intended purpose. Description of the learning objective of the module contains not only the list of formed competencies, but the assessment's criteria; 2) tasks for independent selection by the students are developed based on individual zones of proximal development and



implementation that promotes the acquisition of skills of goal-setting, self-planning, self-organization and self-control. The concept of the module is not considered as something unchangeable. Module's size may increase or decrease depending on a number of factors: the qualitative characteristics of the student contingent for which the training materials are prepared; aims, forms, methods of education of engineers.

The third rule is taking into account of interdisciplinary links. The content of the activities of the modern engineer, carried out through the integration of education, science and industry is interdisciplinary one. The same interdisciplinary must be and the content of education. This leads to the establishment of linkages between technical and other disciplines of the educational curriculum. For example, in the formation of educational material on the subject "Technology of construction materials" it is necessary to take into account the scientific regularities of such disciplines as "materials science", "machine parts", "mechanical engineering", "Economics of engineering production", etc. All technical objects are represented like artificial systems, the consumer (operational) properties of which depend on a large number of interdisciplinary factors. With the help of different technologies one can create a series of externally similar technical objects that satisfy one and the same basic need of the customer. However, other characteristics of technical objects which are not taken into account by the customer can vary considerably. Features of the emergent properties of technical objects depend on the fact what kinds of interdisciplinary factors and their combinations the developer is focused on while projecting and manufacturing the product. The content of education in a specific academic discipline is generated by the teacher, selected, structured and systematized according to the functional ideology of taxonomy, taking into account the interdisciplinary connections, the necessity of application in practical tasks' (projects') carrying out.

Technical disciplines are interconnected internally through a system of terms, theories, and laws. Taking into account of interdisciplinary relations contributes to the development of students' simultaneous perception, i.e. the perception of the studied subject in the simultaneity of its various manifestations, synthesis of its multidimensional and diverse image. The development of this type of perception is especially important for modern engineers. Traditional education is usually based on successive type of perception, i.e. in the sequence, the alternation of the images, their linearity. The selection of the most significant interdisciplinary connections is determined by the goals of the discipline and is based on the integration of personal professional experiences of the teacher and the analysis of the connectivity of the thesaurus of the discipline with other disciplines' thesauri. The number of studied objects in two ways affects the education. When one or very few objects is examined, but comprehensively in all disciplines, it creates the conditions for deep understanding and assimilation of these objects' functioning and it is good thing. However, this decreases the Outlook and it is bad thing. When much is studied, it is good for the Outlook, but there is no time to do it deeply. Compromise one is the choice of a small number of objects (3-4) for their comprehensive study from the perspective of different fundamental disciplines, but it is necessary to use additional information from various subject and applied areas. In practice each discipline naturally is divided into a number of functionally completed sections (modules). Discipline's curriculum also involves a list of all its sections (modules) with denoting of their

meaningful parts. Section implies certain completeness in content, i.e. the contained material in it is characterized by a high degree of interconnections, and its further subdivision in order to do the analysis of the whole training curriculum is impractical.

The fourth rule is a taxonomic representation of interdisciplinary content of education. Taxonomic structure creates the necessary conditions to ensure fundamentality, interdisciplinary nature and integrity of educational content. Taxa are groups of objects related by common characteristics. The taxa of the educational sphere are sets of subordinated objects used in the learning process and linked by a certain commonality degree of characteristics and properties. Full volume of the educational material prepared with the necessary interdisciplinary links intended for study in a particular module, the teacher formulates in the form of individual taxa. Each taxon is represented as an electronic folder, the contents of which are related to the theme of the training sessions. The e-folder includes: "pass-through" taxa of the new theoretical material (the main material to practice on a particular topic or an entire discipline); many taxa containing interdisciplinary information, which is necessary for a deeper understanding of the new material; the taxon that contains the description of the method of specific session; taxon of necessary graphical or other illustrative material; the taxon that contains the package of mathematical methods for processing of educational information; the taxon that contains the training tasks; the taxon of normative regulations; the taxon that contains morphological table, which is the basis to fill a database of independent decision-making; the taxon that contains the students' samples of correctly performed calculated and graphic works on the theme of the class, etc. The system of allocated taxa by the teacher is a balanced set of interrelated educational, scientific and innovative industrial material and is the information field, which is necessary for successful activities of students. All presented in electronic folders taxa have their individual names written in a functional form. Adaptation of ideas of functional computer taxonomy in relation to the educational process ensured the prospects for the implementation of an interdisciplinary system training of engineers for wide range of creative professional activities (Morgunov et al., 2001; Kashina et al., 2016). A functional computer taxonomy developed in the integrated environment of science and modern industry, promotes interdisciplinary synthesis of knowledge about material objects in the stages of their projecting, testing, research and application, finding of a common language between scientists and specialists in various fields of professional activities.

