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Kriskovets Tatyana Nikolaevna,
Doctor of Pedagogy, Associate Professor,
Head of the Department of Foreign languages,
Military Engineering and Technical Institute,
Military Educational Institution of Logistics
named after General of the Army A. V. Khrulev,
Russian Federation, Saint Petersburg,
e-mail: tnkris@mail.ru

Крисковец Татьяна Николаевна,
д-р пед. наук, доцент,
заведующий кафедрой иностранных зыков,
Военный институт (инженерно-технический),
Военная академия материально-технического обеспечения
имени генерала армии А. В. Хрулева,
Российская Федерация, г. Санкт-Петербург,
e-mail: tnkris@mail.ru

THE WAYS OF SYSTEM THINKING DEVELOPMENT OF FUTURE ENGINEERS

СПОСОБЫ РАЗВИТИЯ СИСТЕМНОГО МЫШЛЕНИЯ БУДУЩИХ ИНЖЕНЕРОВ

13.00.08 — Theory and methodology of professional education
13.00.08 — Теория и методика профессионального образования

The article examines the issue of updating the contexts of professional training of the technical university students and cadets. The demand of the strategic training program presented in the State Program "National Technological Initiative" is proved. The article reveals the necessity of making changes in the engineering education in general, the introduction of new methods and a number of innovative educational technologies aimed at development of the systems engineering thinking in general.

The author postulates development of the students' systemic engineering thinking as the basis of the best implementation of general scientific and special professional knowledge in the area of professional activity. The main goal of development of engineering thinking is promotion and implementation of technical innovations to achieve effective results, as well as to find solutions to technological and production problems. The article represents the use of a synergetic approach as a methodological basis of the research. Systemic thinking is presented as a characteristic that promotes holistic perception of phenomena and processes.

The potential of metacognitive educational technologies, such as technologies of development of critical thinking, technologies of systems analysis, reflexive technologies, for development of engineering thinking is shown. They contribute to development of reflexive mechanisms, the ability to generalize, systematize, convey, and work with systems. The article presents the structure of engineering thinking; it provides the results of students' systems engineering thinking development. The author offers typical tasks aimed at systemic thinking

explication. The stages of systems thinking technology include problem acceptance, idea generation, design development, and project implementation.

The author argues that updating educational basis aimed at developing the systemic engineering thinking of students, which is taken as a basis at the educational institutions of the Ministry of Defense, will contribute to achievement of high quality military education adequate to the requirements of the 21st century.

В статье рассматривается проблема обновления контекстов профессиональной подготовки курсантов и студентов инженерных специальностей. Доказывается актуальность разработки стратегической программы подготовки кадров, представленной в Государственной программе «Национальная технологическая инициатива». Обосновывается необходимость внесения изменений в инженерное образование в целом, внедрения новых методов и ряда инновационных образовательных технологий, направленных на развитие системного инженерного мышления в целом.

Автор позиционирует развитие у обучающихся инженерного мышления как основу оптимальной реализации общенаучных и специальнопрофессиональных знаний в сфере профессиональной деятельности. В качестве основной цели развития инженерного мышления представлены продвижение и внедрение технических инноваций для достижения экономически эффективных результатов, а также для поиска решения технологических и производственных задач. В статье обосновывается использование синергетического подхода в качестве методологической базы исследуемого процесса. Системность инженерного мышления представлена как характеристика, способствующая целостному восприятию явлений и процессов. Показан потенциал метакогнитивных образовательных технологий, таких как технологии развития критического мышления, технологии системного анализа, рефлексивные технологии, в развитии инженерного мышления. Они способствуют развитию рефлексивных механизмов, умению обобщать, систематизировать, передавать, работать с системами.

В статье представлена структура инженерного мышления, даны результаты исследования уровня развития системного инженерного мышления, предложены типовые задания, направленные на развитие системного мышления. Автор утверждает, что построение учебного процесса на обновленной основе, направленного на развитие системного инженерного мышления студентов, принятое за основу в образовательных организациях Министерства обороны, будет способствовать достижению высокого качества военного образования, адекватного требованиям XXI века.

