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Model of the Formation of a Technical University Students' Preparedness for Innovative Design Activity*

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The need for innovation in the research and development training of students is connected with the fact that the requirements for the design competence of the new specialist continue to expand. The objective of the proposed technology is to organise such a system of future mechanical engineering specialists' training that will be able to prepare students for research and development activities, to enable students to master modern methodology, to study organisational forms and means of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM), as well as their effective application in future professional activities. Technology development is based on the comparative analysis of the prime characteristics of the modern engineering professional and the training environment, on detection of the contradiction between them and development of the curriculum according to the regional component of the State Educational Standard (SES). Distinctive features of the given technology include maximising the connection between education and professional activity structures, phased familiarisation of students with typical research problems and identifying their solutions.

INTRODUCTION

Many new pedagogical technologies, which are aimed both at improving separate elements of the teaching process and at the training of specialists with higher education, have appeared recently. Feasible modernisation changes in society and the technical sphere urge the need for a higher education system.

The following innovation trends should be highlighted:

- The elaboration and introduction of information technologies in the teaching process enable the overall applications of modern computer means, not only in specialist training processes, but also in their further professional activities.
- The creation of psychological-pedagogical conditions and the methodical development of back-ups in a continuous development of future specialist personal creative features, which are important for intellectual design activities.
- The formation of a student's methodological base of engineering knowledge and systemic technical thinking due to the application of interdisciplinary teaching and methodical complexes in the education process.
- Optimisation of the fundamental, general and special professional component correlation with regard to engineering education and training from a more fundamental approach to specialised disciplines and a more practical approach to fundamental ones.
- Individualisation of specialist training trends aimed at meeting the needs of client of educational services.

All of the above mentioned technologies are characterised by a systemic approach to the educational process of an organisation, the approximation of structures of educational and professional activities, the determination of didactic conditions

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that are required to achieve the educational goals, and experimental testing and evaluation of the efficiency of the suggested innovations. Although the majority of recently developed pedagogical technologies contain scientific and methodical recommendations with regard to their introduction in the teaching process, the conceptual provisions proposed above need a further detailed study in order to be implemented within the system of engineering training in different majors, particularly when taking into account individual engineering educational institution resources.

Currently, the following areas of an engineering graduate's professional activities can be discerned: industrial technology, organisational management, research and development, scientific research, expertise and innovation. Analysis of the Russian State Educational Standards for engineering education over the last few generations indicates that about 70-80% of the qualification requirements for the skills and knowledge base of a specialist are directly or indirectly related to the sphere of Research and Development Activity (RDA). There are several reasons for study activities, which are aimed at the formation of students' preparedness for RDA, dominate the structure of engineering education standards.

The need to increase the design culture of a specialist is connected with increasingly complicated levels of tasks for designing new technological machines and high-tech productions. The wide use of modern means of Computer-Aided Design (CAD) makes the design of technical objects, with its continually advancing methods, means and organisational forms of solving R&D tasks, the most dynamic and developing type of engineering activity. Design involves the synthesis of scientific knowledge gained in all-round research of a technical object, while also carrying out other types of professional activities. Thus, the functions of a design engineer have now becoming broader to include more elements of scientific research, organisational management, expertise and industrial work.

It is in RDA that the particularity of professional tasks to be solved by engineers from different fields is revealed because it fully reflects the subject matter of a specialist's activity, its structure, as well as the levels and stages of a technical systems' functioning. Thus, innovating the system of an engineer's preparedness for RDA is extremely necessary. It will have a positive influence on the formation and development of graduates' preparedness for the design of technical objects, as well as on the preparedness for other engineering activities.

FORMING MECHANICAL ENGINEERING STUDENTS' PREPAREDNESS FOR INNOVATIVE DESIGN ACTIVITY

Preparedness for innovative design activity as a formed system of knowledge, skills and traits professionally significant for a mechanical engineer denotes those activities that would allow for the design and servicing of all of the functioning stages of social and technical systems.

