

Developing economic and managerial competencies of bachelors in mechanical engineering

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Abstract. The paper deals with the development problems of economic and managerial competencies of bachelors after graduating from engineering higher schools to meet employers' requirements, through implementing the Federal State Education Standards (FSES) of the third generation. The case study is conducted on the basis of training programs for the bachelor's degree in Mechanical Engineering at Yurga Institute of Technology (Affiliate) of National Research Tomsk Polytechnic University. The list of economic and managerial competencies for bachelors in mechanical engineering is specified according to the third generation FSES, enlarged with new competences based on surveys and analyses after questioning employers. The criteria and indicators are described to identify maturity levels in terms of economic and managerial competencies for bachelors. A structural and functional model for training mechanical engineering bachelors has been tested in the implementation of the bachelor's degree courses in "Mechanical engineering" at Yurga Institute of Technology (Affiliate) of National Research Tomsk Polytechnic University, in the period from 2011 to 2015.

Introduction

When new technologies are being developed to change the future of the mechanical engineering industry, bachelors graduating from engineering higher schools and universities are required not only to perform tasks in the field of research, development, production and project designing but also to carry out organizational, managerial and economic activities. Only based on engineering education of a high quality with the relevant knowledge in economics and management, bachelors become competent in the field of economics and management, and can effectively manage a modern engineering enterprise in the market environment [1].

In employers' opinions (by questioning the directors of LLC "Yurginsky machine engineering plant", OJSC "Anzheromash" and etc.), the level of expertise achieved by graduates in mechanical engineering is not always appropriate for production tasks performed in the area of economy and management. Therefore, it is necessary to revise approaches to education in training mechanical engineering bachelors to eliminate deficiencies relating to economic and management systems.

Making optimal economic and managerial decisions, according to Vladimir N. Esaulov, Ph.D in Economics,

Director of "Yurga Machine Building Plant" (1987-1997), is a part of functions performed by practicing engineers, which is important for their further professional growth. Training of bachelors in the context of economics and management will contribute to the development of action-oriented mental, cognitive, reflective and creative activity of students. It will also help students to acquire knowledge and skills necessary for an engineer, who is in charge of production and work force organizing the work of a team, which are so essential for social adaptation of a specialist.

The world practice shows that the most successful way of acquiring skills in the area of economics and management is a practice-oriented approach, which is actively used and developed in the world's leading universities, including the Massachusetts Institute of Technology (USA), Chalmers University of Technology, the Royal Institute of Technology and Linköping University (Sweden).

Materials and methods

It is important to analyze deficiencies in vocational training in the context of economic and managerial skills and competences for bachelors in engineering.

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Market relations create conditions for consumers to have preferences over goods for use, including industrial products, building sufficient knowledge to make an optimal choice accordingly. Competition among manufacturers creates very stringent requirements to the level of these indicators and the relation between them.

In light of recent events associated with internationalization of the Russian economy and Russia's special status on the world market, the issue as to development of products in order to replace imported goods is critical. These conditions give an impulse to the training of specialists with economic and managerial competencies, which are necessary for solving production problems in the market-oriented economy.

In Russia, a mechanical engineer is often not only a technician, but also a production manager. She/He is responsible for making basic technical and organizational decisions in order to develop new products, start up production arrange and manage production processes. The process of decision making is not possible without making a thorough economic analysis and evaluating outcomes when using material, labor and financial resources within an enterprise. Therefore, we believe that training with a focus on the competencies and skills developed in the area of economics and management is in demand significantly in modern conditions, and knowledge of methods intended to support decision making in economic management are of importance for future engineers as well.

The learning objective in training bachelors of engineering universities is to prepare graduates for their successful professional life, and thus to help students in developing their economic and managerial competencies. It is essential for students to acquire relevant knowledge, skills and personal qualities with the purpose of enhancing working capacities, entrepreneurial and leadership abilities in the context of technological complexity of products, processes and systems. In our opinion, this justifies an urgent need to revise the list of competencies, their contents, ways and methods of their formation within the framework of the bachelor's degree course in engineering education.

Currently, the problem of enhancing the quality of engineering education is important not only for Russia but also for the entire world. A lot of universities are seeking a way of how to improve the bachelor's education in the sphere of mechanical engineering.

