TEACHING ENGINEERING STUDENTS: FROM PRINCIPLES TO PRACTICES

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ABSTRACT

The paper describes the idea, the process of implementation and the results of a teaching development course for engineering faculty, providing training for engineering students of Siberian Federal University in accordance with new challenges in higher education.
The paper covers the teaching development course that involves two levels: the first level – understanding and acceptance of CDIO ideas and Standards, basic pedagogical foundations and concepts, modern teaching methods and technologies by educational engineers. The second level implies designing advanced, personally significant course content. The developed course is implemented with the use of interactive technologies, involves the formation of professional and personal competencies by means of solving integrated problem tasks, teamwork, active learning. The results of the teaching development course for engineering faculty are demonstrated by a new educational product or technology that a particular educational engineer has developed, and are subjected to expert evaluation. The process of implementing the described teaching development course for engineering faculty is carried out by means of volunteering participation in problem-analytical workshops and roundtables, reciprocal visiting of classes and the idea of mentoring and cooperation implemented in the university environment. The experience of Siberian Federal University in the teaching development course for engineering faculty is provided with the experts' and students' feedbacks and course evaluation.

KEYWORDS

Teaching development course, engineering educators, active learning, problem-analytical workshop, redesign, Standards: 8, 10.

INTRODUCTION

In the process of implementing the educational program "Metallurgy" at the Siberian Federal University in the CDIO ideology, a system for enhancing faculty teaching competence has been developed and introduced for four years of the program implementation. The paper describes the idea and the results of a teaching development course for engineering faculty in accordance with new challenges in higher education. One of the factors of successful teaching engineering students in accordance with modern requirements is providing the educational process with the concerned teaching staff. The huge work on creating teachers' training program and making the staff concerned with new challenging effective teaching methods was started with the analysis of the ideas and approaches of Engineering Pedagogy and still goes on. The experience of engineering schools and technical universities (M.J. Terrón-López et al., 2015) and (W.B. Gaskins et al., 2015), ways of redesigning engineering education (B. Lucas and J. Hanson, 2016), strategies for developing interdisciplinary lessons (A. Gero, 2016) and

many other works have been reviewed before and on launching the described program. The paper opens with a quick vision of the problems engineering educators encountered with teaching engineering students and followed by a presentation of the principles and the results of the teachers' training course; a description of the developed modules and organizational form of the teachers' training process. After the authors' insight of two-level teaching development course elaborated with the examples of the redesigned educational product and achieved faculty progress, the conclusions are presented.

THE TEACHING PROBLEMS ENGINEERING EDUCATORS IDENTIFY

To specify the personally-significant goals of improving pedagogical competences, the engineering educators of the educational program "Metallurgy" of Siberian Federal University have presented a self-assessment of the level of formation of their pedagogical competencies. According to the results, 60% - 80% of them have stated the following professional gaps in:

- organization and management of students' project activities (70-80%);
- understanding and perceiving the features and basic requirements for the implementation of the educational process within the CDIO ideology (75-80%);
- determination the substantive and methodological links at the interdisciplinary level and at the level of interdisciplinary integration (60-75%);
- competence formation methods and competence level assessment (80-85%).

Engineering educators who have passed the teachers' training program have rated these competencies by 20–30% higher than the initial ones.

The problems of motivating students for project activities have been brought into focus. Some university teachers have set the problem of organizing engineering classes, planning and achieving educational results in a holistic pedagogical process.

Analysing the results of self-assessment and further discussions have revealed such problem as the inability of engineering educators to reflect on their pedagogical activity, which has been shown in the difficulties of separating problems from causes and consequences, the lack of clarity in formulating the problems, the inability to build a hierarchy of problems and their interrelation.

DESCRIPTION OF THE WORK DONE

The idea of the teaching development course is based on several principles and is focused on the innovating personally significant content and redesigning educational courses and discipline programs in integration with other disciplines. The developers of the teaching development course have distinguished the following principles of implementing the course which is aimed to enhance faculty teaching competencies in redesigning and integration aspect:

- continuity of the process of teachers' training throughout the period of implementation of the educational program, that allows considering the process of training future engineer of the certain year of study holistically, systematically, reflexively;
- the synchronicity of the problems considered in the teachers' competence development program to the problems of the implemented curriculum of the educational program "Metallurgy" that increases the motivation of the teachers and provokes personal significance of the improvement of the educational process;
- practicing "learning by doing" that determines the need for the teachers to present products of their activities for the team expertise;

– focusing of the educational process of teachers' training on the formation of teachers' competencies in the integration of the educational areas and the development of integrated tasks (Standard 3, 7), support student' project work (Standard 4, 5), effective use of active teaching methods: problem-thinking, case-studies, STEM technology, role-plays, etc. (Standard 8).