The various motives for the professional activity (utilitarian pragmatic, imperative, or value-oriented) serve as indicators of the level of preparedness' motivational component formation. In the authors' opinion, the motivational preparedness of a mechanical engineer for designing social and technical systems is reflected in his/her positive attitude and interest in the design processes and results, in addition to organisational and communicative skills, and in self-evaluating design results. An indicator of the preparedness' cognitive component formation level is the quality of a student's knowledge of professional subject matter, such as the peculiarities of mechanical, heat and mass transfer production processes; the fundamentals of low waste, energy- and resource-saving technologies development; properties of construction materials and machine building technologies; the basics of engineering graphics and mechanical drawing; characteristics of modern technical equipment constructions; and contemporary methods, means and forms of the design of complex technical objects, including computer engineering.

Indicators of the level of preparedness' operational component formation cover the quality of carrying out design procedures at various stages of social and technical systems design. This includes:

- The ability to formulate project goals.
- The ability to consider and rationalise technical decisions.
- The ability to draw up technical documentation according to current State standards.
- Knowledge in various calculation and construction methods for technical equipment and its elements.
- Machines and apparatus selection skills when designing technological lines.
- Knowledge of technical equipment composition and assembly methods.
- Skills to technically and economically evaluate a project's efficiency.
- The ability to analyse design results.

Personal traits of character and abilities, which are sufficient for the requirements of the effective realisation of innovative design activities, to indicate the level of the preparedness of the emotional component. They are reflected in:

- The preparedness for professional communication.
- Initiative and the ability to quickly adapt to changes in external conditions.
- The ability to mobilise forces to solve design tasks.
- An understanding of personal responsibility for design results.

The indicators of the preparedness' informational component are the skills and abilities to search for, process, store and exchange the information necessary for innovative activity, as well as the use of graphic and word processing software, electronic databases and programming languages at various stages of technical objects design. Three levels of preparedness can be distinguished in this respect, namely:

- Use of general-purpose software for the automation of the design procedures.
- Utilisation of special-purpose software for the automation of the design procedures.
- Development of personal software products for the automation of the design procedures.

The authors consider that the application of the above-mentioned computer technologies in an innovative design proves the formation of a specialist's information culture.

All of the components in the preparedness for innovative design activity are connected and interdependent. For example, at the current stage of Computer-Aided Design (CAD) development, the formation of an informational component of preparedness largely determines the formation of operational components. Their unity is reflected in the style of specialist professional work and thinking, which underlie the pattern of solving design tasks.

The definition of the contents of the motivational, cognitive, operational, informational and emotional components of a specialist's preparedness for innovative design activity directly contributes to the development of a model for the formation of mechanical engineering students' preparedness. This relates to the aspect of the innovative design of technical systems in the circumstances of an increasing need to develop and apply high technologies in industry (see Figure 1).

With regard to the principles of the psychological characteristics of innovative design activity and its structure, the authors sought to define the criteria for the evaluation of a mechanical engineer's preparedness for technical systems design with the help of different levels for design activity. These three different levels incorporate the following:

- The reproductive level, which is typified by the ability to solve design tasks according to a known algorithm.
- The productive level, in which one is able to solve problems concerning the modernisation of technological equipment and the reconstruction of production on the basis of algorithmic and problem-searching approaches.
- The creative level, which is characterised by the ability to carry out innovative projects that synthesise algorithmic, problem-searching and research approaches.

The systemic approach to solving the problem of increasing the mechanical engineers' preparedness for innovative design activity, applied in this research, is oriented towards the integrative characteristics of preparedness. This should be considered to be one of the sub-systems that form the professional preparedness of an engineering student. It is also closely connected with other sub-systems that forge the preparedness for industrial technological activity, for organisational and managerial activity, and for research and developmental work.

It is obvious that developing preparedness for any kind of professional activity will increase professional competence of a specialist on a whole. Furthermore, improving the process of specialist training for innovative design activity will significantly influence the level of the competitiveness of technical university graduates in the local, regional and global job markets.