One of the approaches to engineering education, aimed at enhancing the quality of training mechanical engineering graduates, has been developed in the framework of the CDIO Initiative and implemented in many higher education institutions worldwide [2].

The CDIO initiative was founded by a number of European universities and originally conceived at the Massachusetts Institute of Technology (USA). The CDIO approach to modernization and implementation of engineering educational programs is the framework providing students with engineering fundamentals set in accordance with Conceiving - Designing - Implementing - Operating real-world systems, processes and products on the international market. This international project is aimed at eliminating discrepancies between theory and practice in engineering education. The new approach

assumes strengthening of practical orientation of technical education and introduction of the system of problem-based and project-oriented training [3, 4].

According to the CDIO concept, the focus is on the need to form additional professional competencies for bachelors in economics, management, planning, design and entrepreneurship. The ideologist of this approach Edward F. Crawley, the Founding President of Skolkovo Institute of Science and Technology (Skolkovo Tech) in Moscow, has repeatedly stressed that personal, interpersonal, economic and managerial competencies are obligatory for a modern engineer, and their development, respectively, should be an integral part of bachelor's training programs. The CDIO concept is based on the use of the competency-bound approach to the design of educational programs and their components, with setting clear learning outcomes in close cooperation with employers, based on networking cooperation that is founded on the idea of systematic, person-centered and competence-based approaches. The CDIO concept focuses on the social adaptation of a graduate to conditions of the today's economy and the existing market [5, 6].

For this work, we conducted a survey by questioning 73 employers involved in recruiting graduates with a degree in mechanical engineering from different universities in Russia. The primary list of questions, containing economic and managerial competencies, was taken from the CDIO Syllabus. The CDIO Syllabus is a detailed list of learning outcomes for graduates, developed within the framework of the CDIO initiative with participation of industrial and accreditation representatives [6]. A list of Higher Education Institutions (HEIs) offering the baccalaureate in engineering education and companies employing their graduate is provided in *Table 1*.

Table 1. HEIs training mechanical engineering bachelors and Companies employing mechanical engineering graduates.

| HEIs | Companies |
|--|---|
| 1. Tymen State Oil and Gas University | LLC Geology-prospecting equipment and machinery plant; JSC Tyumen Battery Factory |
| 2. National Research Tomsk Polytechnic University | LLC Yurginsky machine engineering plant; OJSC Kemerovsky Mechanical Plant; OJSC Anzhero-Sudzhensk Engineering Plant; OJSC Kemerovo experimental mechanical repair plant |
| 4. National Mineral resources University (Mining University) | Leningrad mechanical factory named after K. Libkhnet; Petersburg Tram Mechanical Factory |
| 5. National Research University "Moscow Power Engineering Institute" | Moscow Machine-building Plant "Avangard"; Mechanical plant No. 149 |
| 6. Moscow State University of Technologies and Management | Experimental machine building Plant; MDB ISKRA named after I.I. Kartukov |
| 7. Volga region state | OJSC Motorostroitel; OJSC Plant |

| HEIs | Companies |
|---------------------------------------|---|
| university of service | named after A.M.Tarasov; OJSC Samara bearing plant |
| 8. South Ural State University | LLC Chelyabinsk tractor plant-Uraltrack; Production and Technical Enterprise URAL; LLC Uralpromtehnika. |
| 9. Moscow State Industrial University | JSC Znanya Moscow Machine Building Plant |

| Core Economic and Managerial Competencies | Lacking Economic and Managerial Competencies after completion of education programs |
|--|---|
| | or reorganizing production areas; to plan team activities and payroll fund. |
| 6. The ability to evaluate economic and social conditions for business, start up and manage new organizations. | 6. The ability to analyze, carry out a feasibility study and manage projects. |

Based on findings from surveys among businesses involved in recruiting engineering graduates, having approximately equal training in economics and management (Table 1), we formed a list of the required and significant competencies in the area of economics and management, which mechanical engineering bachelors are in deficit (Table 2) [7, 8].

