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Applying CDIO-approach at technical universities

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Abstract. The article considers the issue of modern engineering training with the use of CDIO-approach (Conceiving, Designing, Implementing, and Operation) aimed to balance the training goals with the practice of teaching at higher technical institutions. Modern pedagogical technologies and innovative teaching methods enable to create such an education medium where the students will obtain profound knowledge, manage the process of designing and exploiting new items and systems, understand the impact of the scientific-technological process on the society. The article also considers various approaches to developing new practice-targeted programs and methods of creating a special education medium. The abilities of students' engineering thinking are a link between university training and professional activity. Future specialists must not only be able to develop and produce engineering systems, but also combine the knowledge of natural and technical sciences to come up with innovative ideas, have a command of professional ethics and understand the principles of business.

1. Introduction

The main peculiarity of modern technical education is training a specialist ready to live and work in the global world, capable of innovations and entrepreneurship, organizing business, developing, and launching new innovative items to the market.

Since the 1980s and especially since the 1990s in the developed countries the employers' requirements for the graduates of technical universities have grown. These requirements concern the practical skills of designing objects, processes, and systems. Syllabi, however, were more theory-focused rather than practice targeted and aimed at developing a scientific basis for solving engineering problems. This resulted in insufficient communicative skills and the ability to work in a team, lack of practical skills to create objects and processes.

CDIO approach is aimed to solve the problem of the gap between theoretical and practical training.

Moreover, modern syllabi have not provided the students with all the necessary knowledge, but with outdated information. This refers to such subjects that are based on outdated technologies and thus distort the interdisciplinary links, which only confuses and demotivates the students, distracts them from the subject core and its importance in the general professional competence. Nevertheless, the students must obtain sufficient scientific knowledge in the sphere of machine building and develop analytical skills.



2. Theoretical background

The creators of the new concept of engineering training note that workshops, team projects, problem-solving, carrying out experiments, and research must become inseparable constituents of engineering education [1]. Nowadays the CDIO approach is supported by over 120 universities from 30 countries of Europe, America, Asia, Australia, and New Zealand.

Change in the professional training demands the development of such the students' skills as designing and producing engineering systems as well as converge information and natural sciences, creating innovations, command of professional ethics, understanding the principles of business development. Unchangeable remains the need to give the students a profound scientific basis, fundamental knowledge of engineering, and develop their analytical skills.

B. M. Crookston et al [2] study the current challenges the modern generation of young engineers face is constantly changing and evolving classrooms and workplaces. Paper [3] shows the association between neurobehavioral traits and intelligence with university-level grades in majoring subjects.

E. P. Dubovikova [4] considers the possibilities of developing general and professional competences of engineering students trained at higher educational establishments. L. C. Félix-Herrán et al [5] explain the ways a teaching-learning concept applies interactive, experiential activities, motivates students, and encourages their creativity to provide solutions to real-world challenges. R. Efendi et al [6] show the effectiveness of a competency-based learning model in computer network courses for developing learning skills and enhancing learning motivation, empowering students to solve given problems, increasing their responsibility and ability to work in teams. The authors also show the difference between students' performance while taught by conventional learning methods and competency-based learning in favor of the latter, which boosts students' cognitive and psychomotor abilities.

Another research [7] showed the ways the pedagogical design of an academic course can develop digital literacy competencies, support students in regulating collaborative technology-enhanced learning, and help them control and improve their collaborative performance. L. H. Kadyjrova and others [8] discuss the use of information and communication technologies in training bachelor-students of design as one of the innovative organizational forms taught at a university, based on modern achievements of the psychological and pedagogical sciences, new generation learning stuff and a wide range of electronic educational resources.

The research aims to analyze the implementation of the CDIO approach in modern professional engineering training. The main feature of this approach is to practice targeted engineering training, while the main aim of modern technical education is training for successful professional activity in the conditions of increasingly complicated production technologies.

3. Materials and methods of research

Nowadays Ukraine is trying to increase the accessibility of competitive high-quality education according to the requirements of innovative sustainable social and economic development [9]. The peculiarity of the CDIO approach lies in the practice-oriented training of engineering students. The main purpose of modern technical education is the training of students for successful professional activity, development of their professional competency in the conditions of the growing complicity of manufacture.