Thus, the conducted research permits the highlighting of the following features in the process of the formation of students' preparedness for innovative design activity:

- The process of forming the preparedness for an innovative design activity must be studied as a system: the description of its elements is not the end in itself, but must be done with regard to their role in the process of the professional training of mechanical engineers.
- The identification of the aim of modelling and the problems to be solved is based on an analysis of social demands and requirements for competitive mechanical engineering specialists and on the strategic goal of increasing the quality of engineering education.
- The modelling of the process of forming the preparedness for innovative design activity must take into account the various psychological characteristics of different stages of technical systems design and of various types of R&D tasks.
- The formation of motivational, cognitive, operational, emotional and informational components

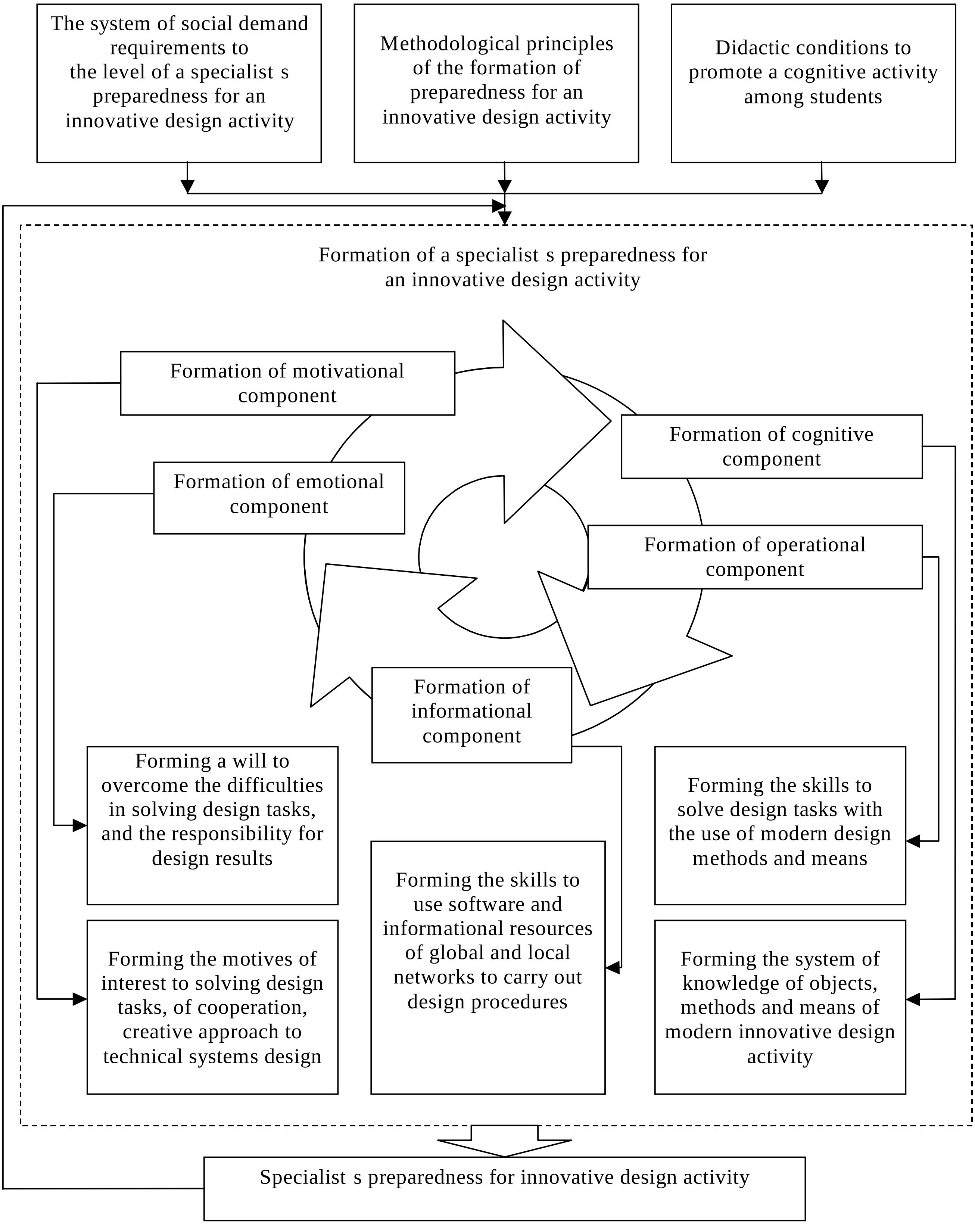

Figure 1: Model of a specialist’s preparedness for innovative design activity.

must not be separate but rather interrelated and coordinated processes.

- The transition from a model of forming preparedness for an innovative design activity to the technology of student training organisation must be realised by determining the methodological principles and didactic conditions for promoting cognitive activity among students.