At Siberian Federal University the design and process of the teaching development course have been implemented in the logic of reverse design, which allows building a clear strategy for mastering program material in the following sequence: learning outcomes – testing – tuning content and pedagogical technologies that ensure confidence in learning outcomes by validated procedure measuring. Designing of the content of the teachers' training program is focused on Standard 10, which defines the necessary content to ensure the ideology of CDIO initiative:
- integrated learning experiences (Standard 7);
- active learning (Standard 8);
- learning assessment (Standard 11).
In addition, the focus on the organization and implementation of students' project work requires the teacher's ability to perform this activity (including educational process design), as well as in project management.

The short description of the challenges that engineering educators had to overcome and the results of the work done are described below (figure 1).

Teachers' training program								
level 1							level 2	
challenges	redesign the course through content integration of related disciplines and learning outcomes	72 academic hours	enrich the course with active learning practices and elicit the formation of the personal and interpersonal competences	72 academic hours	develop and implement new monitoring, evaluation and reflexive procedures	72 academic hours	reduce the individual professional gaps in pedagogy	72 academic hours
	Module 1		Module 2		Module 3		Module 4	
progress	56,75% of engineering educators covered the module		63,04% of engineering educators covered the module		54,3% of engineering educators covered the module		32,6% of engineering educators is currently covering the module	
	45,6% of program courses were redesigned		64,8% of program courses were enriched with active learning practices		62,1% of program courses uses more than two evaluation methods		40,5% of program courses is currently being redesigned	

The results of the development of pedagogical competencies of engineering educators in the framework of the teaching development course have been supposed to be the following:
– the ability to organize interactive cognitive-reflexive activities based on the active teaching methods, through the use of round-table discussions, debates, visualization, revealing the understanding of the content of the discipline being studied.
– the ability to develop integrated tasks based on the analysis of discipline learning outcomes, educational and engineering activities in accordance with the specific requirements of the CDIO concept.

– the ability to implement quasi-engineering activities in the educational process based on the topical practical experience of the particular industrial sector.
– the ability to research into industrial topics and to project management for the specific tasks of the employer and learning outcomes in accordance with the competence model of the future engineering undergraduate.
– the ability to develop assessment methods and activities for each type of educational activity (discipline, project activity, modules).

Control and progress of the process of improving the pedagogical competencies of engineering educators have been carried out through the achieved progress and development of the students' competencies within the framework of requirements for learning outcomes using SMART technology: S (Specific, the most specific and clearly defined result); M (Measurable); A (achievable); R (Relevant); T (Time-bounded). Substantially each of the requirements of SMART-technology is as follows:
– specific – to create new technological processes and products in the relevant industrial area;
– measurable – to make calculations and design products for various technical applications;
– achievable – to create products and technologies according to international standards;
– relevant – to develop new technologies considering the conditions and limitations;
– time-bounded – to meet deadlines in the process of training or performing quasi-professional activities.

The Teaching Development Course (level 1)

The work on the innovative educational program, built in the ideology of the CDIO Initiative, involves, first of all, teachers' awareness of the main principles and requirements of this approach. Therefore, the first, initial module of teaching development course is the module devoted to the critical consideration of all CDIO Standards, which is carried out in an active joint thinking activity of all program engineers and teachers at problem-analytical workshops. The awareness of the requirements of CDIO Standards at this stage contributes to the engineering educators' reflection about their own model of teaching and further self-development as a teacher. It has been noted that a personally meaningful intention to improve pedagogical competencies as well as teaching methods appears.

The above-mentioned requirements for the teaching competences of engineering educators are projected into the appropriate modules of the teachers' training program and determine its invariant component:

Module 1. Disciplinary curriculum. Educational process design in reverse design logic. Interdisciplinary links. The methodology of knowledge.