The above-mentioned complex approach enables to reform professional training of students of technical universities in the context of innovation, leadership, and entrepreneurship, modernize educational programs, teaching methods and the infrastructure of universities, the specialists of the technical sphere are involved into all the stages of the life cycle of objects, processes and systems (designing, planning, production and use) that meet the requirements of the society, use advanced technologies opening new horizons. To solve the set task a modern engineer applying modern technologies and communicative skills can process obtained data to synthesize new

information, working in a team.

The researchers of the issue of improving engineering training highlight the principles that would enable its successful realization. The first of these principles is considering engineering training in the context of real engineering practice at production. CDIO approach is aimed to train specialists in the technical sphere able to apply basic technical knowledge in practical activity; manage the process of creation and exploiting engineered systems, objects and systems; understand the importance and impact of the scientific-technical progress on the society [1].

According to the authors of this approach, modern pedagogical technologies and innovative methods of teaching enable to create such an educational medium, in which students will actively apply obtained knowledge, thus understand and perceive abstract theoretical concepts. The outcome of students' training will be the CDIO Standards, presented in the list of graduate's competencies developed with employers' involvement. This list of competencies presents the context of modern engineering education. The curriculum of specialists' training is requested to be complemented with practical tasks on drafting, designing, and creating technical objects that are possible to carry out within workshops. The assessment of the obtained knowledge and skills must be complex and take into account first of all their applicability in unfamiliar situations.

Nowadays, the CDIO approach for developing engineering syllabi is used in over 100 universities worldwide, however, it is not a standard and can be adjusted to any syllabus. The results of students' training at the university are formed together with the future employer based on the rational need in engineers. The assessment is performed in the form of writing and oral exams, presentation, students' reflection over the achieved competencies recorded in portfolios. The CDIO approach is based on the personality-centered principle of assessment of student's achievements, personal and interpersonal qualities.

We must admit that understanding the value of practical skills for modern engineers has considerably decreased, which caused some dissatisfaction with manufacturing companies with the level of training of graduates in the late 1990s. Much attention is paid worldwide to engineers' training with competency-based approach (standards of the Accreditation Board of Engineers' Training (ABET) in the USA, competency standards for engineers UK-SPEC in Great Britain, project EUR-ACE on accrediting engineering syllabi and graduates all over Europe, requirements to the syllabus assessment of the Canadian engineers' accrediting Council).

From manufacturers, an engineer must find potentially successful economic solutions, have an understanding of their profit for the society, and be able to cooperate with other specialists. Modern engineers' education joins 4 interested parties: students, employers, teachers, and public organizations. The outcome of training based on the CDIO approach must reflect the interests of all the parties. The integrated curriculum which comprises subjects based on the interdisciplinary approach plays a decisive role since it promotes the development of skills of creating objects, processes, and systems. Employers can teach students to apply their own devices and systems through modeling real processes, electronic access to the objects at the production.

The desired result of such professional training can be achieved through the increase of practical lessons in the academic load, time redistribution, and implementation of complex teaching activities. CDIO approach means active learning when students are involved in the study process and are more motivated to obtain engineer competencies. The authors of the approach think that at lectures students must be offered the tasks on perceiving the heard information through group discussions, model and analyze real situations at the production. Problem-based training teaches students to formulate, estimate, and solve a problem. Learning theory through practice is based on the theory of cognitive development the authors of which think that the process of perception depends on the stage of human cognitive development [10]. Therefore students cannot learn to apply cognitive structures that they have not developed yet. To study the CDIO approach as the context of modern engineering training, it is better to look

back into the stages of the life cycle of engineering solutions [1] (see table 1).

Table 1. The stages of the engineering solution cycle.

Planning	The analysis of the demands of the interested parties, choice of technologies, consideration of valid norms and regulations, concept development, and business planning.
Designing	Detailed project description, drafting and composing algorithms describing the final objects, processes, and systems.
Production	Project transformation into real objects, process or system including all stages of production, testing, and checking.
Application	Effective use of the produced item, process, or system, including maintenance, improvement, change, and dismantling.

In the context of modern engineering activity, students must acquire basic technical knowledge and specific subjects, develop competencies, skills, and personal features required by companies. The students' motivation playing the decisive role is reached through context-based learning when students can apply obtained skills to the earlier developed cognitive structures.