Keywords: engineering thinking, functional consistency, synergistic approach, internal and external systemic relationships, systemic connections, system element, training of highly qualified personnel, nonlinear thinking, structural and functional analysis, product marketing, metacognitive educational technologies.

Ключевые слова: инженерное мышление, функциональная системность, синергетический подход, внутренние и внешние системные взаимоотношения, системные связи, элемент системы, подготовка высококвалифицированных кадров, нелинейность мышления, структурный и функциональный анализ, маркетинг продукта, метакогнитивные образовательные технологии.

Introduction

Nowadays, state and public structures are more than ever interested in ensuring the development of industrial sectors of Russian economy. The state program "National Technological Initiative" states the necessity to develop the strategic personnel training program. Its aim is to provide cooperation between the state, business and science in order to ensure technology platforms operation [1]. This task determines **the relevance** of this research.

Knowledge on the subject. Currently, there are some studies in psychology and pedagogy that reveal the problems of systemic engineering thinking development. Scientific research by A. Alekseev, V. Asmus, E. de Bono, D. Lando, I. Lerner, Ya. Ponomarev, V. Razumovsky, T. Ribot, A. Esaulov, P. Jacobson reveal systemacity as engineering thinking characteristic. M. Ochirov, O. Garmaev noted the determinism of professional thinking of an engineer by the totality of economic, environmental, aesthetic, ergonomic, communicative, and managerial requirements for professional activity [2]. Some works offer a view upon the structure of engineering thinking (D. O'Konnor) and describe the levels of its development (D. Mustafina, I. Rebro, G. Rahmankulova). Nevertheless the analysis shows that the necessity of systemic engineering thinking development is still declaratively proclaimed.

The expediency of the research is to meet the requirements of strengthening the practical orientation of education, reflected in the Project "Promoting the development of personnel training system for basic sectors of the economy" [3].

Due to this fact **the aim** of the research is to determine the main ways of students' systemic engineering thinking development. **The tasks** that arise in this regard relate to: clarification of the concept of systemic engineering thinking; determining the mechanisms of its formation on the technological basis.

Scientific novelty of the research lies in the substantiation of the means of systemic engineering thinking development on the base of the technology of systems engineering thinking development.

The theoretical significance of the work is that it complements the knowledge about the formation of technical university student. The features of the formation of the professional consciousness of the future engineer are revealed in the work from the standpoint of the synergetic methodology and are important for the didactics of higher schools.

The practical significance of the work is that the results of our research can be used in the educational process and programs of professional education for future engineers leading to changes in engineering education in general.

General part

Materials and methods. The methodological base of this research is the ideas about the synergetic style of thinking based on the principles of openness and non-linearity. Synergetic paradigm, according to V. Penkov can be used to create "principally new approaches to the studying of surrounding reality" and, therefore, it serves to develop thinking style suitable for solving problems of various spheres of activity [4]. Thus, engineering thinking is non-linear, open and holistic. In the course of the study, such theoretical methods as research analysis, synthesis, analogy, generalization are used.

The main purpose of engineering thinking is the promotion and introduction of technical innovations to achieve economically effective results, as well as to find the solution of technological and industrial problems [5]. This process includes

accepting the problem, generating an idea, which, in turn, leads to a design developing, changing into a real project of new equipment, technology, etc. [6].

The structure of engineering thinking includes such components as:

– technical thinking, implying the skills of structural and functional analysis;

– constructive thinking, allowing to simulate the process of solving the problem, combining theoretical and practical foundations;

– research thinking, which helps identify the degree of novelty of the problem and is reflected in the ability to compare, build a system of evidence and draw certain conclusions;

– economic thinking, which includes evaluating project's economic efficiency and marketing presentation of the results [7].

Scientific research (A. Alekseev, V. Asmus, E. de Bono, D. Lando, I. Lerner, Ya. Ponomarev, V. Razumovsky, T. Ribot, A. Esaulov, P. Jacobson) represent functional systematicity as a fundamental characteristic of engineering thinking.