It is found that the advantages of taxonomic representation of interdisciplinary content of education are the following: 1) systemized objects and processes are displayed by functional formulas that determine not only the morphology of the object, but also the ability to perform certain functions in specified conditions of interaction with the external environment; 2) functional formulas simultaneously is universal information searching language of automated systems. Each functional formula in symbolic form provides the user with information about the morphology of material objects, and about their functions; 3) functional formulas are equally (mathematical and chemical) perceived in all natural languages, what is their integrative and interdisciplinary nature. The interdisciplinary essence of taxonomy is that it allows classifying of material objects, functional processes, and information's documents on common system characteristics and models; 4) a functional computer taxonomy is focused



on computer technology of formation and use of the automated databases; 5) system information about material objects, functional processes and documents has taxonomic structure and functional description; 6) the set of taxa that contains interdisciplinary training material borrowed from other disciplines (already studied, or those which, in accordance with the curriculum only have to be studied) develops the thinking process. New things in the already familiar educational material is manifested when applying it to "re learnt" things, and the amalgamation of "old" and new material with the using of separate portions from the future provides the basis for the development of imagination and intuition; 7) functional network representation of the educational content, which makes it available to any student.

The fifth rule is the system integrity of forms of engineering education. Integrity arises from the vision of the overall structure, a single "further" order that is associated with the existence of general guides – some structure-forming axes. The integrity of a complex system is provided by the coherence of all its subsystems' functioning, and the integrity level is determined by the level of integration of the individual subsystems, i.e. the composition, structure, content, and intensity of different types of interaction between them. The forms of engineering education can be classified on various grounds: the method of obtaining - full-time, distance, open; the participation or nonparticipation of teachers in the process of teaching sessions– self-education, independent work; mechanism of decomposition of the educational content – disciplinary, project; types of lessons – lecture, seminar, laboratory practical work, consultation, training and industrial practice, etc. System integrity of forms of engineering education implies that the structuring of the content of engineering education provides for the possibility of using in different forms. Integrated pedagogical process is characterized by the internal unity of its constituent components and their harmonious interaction.

Experimental verification of the rules' effectiveness for structuring of the content for engineering education

Experimental verification was conducted on the basis of Kazan state University of architecture and construction. In the experimental testing took part 430 teachers, 410 students. Experimental testing took place in three stages: ascertaining, forming and control.

Within the summative phase, it is found that, in the opinion of 94 % of teachers, economic globalization and increasing competition in the market of engineering labor initiates the production of uniform requirements for the quality of engineers' training and ensuring of their international mobility. From the point of view of 87% teachers structuring of the content of engineering education is a tool for problems' solving of engineering education. The majority of students (84 %) believe that the optimal structuring of studied material promotes the success of comprehension and the reliability of their training for future professional activities. At this stage, targeted groups from teachers and students were established for the approbation of the rules for structuring of the contents for engineering education on the basis of the discipline "Fundamentals of manufacturing engineering".

On the forming stage groups developed: 1) learning modules that provide learning, development of skills and formation of professional competences; 2)

lectures and practical classes of an interdisciplinary nature, which is a system of knowledge, skills and practical experience, selected on the basis of interaction between the content of individual academic disciplines for the purpose of internal unity of the educational curriculum; 3) taxa that reflect the invariant and variable components of the content of the discipline.

In the control phase the following positive results of structuring of the content for engineering education on the proposed rules were determined: 1) embedding in the content of education of tools for its integration with science and industry enables the integration of knowledge, experience and value-semantic relations of the future engineer, which is a base for his self-identity as a person and professional; 2) the identification of invariant and variable components in the content of education allows dividing of the educational material into modules, ensuring the mobility of knowledge, and receiving of completed results of the educational-scientific-industrial activities of students within each module; 3) the preservation of logic of the discipline is contributed by the existence of compulsory and elective modules as well as the corresponding components in the structure of each module; 4) taking into account of interdisciplinary connections allows integrating and differentiating of the content of education through curricular development in a complete, concise and in-depth versions; 5) taxonomic representation of interdisciplinary content of education stimulates mental activity of students and formation of innovative approaches to problem's solving, development of creative thinking; 6) system integrity of forms of engineering education contributes to the role's strengthening of consultative and coordinating functions in the activities of the teacher, the significance's enhancement of the management of students' cognitive activities and the accumulation of knowledge, skills, abilities, competencies. Based on the above mentioned results, the textbook "Fundamentals of manufacturing engineering" was prepared.