Table 2. Core and lacking competencies accepted by employers for bachelors in mechanical engineering.

| Core Economic and Managerial Competencies | Lacking Economic and Managerial Competencies after completion of education programs |
|--|--|
| 1. Appropriate mastery of culture of thinking, the ability to communicate, analyze, perceive information; to demonstrate reasonable and logical thinking, a good command of oral and written language; to set goals and choose ways to achieve them. | 1. The ability to evaluate conditions and make organizational and managerial decisions, develop methods for staff management, participate in the implementation of innovative approaches to management |
| 2. The ability to work in a team, effectively using management methods, demonstrate business communication skills for more effective presentation of solutions and ideas, understand implications of management decisions and take responsibility for them | 2. The ability to develop business plans; to build, develop and manage new organizations. |
| 3. The ability to apply the acquired knowledge and skills; self-assessment of strengths and weaknesses abilities, striving for personal and professional development | 3. The ability to collect, analyze and process data for the solution of economic and financial problems |
| 4. The ability to perform technical and economic calculations, analyze and estimate production and non-production costs, solve problems when establishing or reorganizing production areas; to plan team activities and payroll fund | 4. The ability to organize the teamwork, make a clear work plan; to be responsible for managerial decisions and to analyze the quality of completed tasks. |
| 5. The ability to analyze, conduct a feasibility study and manage projects. | 5. The ability to perform technical and economic calculations, analyze and estimate production and non-production costs, solve problems when establishing |

Analyzing the deficiencies in economic and managerial competencies allows us to consider the basic mechanical engineering education for the bachelor's degree in the logic of modernization of economic and managerial competencies, structured in the format of the FSES 3, with updating and adding new competencies. These new competencies include: the abilities to assess and make organizational and managerial decisions, to collect, analyze and process economic and management information, to initiate and formulate business ideas, to design, develop and manage business projects [8].

Table 3. Economic and Managerial Competencies for Mechanical Engineering Bachelors.

| Competencies in the field of Economics and Management according to the FSES 3 | Revised And Expanded List of Economic and Managerial Competencies |
|--|--|
| 1. General Cultural Competencies (GCC): - Interpersonal communication with a focus on rights and duties of a citizen, striving for improvement and development of society on the principles of humanism, democracy and freedom, the ability to manage people and be subordinate (OK-4); - The ability to organize own activities scientifically, assess results of activities with a high degree of independence, have self-activity skills (OK-6); - Grammatically correct and business oral and written fluency in Russian, public and scientific speaking skills; the ability to write and edit professional texts, analyze the logic of arguments and statements (OK-14); | 1. General Cultural Competencies (GCC): - The ability to communicate, analyze, perceive information, to demonstrate reasonable and logical thinking, a good command of oral and written language, to set goals and choose ways to achieve them; - The ability to apply the acquired knowledge, skills, self- assessment of strengths and weaknesses abilities, striving for personal and professional development; - The ability to work in a team, effectively using management methods, to demonstrate business communication skills for more effective presentation of solutions and ideas, to understand implications of management decisions and take responsibility for them; |
| 2. Professional Competencies (PC): - The ability to organize personal activities and the work in small groups, including interdisciplinary projects (PC-9); - The ability to perform | 2. Professional Competencies (PC): - The ability to assess conditions and make organizational and managerial decisions; to develop methods for staff management, to participate |

| | |
|---|---|
| <p>Competencies in the field of Economics and Management according to the FSES 3</p> | <p>Revised And Expanded List of Economic and Managerial Competencies</p> |
| <p>activities related to supervision of individual actions of personnel, assist subordinates (PC-10); - The ability to estimate and analyze production and non-production costs to ensure the required quality of products, analyze activities of production units (PC-12); - The ability to prepare initial data for the selection and justification of scientific, technical solutions and organizational decisions based on economic calculations (PC-14); - The ability to perform calculations when planning actions in case of establishing or reorganizing production areas, to plan team activities and payroll funds; (PC-15) - The ability to conduct a preliminary feasibility study for making project decisions (PC-24).</p> | <p>in the implementation of innovative approaches to management; - The ability to collect, analyze and process economic and management information; to resolve conflicts; to know modern technologies in staff management; - The ability to organize teamwork, make a clear work plan; to be responsible for managerial decisions and to analyze the quality of completed tasks. - The ability to perform technical and economic calculations, analyze and estimate production and non-production costs, solve problems when establishing or reorganizing production areas; to plan team activities and payroll fund.</p> <p>A. Project and designing activities: - The ability to analyze, conduct a feasibility study and manage projects</p> <p>B. Computational and managerial activities: - The ability to calculate socio-economic and financial performance by means of basic methods, describing the activity of company's business units.</p> <p>C. Entrepreneurial activities: - The ability to evaluate economic and social environment for business, find and assess market opportunities for business ideas, have practical skills in starting up and managing new organizations</p> |

In order to correct the learning objectives, we employed an ABET double loop model for designing and implementing education programs. ABET is an organization that accredits education programs in the field of applied science, computing, engineering and technology in the USA, one of the most recognized accreditors of college and university programs. The ABET double loop model is recommended as design technology for university education programs in the context of TPU education standards, because this model allows for employers' requirements to the quality of education to the greatest possible extent [9].