Systems thinking helps a person perceive objects and processes holistically, to see the interconnections that unites elements into a system [8]. A system is not a simple combination of components; it consists of many subsystems, which include system elements. System elements have all the characteristics of a system. These relationships determine the holistic functioning of the system. According to the ideas of D. O'Connor and I. McDermott, the more connections there are in the system, the more ways you can find to influence the system [9].

Logic helps to identify the elements of the system, to present their characteristics. Logical thinking involves the abilities of the analysis and synthesis of information. However, it does not allow taking into account internal and external system relationships, in contrast to systems thinking [10].

Systems thinking is based on a combination of integrity and hierarchy. Integrity means that each element has the properties of the entire system. Each system is a subsystem of a higher order system. Therefore, it is necessary to take into account the structure, function and process of the system. Their study allows to know the properties of each element both separately and in the system [11].

However, there is an imbalance between the desire for a short-term effect and the potential problems that arise in the long run.

The results of the research. A survey was conducted among the cadets of engineering specialties of the Military Institute (engineering and technical). The teachers assessed the cadets' level of development of engineering thinking. Assessment of the cadets' level of development of engineering thinking showed that 3rd-year cadets of engineering majors have problems with systematic vision of the problem (34 %), taking into account possible limitations when finding solutions (22 %), the ability to predict the further development of the idea (24 %), ability to calculate the economic effect of an idea (12 %).

The skills of structural-functional analysis (56 %), marketing presentation of a product (46 %), the ability to generate new ideas (46 %), the ability of self-education (48 %), and practical application of theoretical calculations (46 %) are slightly better developed. However, these qualities require further improvement.

The abovementioned data make it necessary to change the contexts of professional training of cadets and students of engineering specialties. We need new approaches, a different system of tasks, and a change of educational technologies.

Metacognitive educational technologies such as critical thinking development technology, system analysis technology, reflective technologies have high potential in the development of engineering thinking. They contribute to the development of reflective mechanisms, the ability to generalize, systematize, transfer, work with systems.

The technology of systems engineering thinking development, created on the basis of the ideas of G. Shchedrovitsky by his followers, suggests a chain of technological operations (fig.) [12].

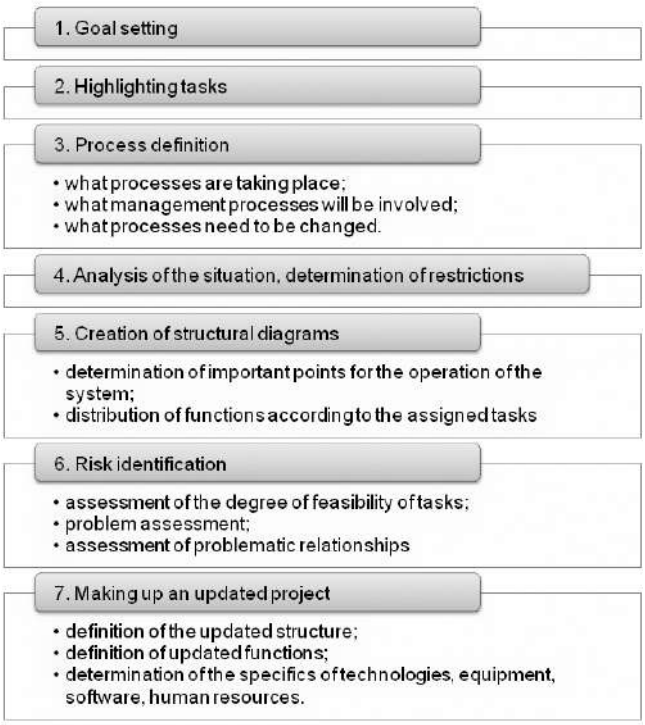

Fig. Technology of systems thinking development (according to G. P. Shchedrovitsky)

Outputs

As we have said above, engineering thinking is based on a synergy methodology and is non-linear, open and holistic (holistic). The synergistic paradigm allows the formation of a style of thinking suitable for solving engineering problems. The synergistic style of thinking is based on the synthesis of natural science, humanitarian and philosophical styles of thinking and represents a unified methodological basis for engineering thinking development the due to the following facts:

Firstly, engineering problems can be viewed upon as complex system. The functioning of it as a whole cannot be described as a simple sum of characteristics of its elements.