Module 2. Competence approach in education. The shift from the process characteristics of the educational process to competence-based results. Meta competencies. Integrative learning in the development of personal, interpersonal competencies of the students.

Module 3. Monitoring and evaluation of the educational process and learning outcomes in the implementation of the CDIO ideas. The functions of the evaluation procedure (diagnostic, organizational, educational, controlling). The principles of evaluation activity. The subject matter and technology of formative assessment. The structure and methodology of creating assessment materials and activities.

The organization of the process of improving the pedagogical competencies of engineering educators is aimed at bridging the gap between the requirements for the implementation of innovative activities and the existing pedagogical competencies of the teaching staff. The procedure for entering the process of improving the pedagogical competencies of engineering

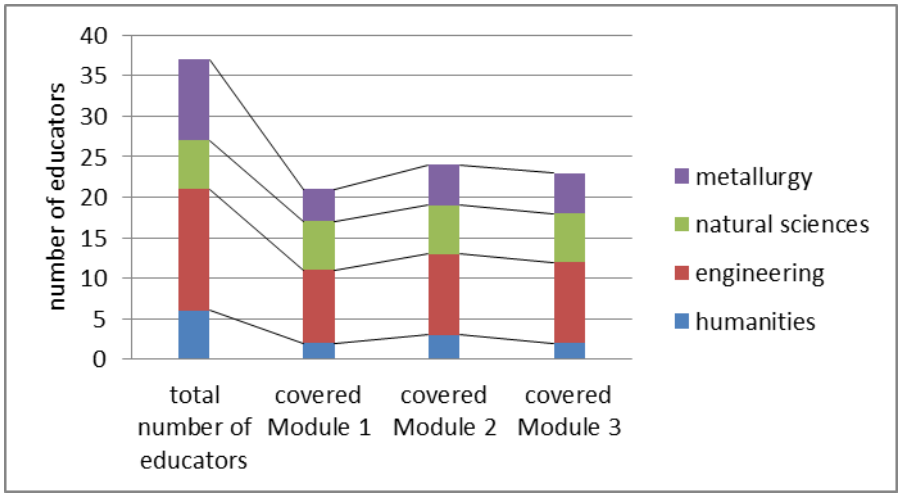
educators, who start the implementation of the educational process in CDIO ideology, begins with a workshop that defines the goals and results of this process. Professional development of engineering educators has a continuous prolonged nature with the discussion of problems that simultaneously appear in the educational process. The organizational form of teachers' training program has become a problem-analytical workshop, which has several advantages:

1. allows to organize a dialogue of each teacher with everyone and collaborate within the program, to consider the problem from different sides, to expand the knowledge and experience, to acquire new ways of activity;
2. stimulates brainstorming of engineering and pedagogical ideas of engineering educators, developing communicative and presentation skills, including the skills of public speaking;
3. creates the conditions for teachers' teamwork.

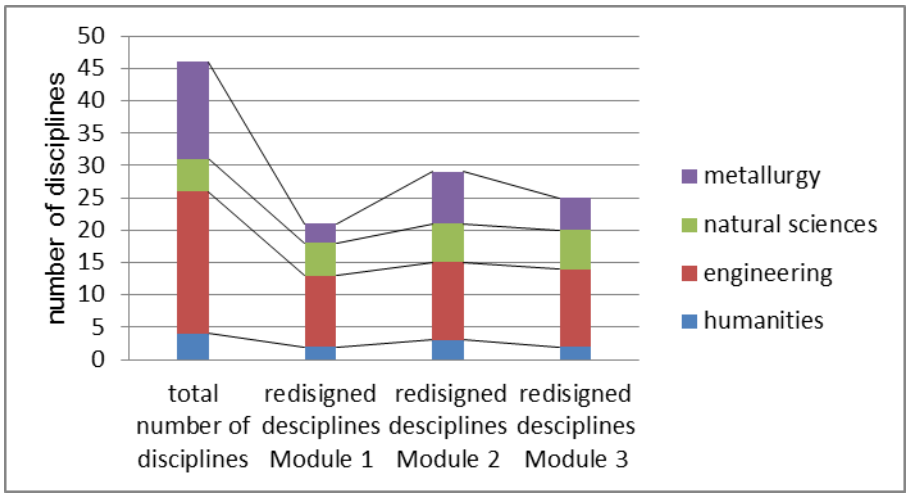
In the course of the problem-analytical workshop, a pedagogical problem is presented for discussion, the solution of which is either absent or ambiguous, there are no specific methods for its solution. The formulation and interpretation of problem-solving tasks are assumed. Such problems as "Crisis of engineering education, causes and solutions", "Ways to increase students' motivation to learn", "Modern student as a representative of the digital generation", "Styles and models of pedagogical training", "Organization of effective interaction of participants of the educational process" have been discussed.

