Implementing CDIO project-based learning in training of Heat and Power engineers

E A Boiko¹, P V Shishmarev¹, D I Karabarin¹, S R Yanov¹ and A A Pikalova¹

¹ Siberian Federal University, Krasnoyarsk, Russia

E-mail: eboiko@sfu-kras.ru

Abstract. This paper presents the experience and current results of CDIO standards implementation in training of bachelors in Heat and Power Engineering at Thermal Power Stations academic department in Siberian Federal University. It provides information on methodology of modernization of educational programs, curricula and programs of disciplines in transition to CDIO project-based learning technology. Preliminary assessment and analysis of lessons learned and scaling perspectives are given.

Attention to the quality of engineering education is exacerbated all over the world as technologies and technical systems become more complex and their role in the development of the economy and society as a whole is increased. The main and rather persistent problem in this area is the contradiction between the requirements of stakeholders (employers, including production, business, government structures, parents, students) and the quality of training of specialists in engineering and technology. There are few reasons for the stability of the above contradiction, they are well known, they are both objective and subjective in nature and in essence represent modern challenges that the external world sends to universities and scientific and educational communities [1].

The CDIO concept (Conceive - Design - Implement - Operate), which was put forward more than 10 years ago by the Massachusetts Institute of Technology (MIT), one of the leading engineering universities in the world, is an effective response to these challenges. The implementation of this concept aims to meet the requirements of employers for the quality of training of specialists and involves a significant adjustment of curricula, educational programs and educational technologies, so as to enable graduates of engineering programs to gain competence during the training that will significantly shorten the period of their adaptation to the conditions of production [2]. Over the past 10 years, CDIO concepts have been followed by more than 115 universities in Europe, North and Latin America, Asia, Australia, New Zealand and Africa. In Russia, the Tomsk Polytechnic University, Ural Federal University, Skolkovo Institute of Science and Technology, Moscow Polytechnic University, MAI, MEPhI, MIPT and others achieved the most striking results of implementing this concept.

The application of the CDIO concept in engineering education allows to significantly change the approach to the formation and implementation of educational programs, and includes [3]: the application of the basic concept of CDIO throughout the training period; A clear description of personal, interpersonal and professional competencies approved by all program participants; A curriculum that forms, among other things, competences that enable the specialist to create products and systems; Inclusion in the curriculum of an introductory course on the basics of engineering practice in the field of creating products and systems; Ensuring student participation in at least two
projects to create products at various levels; Creation of design conditions for students which are close to the real conditions of design organizations; Provision of conditions for the integrated nature of specialist training (training, real work); The application of an active practical approach in conducting classes; Ensuring the improvement of teachers’ competences in the field of CDIO; The creation and application of systems for assessing the progress of students in both the assimilation of their disciplinary knowledge and their ability to create new products and systems; Ensuring the evaluation of the educational program and educational technologies by all stakeholders.

Despite the considerable scale of the implementation of CDIO technology in various universities in the world, beyond the practical recommendations remain numerous aspects of theoretical and applied tasks of systematic implementation of the educational initiative in a specific educational program, in particular, in the preparation of bachelors in Heat and power engineering. This situation is exacerbated by the fact that at present no university in the world is implementing this international educational initiative in the field of training "Thermal Power Engineering and Heat Engineering". This article presents the experience and interim results of CDIO standards implementation in the preparation of Heat and power engineers at the Department for Thermal Power Stations of the Siberian Federal University. Currently, the implementation experience is 5 semesters since the official inclusion of the Siberian Federal University in 2014 in a community of universities implementing the CDIO standards.

**Figure 1.** The complex system of projects used in the preparation of bachelors in Heat and power engineering in CDIO technology.
The construction of a system of individual and team projects, including graduation project (Figure 1), ensuring the acquisition by students of personal, interpersonal and professional competencies, allowing the future specialist to create and implement various products and systems, is fundamental for achieving the effectiveness of the educational program that implements the ideology of CDIO. Proper formation of goals, objectives and content of projects along with effective modernization of the curriculum and work programs of disciplines is an effective mechanism for achieving a new result: the development of critical thinking and the ability to solve unstructured problems; Development of logical and systematic thinking; Development of project thinking (engineering); Development of communication and cooperation; Development of imagination, creativity and initiative; Development of global thinking; Initiative education: student activity and participation of professional communities in training etc.

Within the first year of training, four projects are envisaged: within the first semester, the command game "Engineering Cluster" and the team social project (the number of students in teams is from 3 to 5 people). The "Engineering cluster" (developed by Moscow Polytechnic University) is a gaming tournament that involves the creation of an engineering and manufacturing companies engaged in the creation of high-tech products in a virtual environment within the extramural stage and the manufacture of a physical device for a given purpose in the full-time phase (Figure 2). The creation of products requires the solution of interdisciplinary tasks in mathematics, physics, chemistry, informatics and descriptive geometry, with limitations in the form of a budget allocated for each order. The evaluation of the quality of the product determines how optimally the problem was solved, shows how much the customer will be satisfied with your work, and affects the final result of the tournament.