The application of CDIO means the transition to students' integrated teaching aimed to create products, processes, and systems. This is possible only at the subject's integration and practical activity. Naturally, it is complicated to develop practice-aimed syllabi based on new teaching technologies. Open access to materials on designing new programs enables universities to exchange information about the projected training results (CDIO Syllabus) and gradually switch to a new education model. Cooperation of universities enables to allocate the tasks among partners, use the most successful practical experience and education models. The skills of technical thinking are a linking part between university training and real practical activity.

The main document on reforming syllabi for engineering education is CDIO Syllabus, which is sort of a list of employers' requirements for the professional training of technical specialists (engineers). This list comprises a set of competencies, which a future engineer must possess and a list of lacking skills and abilities of graduates [11] (see table 2).

Table 2. The list of important lacking skills and abilities of engineer graduates.

Skills most important for employment	The lacking skills upon graduation
Effective teamwork	Running business
Information analysis	Managerial skills
Effective communication	Project management
Collecting information	Quality management, Effective communicative ability, The knowledge of marketing principles, Professional ethics

Many countries carry out reforms aimed to integrate engineering training and engineering practice with the increase of students' scientific research (Massachusetts Technological Institute in the US, The Royal Institute of Technology in Sweden, The University Jinhua in China).

The list of necessary skills and competencies of graduates (CDIO Syllabus) was first published in 2001 and amended in 2010 and 2011 by the university teachers according to the national peculiarities [1].

CDIO Syllabus became a framework for the development of curricula and is used for the description of specific knowledge the students must obtain within engineering courses. It comprises the following chapters:

1. Subject knowledge and comprehension:
 - basic scientific knowledge,
 - fundamental engineering knowledge,
 - profound engineering knowledge, methods, and means.
2. Personal competencies and professional skills:
 - analytical thinking and ability to solve problems,
 - experimenting, research and obtaining knowledge,
 - systemic thinking,
 - professional competencies and personal qualities.
3. Interpersonal competencies:
 - teamwork,
 - sociability,
 - foreign language communicative competence.
4. Planning, designing, production, and application of systems within the enterprise, society, and environment as an innovative process:
 - external, social and environmental context,
 - business context,
 - planning,
 - designing,
 - production,
 - application.

The presented CDIO Syllabus has a complex nature and in comparison with the national accreditation criteria for engineering syllabi in other countries, enables us to fulfill a broader task, helping to define the ways of improving valid curricula. In the modern world, the role of each graduate of a technical university changes and requires his ability to interact with the representatives of other spheres about life-long learning innovations, entrepreneurship. For instance, a complex concept for steady human development calls for the search of balanced technology that would enable safe utilization of used resources, creating new systems without carbon fuel to preserve the environment. This stresses the importance of the role and responsibility of the graduate of a technical university for the society and the environment. It is necessary to take into account the function of modern engineers in the innovative process since they present new technologies, goods, and services.

The authors of the described approach note the necessity to develop engineers' global outlook and skills to work for an international company, which calls for communication in foreign languages and understanding international standards and norms [1].

The primary tasks of the universities are raising the quality of education, organization of the study process based on a personality-centered approach, creating conditions for students' comprehension activity. At the same time, students must be able to work according to the trends in the modern world economy. The intellectual revolution of the labor forces entailed the rapid advance of intellectual economies, thus overall, harmonious, creative personality development, which meets the employers' requirements. Before switching to CDIO Syllabus all engaged parties

(teachers, employers, and students) define the desired level of competencies for future labor activity (production, management, and entrepreneurship).

According to Bloom's taxonomy, training embraces three spheres: cognitive (knowledge and thinking), emotional (personal qualities and values), and psychomotor (movement skills and actions and manipulations). Comparing the level of development of each skill with Bloom's taxonomy, it is possible to differentiate the most significant ones for the graduates: engineering thinking, communication, designing, and personal competencies.

The issues of developing education policy based on competencies, determining the content of curricula, syllabi, textbooks, educational standards for monitoring the quality of education are considered in the guidelines of the educational policy of Ukraine [12].