The differences that exist between functional, methodological, structural, informational, procedural and organisational invariants can be identified within the structure of RDA. Structural informational invariants include information (knowledge system) on the subjects of professional activity (eg machinery, apparatus, processing lines, technological processes, etc). Functional methodological RDA variants incorporate knowledge of engineering design strategy, tactics and means, methods of simulation and optimisation of designed technical units. Procedural and organisational RDA types include the patterns of mental and communal processes and activities necessary to organise and accomplish R&D tasks.

Thus, the choice and structure of teaching materials for a specialist's research culture formation should be carried out by taking into account the design elements hierarchy and the basic types of research tasks that are to be to be solved by the specialist.

The formation of a comprehensive system of engineering design knowledge, abilities and skills should be carried out using an integrative module approach. Essentially, this lies in an interdisciplinary study of the most difficult and professionally valuable theoretical problems during lectures, in an analysis of solutions of typical and original design problems in practice classes, in the realisation of a comprehensive course project, in a specialisation discipline and control of students' level of preparedness to an R&D activity, according to an original study structure.

The development of a model of mechanical engineer training was based on the following assumptions:

- A model of a specialist's training must take into account the requirements of a client of educational services, higher education legislation, specific conditions of local business and industry, and the internal resources of the technical university in question.
- A model of specialist training must be based on an analysis of contemporary engineering activities and must fulfil the objective function of a specific educational programme, which conditions the choice and structure of study contents.
- A model of specialist training must contain the sub-systems for the formation of engineering thinking and graduates' preparedness for industrial, managerial, research and design activities.
- In addition to a structural content component, a model of specialist training must include organisational procedure and control diagnosis components that allow for the efficient realisation of that training system and the estimation of a graduate's level of professional competence.
- A model of a specialist's training must be subject to operational adjustment when external conditions and parameters of engineering activity, as well as the level of professional knowledge and personality characteristics of a graduate, change.

The proposed model for a mechanical engineer's RDA preparedness has a block structure consisting of chemical and technological, mechanical and machine building, as well as informational components.

The chemical and technological block envisages the mastering of the disciplines in order to generate the concept of a chemical production system, its optimisation and control. The subjects studied include safety and technical issues, and the quality evaluation of assembly, repair and maintenance work.

The informational block includes disciplines that are focused on the new application of information technologies. The major problem solved by this block is the interdisciplinary integration and elaboration of intellectual CAD/CAM systems, production systems, etc. The synthesis of these blocks is achieved in the structure of the graduation project.

If a student's graduation project displays important scientific, practical or methodological results, the State Examination Board may decide to recommend the project's author for postgraduate study. Depending upon the results obtained, and the inclinations and abilities shown, the graduate may continue education at the postgraduate level in the following areas:

- Processes and apparatus of chemical technology.
- Machines and apparatus of chemical industry.
- Theory and methods of professional education.

The nomenclature of postgraduate training majors corresponds to the structure of the elaborated model.

The development algorithm of a specialist RDA training model includes an analysis of the qualification characteristics and job description of a mechanical engineer, regional specifics and engineering design development perspectives, study of the requirements for modem design documentation, analysis of state education standards of specialist training, curricula, working plans and programmes, as well as graduate qualification theses and State Examination Board reports.

The structure and content, organisation and procedure components, as well as methodological principles of specialist training system organisation in accordance with the modem requirements, need to be paid special attention. A model of specialist training is represented by those systems of interdisciplinary problems that are aimed at solving typical R&D tasks. The implementation of the suggested model at an institution of higher technical education requires certain didactic conditions so as to ensure the optimisation of the learning cognitive processes of mechanical engineering specialist training for an R&D activity.

DIDACTIC PRINCIPLES AND CONDITIONS OF THE FORMATION FOR PREPAREDNESS TO RDA

The design of innovation technologies should be carried out on the basis of didactic principles of integrity and systematisation, the scientific and problem-based character of education, as well as professional orientation, independence, self-fulfilment and the promotion of cognitive activity, plus some others. These principles have been laid into the foundation of the development of a scientifically grounded integral methodical system of R&D training at a technical university. At the same time, it is assumed that the dominating character of professional orientation is realised by simulating in the educational process the structure of the professional activity of a modern engineer. The goal of professional activity simulation is that of singling out typical design tasks, their transformation into teaching professional tasks and the choice of the corresponding forms and methods of the education process organisation.