Realization of social projects is carried out within the framework of the disciplines "Basics of business relations" and "Basics of professional communication" during the first and second years of study. The list and content of social projects are aimed at the development of a number of personal and interpersonal skills: ethical behavior and reliability; Employment skills, including self-confidence and
a positive point of view, willingness to take responsibility, perseverance, respect for others, common sense; Effective communication, including advocacy of their ideas and persuasion of others; Effective cooperation, including leadership skills, partnership and agreement; Ingenuity and ability to independent education; Intra- and interdisciplinary (systematic) thinking; Creativity, empathy (empathy) and social responsibility; Awareness of the global problems of mankind.

It should be noted that at the start of social projects, student teams are offered some options for social problems, the stakeholders in which are the issuing department (for example, projects related to the vocational guidance of schoolchildren), the university (for example, adaptive, creative or sports events), or the employer (for example, organization and conduct of professional initiation or joint volunteer work with youth councils of energy enterprises) (Figures 3,4).

Figure 3. Demonstration tests of the project "Cycling Energy Meter" for vocational guidance.

Figure 4. Vocational guidance quest in the department for TPS with schoolchildren.

The final project of the first year of training in the preparation of bachelors in Heat and power engineering is the individual engineering project "Micro Thermal power station", within which each freshman implements the life cycle of a miniature thermal power plant operating in the Rankine cycle – calculation and 3D design, manufacturing, testing and adjustment of operating modes of the product (Figure 5).

Results of work on the project during the second semester are summed up in competition in which each participant demonstrates the operability of the installation with fixation of the generated power. All results are subsequently ranked according to the performance level of the facilities, and the place occupied by the student is used to form the final mark, which also takes into account the quality of the project documentation, the appearance and originality of the design, and the quality of their responses to the expert commission questions (Figure 6).

The projects for the second year of training of Heat and power engineers are team projects, implemented throughout the whole year, aimed at creating various types of generating facilities (thermal or electric energy, including cogeneration and ternary generation). This formulation of the problem allows organically combining the elements of "learning in advance" and the acquired knowledge within the framework of various natural science and special disciplines: the fundamentals of engineering activity, computer science, engineering and computer graphics, physics, mathematics, mechanics, thermodynamics, heat and mass exchange, hydrodynamics. The main variants of the generating plants are: variations of the Rankine cycle with various combinations of heat engines (Cyclone Engine, Waste Heat Engine, volumetric steam expansion units, steam rotary (rotary-blade) units, Scroll-expander turbines) and coolants (organic Rankine cycle); Various combinations of traditional and renewable energy sources (wind-solar-diesel installations, heat pumps, gas generators using solid fuels plants), hybrid devices.
Figure 5. The prototype of "Micro Thermal power station".

The project implementation provides for detailed elaboration of the technical task, preliminary technical and economic analysis of several alternative options, elaboration of the main design stages (preliminary design, draft and technical projects, simplified design of the working documentation) with an assessment of specific energy characteristics and cost of generated energy, the formation of design and estimate documentation. Examples of implemented projects are shown in Figures 7 and 8.

Some topics of the second year projects with a high degree of commercialization "flow" into the graduation project (GP), some of the innovative GPs are formed on the basis of the research work of the department, which in this case acts as a stakeholder, and the rest of the GP topics are formed by various energy enterprises and is associated with design of new facilities, modernization and reconstruction of existing heat and power equipment. At the same time, the themes of GP can be both of an individual and group complex interdisciplinary type. For the implementation of engineering projects in the third and fourth years with the continuation in the GP, the curriculum includes the discipline "Designing of thermal mechanical equipment" in the amount of six hours a week, with the
allocation in the schedule of lessons for the project day, when the student has the opportunity to perform an applied project directly at the enterprise under the guidance of professional mentors.

Figure 6. Public presentation of the "Micro Thermal power station" project.

Figure 7. Generating plant based on Organic Rankine cycle 1.2 kW.
In parallel with the implementation of the applied projects defined by the topic of the future GP, during the third and fourth year of training four course projects (works) are consistently implemented for the formation of basic professional knowledge: "Modeling of heat and power processes and installations", "Boiler installations", "Heat engines" and "Thermal and industrial power stations".

Coursework on modeling of heat and power processes and installations provides students with modeling of the processes of aerodynamics, complex heat exchange and combustion of pulverized fuel in the combustion chamber of the boiler unit by means of three-dimensional numerical modeling CFD Simulation: ANSYS Fluent. An example of the results of computer simulation of the furnace process of an energy steam boiler is shown in Figure 9.