This model has been adapted and used by authors for the process of designing economic and managerial competencies of bachelors in engineering education

(Figure 1) to meet the requirements of employers relating to a discipline of *Economics and Machine-Building Production Management* [9].

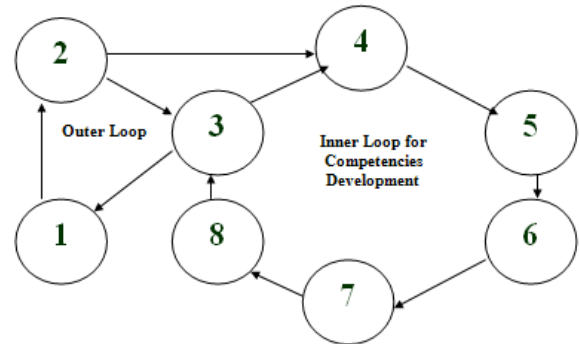


Fig. 1. A double loop model for the process of designing economic and managerial competencies (EMC)

- 1- Defining needs of parties interested in EMC for mechanical engineering graduates;
- 2 - Defining goals and learning objectives for the course "Economics and Management of Machine Building Production" in the development of EMC;
- 3 - Checking the progress made in developing EMC against the evaluation of learning outcomes;
- 4 - Determining the required EMC for bachelors;
- 5 - Determining how EMC will be developed;
- 6 - Determining how EMC will be evaluated;
- 7 - Setting indicators for EMC achievement;
- 8 - Organizing the education process.

The outer loop of the model sets initial data for a list of economic and managerial competencies required for bachelors, and the inner loop shows the process in terms of phases when designing economic and managerial competencies; the intersection of both loops at point 3 implies the process of monitoring, evaluating and correcting, if required, achievements in acquiring economic and managerial competencies by bachelors [10].

In the context of the revised and added economic and managerial competencies for engineering graduates (Table 3, column 2), the criteria and relevant features were identified (Table 4) [11].

Table 4. Criteria and Features of Economic and Managerial Competencies Developed by Mechanical Engineering Bachelors.

| Criteria | Features |
|---|---|
| Organizational and managerial abilities | The ability to evaluate conditions and make organizational and managerial decisions, develop methods for staff management, participate in implementation of innovative management approaches, manage personnel at a modern level, resolve conflict situations, be responsible for managerial decisions and analyze the quality of performed tasks |
| Technical skills and knowledge in economics | The ability to process and analyze technical and economic information, to perform technical and economic calculations; to calculate and analyze production and non-production costs, to handle problems when establishing and reorganizing production areas; to plan staff activities and payroll fund |

| Criteria | Features |
|--------------------------------------|---|
| Project skills | The ability to analyze, conduct a feasibility study and manage projects |
| Entrepreneurial knowledge and skills | Knowledge of economic and social environments for business, the ability to assess market opportunities for initiating and developing business ideas, to develop business plans, to start up, develop and manage new organizations |

The suggested combination of criteria and features was agreed with experts of LLC Yurginsky Machine engineering plant at various levels (Deputy Director for production, heads of production shops, supervisors and works foremen) in terms of their completeness and significance evaluations.

Results and discussion

The results were evaluated during the period of 2011 – 2015 within academic programs for bachelor's degrees in Mechanical Engineering offered by Yurga Institute of Technology (Affiliate) of Tomsk Polytechnic University. 178 students enrolled in bachelor's programs took part in the experiment, including 83 students in the control group and 95 in the experimental group. In the learning process, students used the original tutorials and educational material developed by the authors and intended to support teamwork and project work, including business planning and using case studies. The curriculum content and teaching practices are aimed at training engineering students able to perform action-oriented economic and managerial activities [12].