Research has shown that the efficiency of system implementation is influenced by the following prime factors:

- The organisation of a professionally oriented teaching information environment should be aimed at facilitating systemic technical thinking and the achievement of the necessary level of an engineer's preparedness to RDA.
- The securing of continuous and successive R&D training of students in the process of mastering general, professional and specialist disciplines.
- The desired level of R&D preparedness should be the aim with regard to obtaining the content selection, method of structuring training material, combination of training forms and methods at each training stage.
- The design of different levels for the presentation of education materials, depending upon the psychological and pedagogical specifics of the students, the formulation of problems for personal self-fulfilment and the development of engineering thinking.
- An interdisciplinary approach with regard to the content selection of R&D training, a level of theoretical analysis and practical professional orientation.
- The quality of R&D training monitoring systems is important in order to assist with correcting the structural, content, organisational and procedural aspects of the education process.
- The possibility for the transformation and operative renewal of the structural, content, organisational and procedural elements of a specialist training model. This would be in accordance with current and forecast changes in the field of professional activity.
- The wide application of multimedia teaching systems and professionally-oriented software products in the education process.

TECHNOLOGY IN PHASED FORMATION OF PREPAREDNESS FOR RDA

The preparedness of future mechanical engineers for R&D activities in the process of studying at a technical university consists of several qualitatively different stages (levels), thereby also dividing the training system into stages, completion of which should guarantee a desired level of preparedness.

The technology of R&D training includes the stages, aims, structure and content of an educational activity at each level of training. It is envisaged that the subjects will ensure the formation of R&D preparedness, methods, means and organisational forms of a cognitive educational activity and generate the required results for the preparedness and development of motivation and operational sphere of students (see Table 1).

Today, the training of a competitive specialist is impossible without a wide application of resources in information and telecommunication technologies in the education process. It is particularly topical for RDA training as various software products are used nowadays in engineering design. This resulted in Computer-Aided Design (CAD) becoming an integral component of engineering training in different specialisations. An engineer who has not gained the necessary knowledge and skills in CAD applications cannot be considered a fully-fledged specialist.

COMPUTER SUPPORT IN FORMING AN ENGINEER'S PREPAREDNESS FOR RDA

Expert analysis of resources of technical and didactic computer technologies should single out the aspects of student training for RDA in which they may be used most effectively. There are issues of various design tasks with the application of professional software products, the creation of automated laboratories with remote computer access, the application of information and telecommunication resources to the operative renewal of the content of leaching aids, the

Table 1: The use of technology in the phased formation of the preparedness for RDA

	(1-2 semesters)	(3-5 semesters)	(6-9 semesters)	(10 semesters)
The aim of training at a given stage	Formation of general notions of RDA and preparation at a technical university, with a focus on natural science and engineering activity. The initial stages of forming motivation and spheres of operational professional activity.	Formation of basic knowledge and skills in the engineering design of parts, general machine and mechanism construction elements, development of professionally important qualities of specialist in motivation and operational fields.	Formation of special engineering knowledge and skills of R&D tasks solution, their integration with general professional knowledge and abilities, development of professionally important qualities of a specialist in motivation and operational fields.	Approbation of general and special professional knowledge, skills and professionally important traits of a specialist when solving R&D problems in industrial conditions, their correction and development.
	(1-2 terms)	(3-5 terms)	(6-9 terms)	(10 terms)
Disciplines ensuring the formation of preparedness for RDA	Mathematics and general natural science subjects: *Mathematics, Information Science, Physics, Chemistry, Theoretical Mechanics.* Special subjects: *Introduction to Specialisation, Optimisation of Education Cognitive Activity.*	Subjects of general professional cycle: *Strength of Materials, Theory of Machines and Mechanisms, Machine Pans, Material Engineering.* Specialised disciplines: *Mechanical Engineer Workstation.*	Subjects of general professional cycle: *Processes and Apparatus, CAD/CAM, Economics* Subjects of special cycle: *Simulation and Optimisation of Technological Processes, Branch Equipment, Design and Computation, Methods of Scientific Technical Creative Work, Design of Production Units and Lines.*	Aggregate of previously studied subjects belonging to federal and regional components of the state educational standard of mechanical engineer training.
The content of training and types of RDA tasks	Notion of professional tasks, general concept of project and design problem types, mathematical information and natural science fundamentals of technical problem solving.	Laws of construction and operation of technical units, construction material characteristics, solution of typical tasks of design, computation of machine parts and elements and general-purpose mechanisms.	Command of technical units mathematical simulation and optimisation methods, solution of design and calculation problems for special technological equipment with the use of CAD.	Systemic approaches to technological processes and production equipment design, developing CAD application skills and modem information and telecommunication technologies in engineering design.

use of multimedia, the provision of individual study tracks for students, as well as professional education quality monitoring, using a teacher workstation system connected with that of the student.