Problem-analytical workshop creates an environment where engineering educators get experience in identifying and understanding the nature and specifics of the problem, finding ways to solve it through the formulation of a sequence of tasks. The acquired skill is transferred to the organization of problem-based learning with students.

The most part of the participants of Teachers' training program who have covered all three modules developed the initial redesigned courses but still, there are quite many problems with content integration considering the formats of the lessons, evaluation methods and etc. Figure 2 shows the number of educators of a particular module who completed the programme. As it can be seen the Module "Natural Sciences" which includes here Chemistry, Physics, Mathematics, Material Science and Thermal Physics has the best results in covering the Teachers' training course. For the educators of Metallurgical Module, the program has appeared to be quite difficult to cover especially considering the course redesigning. They had to solve the problem with integration and implementation of active methods of teaching.



The number of courses (disciplines) which have been redesigned after covering the Modules of Teachers' training program is demonstrated in figure 3.



The substantive content of the modules of the teaching development course (level 1) meets the requirements of CDIO Standards, but is not sufficient for implementing systemically complex changes in the educational process, especially considering a large number of engineering educators with technical and technological degrees who are not familiar with psychology and pedagogy. Thus, the teachers' training program of the first level comprises such encouraging extra-program activities as:

– learning at pedagogical courses and seminars at different universities and schools;
– organizing and participating in communities of practice;
– reciprocal visiting of classes (classroom observation) and expert consultations as a means to promote reflection and peer exchange;
– participating in pedagogical conferences, meetings and making research in education.

The results of the passing teaching development course (level 1) can be noted as *the achieved faculty progress* which is demonstrated in:

– creating teams of teachers concerned in the development of a particular CDIO Standard within the educational program;
– working out and implementing an assessment method for the integrated course/discipline (for instance: one integrated examination on 3 different disciplines);
– implementing e-learning in the course by means of using MOOCs, digital tools and platforms, webinars and videos in collaboration with the employer;
– publishing findings in pedagogical journals;
– preparation and presentation of the final teaching projects on the following topics: "Development of a cluster of professional competencies of future engineers during the implementation of the integrated interdisciplinary project in the CDIO ideology", "Assessment of the formation of design and implementation competences of the students based on the components of the product life cycle", "Digital educational environment for the development of project activities", "Curriculum model as an organizational and content dominant of ensuring the quality of engineering education".

The Teaching Development Course (level 2)

The second level of the teaching development course implies applying an individually-differentiated approach to improve pedagogical competences of engineering educators. It has been implemented by individual mentoring work depending on the current level of the development of personal pedagogical competencies, the awareness of personal professional gaps in implementing pedagogical activities, the period and experience of teaching. The work has been organized by regularly conducted individual consultations with the program leaders, project managers and experienced colleagues. The round-table discussions of the teaching

problems of a certain engineering educator were carried out by means of solving specific pedagogical cases, which has allowed to reveal the problem in the course/discipline design and to learn how to apply definite teaching methods by means of learning by doing. Working on pedagogical cases in the context of improving pedagogical competencies has let the engineering educators form a methodological culture both in the aspect of developing case assignments as the assessment tools and in the aspect of organizing and managing students' project activities. This training has been facilitated by mastering the algorithm of case solving:

- the study of the presented pedagogical situation;
- problem analysis;
- the development of criteria for solving problems;
- making hypotheses for problem solving and mechanisms for its implementation;
- the analysis of possible risks;
- the development of a problem-solving program (plan) through solving a sequence of research tasks.