Discussions

The content and organization of engineering education is the subject of many studies. In the publications of A.I. Subetto (2002) the content and organization of engineering education are considered from the viewpoint of its quality. According to A.I. Subetto (2002) the quality of education is a system of knowledge, capacity, relationships, books, techniques, technologies, mechanisms for ensuring of the access to higher education for all social layers of society with the reproduction of all stages of continuous education. The apparent advantage of his works is the establishment of a link mechanism of the rising quality of public intelligence's reproduction and quality of management as appropriate ones to the law of advanced development of the educational systems' quality. However, A.I. Subetto (2002) doesn't specify the current requirements for the content of engineering education. In studies of N.A. Seleznyova (2002) a student-centered focus of the educational process is allocated. However, this idea is not disclosed within the content of education. In the monographs and papers of V.M. Zhurakovskiy (1997), A.A. Kirsanov (2001) and D.V. Chernilevskiy (2002) the relationship of engineering education with other spheres of social life is clarified, mainly with science. But in the works of these authors the engineering education, generally is considered by external determination, the main actors (teacher and student) do not participate in the selection and structuring of the content of engineering education.

All the above have highlighted the purpose and objectives of our research.



Conclusion

The technology for forming of the innovative content for engineering education includes the selection and structuring of knowledge, abilities, skills, competencies required for the modern engineer for successful professional activities at the level of specific academic disciplines and their classification. It is found that the process of selection and structuring of the content for engineering education consists of three stages. First, the stage of theoretical justification: clarification of current requirements for the content of education, formation of information base of the educational-scientific knowledge, defining of the purpose and objectives of education, the identification of invariant and variable components in the content of education. Secondly, the stage of structural-semantic projecting of the content for engineering education: definition of rules for structuring of the content for engineering education, embedding in the content of education of mechanisms for its integration with science and industry, forming of training modules, establishment of interdisciplinary relationships, taxonomic representation of interdisciplinary content of education. Thirdly, the stage of scientific and methodical support of formation of the innovative content for engineering education: selection of software of functional computer taxonomy, classification of structure-forming components of engineering education.

It is established that modern requirements to the content of engineering education (consistency with invariant structure of professional activities; the system integrity of knowledge, abilities, skills, competences; taking into account of innovative educational, research and industrial developments) are conditioned by the development of science-intensive technologies. Modern post-industrial society produces social order for the engineers, who are able to work successfully at companies of different types and forms of ownership, and ready for multi-level socio-managerial modeling. This implies the integrated nature of their training, ensuring the unity of the functional and social components, knowledge of the specifics of professional activities. Among the important tasks of the present stage of modernization of engineering education is the improvement of its content to reflect technological advances, prospective requirements for the competencies of engineers in specific, but rather broad areas of professional activities. Innovative transformations in the content of engineering education are in the selection of knowledge, abilities, skills, competences, in accordance with scientific achievements, promising industrial needs, the needs of society in obtaining of specific diagnosed results of educational-professional activities of future engineers. The content of each technical discipline must be systemically oriented on the formation of the competence of future engineers in the field of multi-criteria interdisciplinary practical tasks' solving of professional orientation.

Structure-forming components of the content for engineering education should be sufficient to obtain functionally complete learning outcomes of students for each teaching session in the light of the regulatory set conditions. The rules for structuring of the content for engineering education include: the conjugation with professional functions; the identification of invariant and variant components; forming of training modules; establishing of interdisciplinary relations, their taxonomic representation, system integrity of the structure-forming components of engineering education. It is found that the structuring of the content for engineering education according to the rules produces new conceptual orientations that determine the choice of methods and means of

education which integrate educational and professional activities of students, research and teaching activities of teachers.

The paper submissions can be useful for teachers of research universities engaged in the training of future engineers; for employees of centers for advanced training and retraining of personnel in the selection and structuring of the content for the qualification's improvement of engineers and scientific-pedagogical specialists of scientific-research universities.

Taking into account the obtained results of this study a number of research challenges and promising directions that require further consideration can be highlighted: the technology of formation of a uniform educational environment of a technical University, science and industry; the managerial mechanism for development of integration processes in technical high school; technology of integration of engineering education, science and industry; criteria and indicators of productivity of engineering education.

Disclosure statement

No potential conflict of interest was reported by the authors.

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