Secondly, the constant flow of information makes engineering cognition an open, dynamic, constantly updated system. In an engineering case random factors and fluctuation processes are of great importance. The need to take into account the diversity of reality explains the necessity of various methods and forms of cognition.

Thirdly, the complexity of engineering problem, characterized by instability, constant variability, determines the necessity of a nonlinear type of thinking. The idea of development of nonlinear analysis makes necessary to introduce new methods and a range of innovative educational technologies aimed at developing systems engineering thinking in general.

In practice, the synergistic approach is based on the principles of self-organization, nonlinearity and is implemented through the technology of systems engineering thinking development.

This technology includes the use of a set of methods aimed at developing skills in modeling and analysis of practice-oriented situations. Among them are the following:

– Methods of scientific knowledge: analysis and synthesis (separation of components from the whole and uniting parts into a single whole), deduction and induction (derivation of evidence from general to particular and from particular to general), analogy, abstraction (distraction from certain properties) and idealization (work with abstract concepts). These methods include tasks related to the analysis and description of graphs, diagrams, cyclic diagrams (processes), with the creation or decoding of diagrams, with the allocation of logical patterns based on the analysis of a series of diagrams.

– Methods of comparison, the search for patterns in logical sequences and structural diagrams, the search for relationships between elements, the compilation of a new object based on one or more given ones, the transformation of an object in a changing environment. The complexity of tasks based on these methods is that cause and effect can be dispersed over time.

– Methods of modeling (creation and study of the model). The model is a generalized copy of the analyzed process. It is abstracted from particulars and contains the most important functions and relationships of the system. Modeling is the process of creating a model as a conceptual representation of some phenomenon. Typically a model will only deal with some aspects of the phenomenon under consideration, and two models of the same phenomenon may differ significantly. The differences between them will be not only in the simple renaming of their constituent components [13]. Tasks based on these methods contribute to the development of students' skills to abstract from unnecessary things, to model the situation, both with real objects and situations, and with fictional ones.

– Methods of analysis of the effective systems functioning. The presence of similar characteristics of systems suggests the existence of similarities in the ways of their functioning. The study of the interconnection of the system components, the quality and conditions of its functioning makes it possible to transfer the specifics of one system to another.

– Presentation of problem solving activities. At first the students are offered a number of typical tasks in order to learn to follow an algorithm. Then they are supposed to cope with non-standard problems or uncertain operating conditions. These actions will prepare students for the real conditions, characterized by lack of stereotyping.

– Methods relating to work with information. In conditions of information overload, the ability to work with large information arrays acquires special significance. These methods include tasks connected with the systematization of information fragments, the search for the relationship between them, the determination of the falsity, truthfulness or impossibility of evaluating statements regarding the text.

– The task of making questions to the concepts denoting a phenomenon or an object (L. Sharagina's methodology.) [14]. The questions are divided into general (not containing information about the object) and system (concerning the functions and properties of the object, its internal relationships).

– Development of the ability to see feedback. These methods include tasks aimed at assessing both the short-term effect of the solution and long-term prospects. The feedback system reflects the dependence of the input on the output results. This dependence can be traced in four main feedback processes: measurements of primary and secondary properties, comparison with a standard, search for a solution to the problem, and changes in input parameters [14].

The mentioned tasks are aimed at developing significant skills to keep in mind the whole and the component, to see the role of each concrete action in achieving a common goal.

Conclusions

Changing the context of professional training based on a synergistic approach contributes to the active use of the student's personal resources, an increase in the need for self-development, which is a guarantee of his professional relevance. A future engineer needs these qualities, as they are the basis of modern engineering thinking, which implies flexibility and global thinking, active generation of ideas and prediction of the results of their implementation.

Therefore, the global task of a technical university is to build the educational process on an updated basis, aimed at developing students' systems engineering thinking for the optimal implementation of general scientific and special professional knowledge in the sphere of professional activity. This system of actions adopted in the educational organizations of the Ministry of Defense will contribute to achieving high quality of military education that is adequate to the requirements of the 21st century [15].

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