The training technology was based on computer engineering means: a system of practical tasks by industry professionals with the use of computer aids. The objective of computer engineering-based training at a technical university is to achieve a particular level in a graduate's preparedness to RDA, as required by modern industry, through the optimal combination of special engineering and information technological training.

The programme of specialist training on the basis of computer engineering developed and effectively implemented at the technological institute of Tambov State Technical University (TSTU), Tambov, Russia, includes the following main directions:

- The formation of a specialist's methodical culture through a detailed study of general design laws and building student knowledge and skills for the phased setting of aims and the means of it being achieved as a basis for the further systemic design of specific technical units.
- Students' mastery of methods of computer simulation and calculation of special machines, apparatus, production lines, as well as analysis of computer models in all stages of R&D work: from concept design to final product certification.

- The development of students' practical skills in the integrated application of CAD, as well as Computer-Aided Manufacturing (CAM) and Computer-Aided Engineering (CAE).
- The integration of university departments and industrial engineering centres so as to carry out joint technical projects and targeted specialist training covering CAD, CAM and CAE.
- The creation of original works in the field of computer simulation, research, optimisation and design of technological processes and systems oriented to meet regional needs.
- The rise in the proportion of course and diploma papers carried out with the help of CAD/CAM/CAE systems, as well as in the number of the required teaching aids and software products.

Computer support of educational processes was carried out with the help of special software products that enabled students to choose the most competent technological and design solutions, which would be very close to optimal, in order to visualise the calculated units and the results obtained, and to produce drafts of technical equipment in accordance with the unified system of design documentation. This would be done quickly and effectively so as to evaluate the efficiency of any realised projects. The training of students should be based on computer engineering results in order for them to gain a good command of modern design methods and special software products that are most commonly used in industry.

BIOGRAPHIES

Sergey V. Mischenko is the Rector of the Tambov State Technical University, Tambov, Russia. He was born on 30 April 1949 in Moscow and graduated from the Faculty of Automation at the Tambov Institute of Chemical Engineering with honours in 1971. In 1975, he completed the postgraduate course in Moscow and obtained the degree of Candidate of Technical Sciences. In 1981, he gained his Doctor's degree in engineering.

His scientific interests lie in the sphere of automatic systems and devices development, as well as education administration. The title of Honoured Scientist of the Russian Federation was conferred upon him in 1993. In 1999, Sergey Mischenko was awarded the title of *Laureaute of the Govermental Prize in Education*. He also received the UICEE Silver Badge of Honour in 2001 at the *2nd Russian Seminar on Engineering Education*, which was held at the Tambov State Technical University.

Prof. Stanislav I. Dvoretsky of the Tambov State Technical University, Technological Institute Director and an Honoured Professor of Higher Education of Russia. He was born in 1949 in Tambov, Russia, and graduated from the Tambov Institute of Chemical Engineering in 1973, and received his diploma to be an electro-mechanical engineer. He defended his thesis and obtained a Candidate degree in 1979. In 1991, he gained his doctorate in automation and control of processing and productions.

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Nikolay P. Puchkov is Vice-Rector for Educational Activities at the Tambov State Technical University, Tambov, Russia, and a professor in mathematics. He was born on 1 June 1948 in the Tambov region. In 1968, he graduated from the Tambov State Pedagogical Institute (Faculty of Physics and Mathematics). Later, he completed a postgraduate course in Moscow and gained the degree Candidate of Technical Sciences in 1978.

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Vladimir P. Tarov was born in 1947 in Tambov. In 1970, he graduated from the Tambov Institute of Chemical Engineering and received his diploma in electrical mechanical engineering. In 1975, he defended his dissertation thesis and obtained the degree Candidate of Technical Sciences. His scientific interests include engineering education.