In our opinion, the next step is determining the ways and means of reforming engineering training. Modern research into practice-based engineering training testifies to the fact that each syllabus for the subject included in the integrated curriculum contains interconnected parts: the objective and tasks; the matrix of the program, its plan with determined methods, and evaluations of the results of CDIO Syllabus. All university training engineers according to CDIO standards ensure that these subjects interlink, converge which is reflected in the matrix of the integrated curriculum. Therefore, there is a method developed to determine the effectiveness, reserves, failures, and advantages of CDIO Syllabus.

There are several approaches to forming a curriculum:

- classical curriculum without taking into account developed skills,
- integrated curriculum with interlinked subjects, skills and students' project work,
- the problem-based curriculum aimed to solve existing problems,
- project-based curriculum to implement practical tasks.

Well designed project work with the aim of its completion serves as an important motivating factor. There are several ways of integrating courses: temporary integration, parallel integration, embedded integration. The integrated course can be taught by one or several teachers who coordinate their actions. This approach is very effective for a project or course paper and basic engineering subjects involve the implementation of some design or project. It is usually done in the conditions very similar to the real practical setting.

The succession of courses is also very important since every course is built on already developed skills. For example, lecturers of the Royal Institute of Technology (Stockholm, Sweden) developed so-called paths of skill development from one course to another, to obtain the final product – developed competencies of creating products, processes, and systems.

The teachers of Singapore technical institute set the integration of personal competencies, professional skills, teamwork as a priority in modern engineering training. The School of machine-building and aeronautics of this institute offered first-year students learning the "Fundamentals of engineering" to design and assemble a race car. While carrying out this task the students produced chassis according to their drawings and modeled the body of the car. After that, the race cars assembled by students were tested to define the failures and strong points. The next step of this integration was the development and production of pilot samples of items for social projects. Before this, the students studied the demand of the market and developed new items employing critical and creative thinking. A compulsory course "Introduction into engineering" implies a lot of practical work and writing projects which are presented at the final conference.

It enables the students to reflect on the outcome of their work, assesses the skills developed as the result of designing and implementing projects, and define ways to improve them. The project-based learning can be presented in laboratory experiments or ICT designed experiments, and the assessment of their results. It enables us to consolidate the obtained knowledge, develop skills and abilities to solve problems, modeling working conditions.

According to some researchers, third-year students should be given tasks to remodel the existing industrial items, to increase productivity, reduce their nominal value, to use the natural resources more rationally and to build environmentally friendly production. Fourth-year students must build the model of a real process. For example, the students of the Massachusetts Institute of Technology had to design two independent 2-kilogram robots able to communicate in space. The project involved 15 students who designed and created prototypes, power plants, navigation, monitoring, and control systems, then tested in the conditions of zero-gravity [1].

4. Results

To achieve an appropriate result, the task for the design-implement activity must be complicated enough, and the role of teacher shifts from lecturing to tutoring and monitoring. Naturally, teachers must be well prepared to teach according to CDIO, therefore training of scientific staff is an important part in this respect. Ukraine’s entrance into the European educational and scientific community calls for modernization of the structure of qualifications chart [13].

The realization of the national scientific policy including the system of training university teachers is one of the state’s main functions. The next important step is to search for the optimal model of training scientists so that national science and higher education could reach the world level, while preserving national identity, increasing the country’s intellectual potential [14].

For the realization of design-implementation activity, it is necessary to create an appropriate setting in the workshops and laboratories with Internet access, library access, computers, and different software. The rooms can be zoned according to the stages of realization of the CDIO model (planning, designing, production, and implementation), where students can communicate with one another and teachers.

To estimate the level of developed competencies of future engineers, their readiness for professional work, we researched at the Zhytomyr Polytechnic State University, comparing the performance results of bachelors and masters. For the research, we used the results of the methods of socio-pedagogical analysis (performance monitoring, expert evaluation, pedagogical observation, questionnaire design of both students and teachers) [4]. Such methods are quite popular since they conform to international standards of teaching and learning results at university and developed competencies of future engineers. First of all, we diagnosed the bachelors’ and masters’ levels of proficiency in certain competencies according to the 100-point score (see table 3).

Table 3. Bachelors’ and Masters’ developed competencies (according to 100-point score).