Table 5 shows positive dynamics in the development of economic and managerial competencies for mechanical engineering graduates. An increase in organizational and managerial abilities (K1) made 25% (23 people). This can probably be explained by use of role-based, thematic and business games, and other active forms and methods of training and teaching in the educational process, with a focus on the development of organizational and managerial abilities attainable by mechanical engineering graduates in the context of their future professional activity.

Table 5. Dynamics of the development of economic and managerial competencies to be acquired by mechanical engineering bachelors according to the identified criteria, %.

| Criteria | Before the experiment | | | After the experiment | | |
|--|-----------------------|-------------|-----------|----------------------|-------------|-----------|
| | low (p1) | medium (p2) | high (p3) | low (p1) | medium (p2) | high (p3) |
| Organizational and managerial abilities (K1) | 49 | 45 | 6 | 10 | 59 | 31 |
| Technical skills and knowledge in economics (K2) | 27 | 59 | 14 | 10 | 55 | 35 |
| Project skills (K3) | 50 | 43 | 7 | 30 | 57 | 13 |
| Entrepreneurial knowledge and skills (K4) | 45 | 48 | 7 | 12 | 43 | 40 |

There is a positive trend according to the criterion *Technical skills and knowledge in economics* (K2): a rate of growth in P3 is 21% (20 people). We assume that this positive trend results from coordinating the course content of "Economics and Management of Machine-Building Production" with curriculum contents of natural science disciplines (Fundamentals of Design, Mathematical Modeling in Engineering, Manufacturing Management in Mechanical Engineering), aimed at integrating the knowledge gained by students for solving technical and economic problems.

The criterion *Project Skills* (K3) shows the satisfactory results. The dynamics of P2 and P3 is insignificant: P2 - 12% (11 people) and 14% (11 people). This fact is explained by the weak framework for the academic program *Economics and Management of Machine-Building Production* and the lack of effective means and methods used for training bachelors in mechanical engineering in the field of project activity.

The highest rates of growth are marked with criterion K4 *Entrepreneurial knowledge and skills*. The growth in P3 is 33% (30 people). This behaviour pattern of the results can be explained by introducing programs that encourage teamwork during practical studies in the form of making business plans for machine building factories, with reference to engineering activities and according to the CDIO approach *Conceiving – Designing – Implementing – Operating*. This approach allowed us to most effectively combine theoretical and practical knowledge in the baccalaureate engineering education with practical orientation to ensure successful implementation of team projects [13]. Criterion K4 combines the economic and managerial competencies for bachelors in mechanical engineering, including communication skills, teamwork abilities, leadership skills in staff and company management, the ability to process and analyze information in the field of economics and management, evaluate and assess economic and social environments for business [14].

An increase in the level of expertise regarding economic and managerial skills of mechanical engineering bachelors indicates that the tutorials, educational material and courseware, developed by the authors to support students' teamwork and project work, are effective. The curriculum content and teaching practices are aimed at fostering the training of engineering students able to perform action-oriented economic and management activities [15].

Conclusion

First, using the finding from employers' surveys, we identified the lacking economic and managerial competencies for students completing the bachelor's program in *Mechanical Engineering*: the abilities to make and evaluate organizational and managerial decisions, to collect, analyze and process information about economics and management, to initiate and formulate business ideas, to design, develop and manage business projects. The list of economic and managerial

competencies for bachelors in compliance with the requirements of the FSES and employers' needs is a basis for revising the processes of forming economic and managerial competencies within the educational program using the ABET double loop model, adapted to the research problem.

Second, the main criteria and their respective features are described to define how effectively the economic and managerial competencies are being developed by mechanical engineering bachelors to suit the socially-oriented market environment:

- Organizational and managerial abilities to make organizational and managerial decisions, develop methods for staff management, resolve conflicts, to be responsible for managerial decisions;

- Technical skills and knowledge in economics to analyze and process the technical and economic information, to perform technical and economic calculations; to calculate and analyze production and non-production costs, to plan staff activities;

- Project skills to analyze, conduct a feasibility study and manage projects;

- Entrepreneurial knowledge and skills to evaluate economic and social environments for business, to assess market opportunities for initiating and developing business ideas, to develop business plans, to start up, develop and manage new organizations.

Third, our researches have proved that using the original tutorials and methodical ware in the course of study, to earn the bachelor's degree in "Mechanical Engineering" at Yurga Institute of Technology (Affiliate) of Tomsk Polytechnic University, in the period from 2011 to 2015, are effective to a high degree.

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