As a result, some basic disciplines and courses have been changed completely adjusted to the project tasks, industrial demands and a metallurgical component of the educational program. One of the examples is Chemistry which has been redesigned in integration with Physical Chemistry, Material Science, Foundry Technologies, Project work and English for the Specific Purposes. The content and the teaching methods of the discipline have to be changed due to the new challenges such as the need to work on the 2-year industrial interdisciplinary project the results of which have to be presented and described in English.

Another example of redesigning engineering course is connected with Standard 4 – Introduction to Engineering, which is an introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills. The first idea of the course was provided by 2 disciples: Theory of Inventive Problem Solving and Engineering Thinking, which were conducted in a conventional manner. The stated learning outcomes haven't been reached and the lack of real engineering practice and thinking as well as weak teamwork has been recognized by the experts and educational engineers. The active role of the teaching staff in participating in different kinds of pedagogical courses and teachers' training program implemented in Siberian Federal University and also the collaboration of two technical universities has resulted in creating new interactive course consisting of such modules as: Engineering Start, Engineering Cluster, Engineering Laboratory which is implemented in STEM technology and supported by the developed redesigned disciples: Project Management, Information Technologies, Technical Case-Studies, etc. The students' feedback to the newly redesigned course of Introduction to Engineering proves the success in reaching learning outcomes as well as the emotional reactions to the educational process. In the freshman year of engineering, it is important for students to participate in an active learning environment to foster a positive experience as the first year experience is linked to success and retention. Research has shown the more positive and dynamic the first year experience for engineering freshman, the more positive students' attitudes, expectations, and skill level (A. Rugarcia et al., 2000).
The experts evaluate the redesigned course as useful engineering practice however there is still some lack of metallurgical integrated tasks in the course. Some students' feedbacks proposed here to underline the importance of gaining new practical experience while doing the course.

"That is a rather challenging approach to learning with lots of practice and self-work."
"That was a real test for my personal abilities. What can I do in solving engineering task?"
"During the course which lasted for 4 weeks I've received more knowledge and practical experience than during all physics lessons at school."

Many students imply the development of their personal, interpersonal, communicative skills at working on the problem engineering tasks in a team which appeared to be a quite new practice for them as before they solved the tasks individually.

"That was my first experience in creating engineering products in a team of just first-year students."
"That was real teamwork when you are united by solving a problem in a very short time period with intensive engineering practice."

Also, the students distinguish the role of a teacher.
"Teacher's role is great, he is a motivator and assistant in the specific field where I have lack of knowledge."
"What I like the most is creating the product together with an engineering practitioner."

The results of the passing teaching development course (level 2) can be noted as *the achieved personal teaching progress* which is demonstrated in:
- collaborative work in the teams of teachers of different disciplines focused on getting the particular learning outcomes (engineering skills and interpersonal competences);
- working out and implementing different assessment methods according to the learning outcomes of the discipline/disciplines;

The Humanities which consists of four disciplines and five competences are assessed by 12 different assessment methods including expert evaluation, role-playing, cases, and others.
The Science which is presented by five disciplines and develop five competences are assessed by 14 assessment methods including peer and self-assessment.
Engineering and industrial disciplines which are presented by the most number of disciplines and competences in the curriculum are assessed by 11 different methods.
- redesigning the course by means of using digital tools and platforms engaging the industrial engineers;
- reducing personal pedagogical gaps by mastering active teaching methods (each member of the educational program has completed more than 2 pedagogical courses).

CONCLUSIONS

A survey of engineering educators has shown that the most part (80%) of them determines the integrated goals of improving pedagogical competencies through mastering knowledge of modern ways of solving professional tasks, taking into account advanced international practices, gaining experience in learning the active, STEM, project-based teaching technologies. Engineering educators recognize that comfortable psychological climate in the process of teaching development course, high interactivity of problem-analytical workshops as the main form of the educational process has contributed to the formation of personal and significant goals of their own professional upgrading. The comparison of personally-significant goals and expectations from the teaching development course and their achievements has been shown through the implementation of the results of teachers' training program into the educational process by means of increasing the use of active, integrative technologies, different types of integrative tasks, including case assignments, project management, developed assessment methods. Therefore, the teaching development course has provided the progress in implementing such CDIO Standards within the educational program "Metallurgy" as Standards 1, 7, 8, 11.

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