A distinctive feature of this course project is the multivariate choice and optimization of technical solutions to problems arising during the verification and design calculations in the MathCAD environment, for which an obligatory condition is the computer calculation of individual elements and the boiler unit as a whole. The results of the design of the boiler unit are presented in the form of a
three-dimensional model, made in the design and technological graphics package SolidWorks with extensive interpretation capabilities of the results (Figure 10).

![Figure 10. Results of three-dimensional design of the boiler unit.](image)

A similar principle was implemented in the course projects in "Heat Engines" and "Thermal and industrial power stations". All coursework are cross-cutting and linked by technical and technological parameters in the form of a technical case, and for many students are transformed into graduation project. It should be noted that the implementation of the above project-oriented approach is possible only with the total introduction of computer and information technologies into the educational process.

Significant modernization of the educational process became possible only with the active participation of strategic partners – large energy enterprises, industry leaders interested in training highly professional staff. Among such enterprises actively involved in the promotion of the experiment are Unipro (ex E.ON Russia), OOO Siberian Generating Company, OOO Gazprom Energoholding (OGK-2), Danfoss, an engineering company "Powerz" and a number of other regional and federal energy companies. As the project progressed, these companies significantly changed the attitude towards the content and organization of the educational process of heat and power engineering in the SFU, which is manifested in the implementation of not only traditional forms of interaction (targeted training, nominal scholarships, provision of places for practice, participation in final certification of graduates), but also in informal agreements on strategic partnership. In particular, the increase in the effectiveness of partnership is expressed: in the development of the material and laboratory base of the department; Creation of new workspaces; Co-financing project activities of students; The formation of topics, support and implementation of projects; Joint vocational guidance activities (creation and support of special energy classes in secondary schools in Sharypovo, Nazarovo, Minusinsk, Abakan with the aim of increasing the level of knowledge of natural science disciplines, introducing them into the energy sector and acquiring initial design skills); In the participation of students in the activities of youth councils of partner companies of the department, as well as in various sports, creative and corporate events of energy companies.

The complex modernization of the educational process is reflected in the integrated curriculum, the graphic interpretation of which is presented in Figure 11.
Figure 11. Integrated curriculum for bachelors training in "Thermal Power Engineering and Heat Engineering".

Particular attention in this curriculum is given to the disciplines in which the student masters the skills of project-innovative activity: "Introduction to engineering" (first and second year of training) and "Designing of thermal mechanical equipment" (third and fourth year of training), "Basics of business relations", "Basics of professional communication" and a number of elective disciplines "Solving of technical cases", "Project management", "System engineering", "Management in conditions of changes". This led to a significant change in the structure and content of the educational program, including the integration of CDIO's planned learning outcomes (CDIO Syllabus) and disciplinary skills, the introduction of active teaching methods and the involvement of practitioners.

This new educational model required the modernization of the functional and organizational structure of the department, in terms of transition to the management of the educational program, which allows ensuring the fulfillment of the main parameters of the project's effectiveness, as well as ensuring the optimization of human, financial and material resources (Figure 12). In this setting, the new structure of the educational program regulates the implementation and control of unique mandatory processes (educational activities, R&D, educational work, international activities, interaction with strategic partners and career-oriented activities).

Intermediate experience of the introduction of the model of the project-oriented technology for the preparation of bachelors in Heat and power engineering in the Siberian Federal University received positive expert assessment from strategic partners (employers), who took an active part in the project weeks, and also increased a number of performance indicators for educational units. So for three years of the experiment (from the moment of the first recruitment for the CDIO program in 2014), the average Unified State Examination score for the three introductory disciplines increased from 182.3 to 197.5 with a recruitment of 50 people; The geography of the admission includes 18 regions of the
Russian Federation and 5 countries of near and far abroad, which allowed to raise the level of internationalization on the program from 1.2% to 16%; The keeping of the contingent was increased from 63% to 95%; The publication activity of students, as well as their participation in conferences and scientific and technical competitions of various levels, has tripled.

Figure 12. Integration model of the educational program.

At the same time, it should be noted that there are some risks that accompany the introduction of new educational technology, the main of which are: the lack of the required qualifications of the teaching and support staff, which is the lack of an independent project experience; Unsatisfactory infrastructure of the university and, accordingly, the educational program (department); The need for a much larger administrative, organizational (at the university level), material and financial resources.

Despite the intermediate state of the project, we can state the achievement of a number of positive objective and subjective results, which makes it possible to recommend the above approach for practical use in the modernization of engineering education in other university's educational programs and in similar programs in other Russian universities.

References

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