Competencies	Bachelors	Masters
Fundamental knowledge	90	95
Analytical problem substantiation	80	83
Creative thinking	75	90
Experimental research	85	88
Invention	80	95
Team-work	90	90
Communicative skills	90	95
Engineering entrepreneurship	75	85
Planning and project management	85	95

These competencies include the necessary knowledge, skills, and abilities to solve professional tasks, developed personality qualities for effective collaboration and teamwork, the ability to

perform production functions.

The results of estimating students' competencies (average rate for students participating in diagnostics) showed, that the majority of future engineers have sufficient fundamental knowledge, can work in a team, possess necessary communicative skills, but are not ready to provide analytical substantiation of any engineering problem, are not enough knowledgeable about experimental research in engineering entrepreneurship. Questionnaires' analysis enables to state that the educational process pays little attention to the development of these important professional competencies. Suffice it to note that in recent years the university has been forming a new educational medium aimed at active cooperation with enterprises, implementing new integrated technologies, technical and informational communicative education tools, practice-oriented curricula into the study process.

After the conducted questioning the students we proceeded to their evaluation according to descriptors with the help of experts working at the enterprises hosting students' practical externship. The obtained results enabled us to distinguish three levels of students' professional competency (optimal, functional, basic, and insufficient) in 4 components: motivational, cognitive, operational, and reflexive (see figure 1). When distributed according to these criteria, we have seen the most developed and less developed in the professional competency of students (see figure 1).

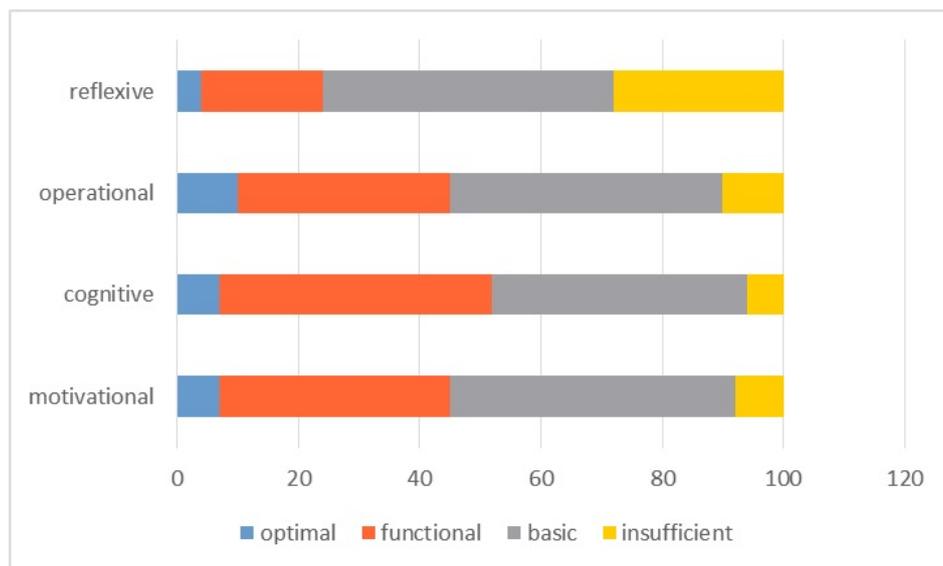


Figure 1. Distribution of students according to the criteria of professional competency.

The diagnostics results of the acquired professional competency of future engineers enabled to conclude:

- most students graduate from the university with the basic level of professional competency in all the above mentioned four criteria,
- as for motivation, 45% of graduate students showed optimal and functional levels, which testifies to their professional interests, engagement, and strife to realize their abilities,
- 52% of students also showed a remarkable level (functional and optimal) in the cognitive criterion of their professional training,
- however, the indices in the operational criterion were the lowest (functional and optimal – 42%), which stresses the need to intensify the practical component of CDIO training,

- the lowest rate was shown in the reflexive criterion (functional and optimal – 24%), since the professional and life levels are the lowest as well, which calls for drawing more attention to students' production internship practice.

The conducted research and the experience of the practical training of the students of Zhytomyr Polytechnic State University testify to the fact that for the transition to the CDIO approach it is necessary to have sufficient staff resources. For the realization of project implementation, there should be an educational setting instead of traditional classrooms, which should be equipped into workshops and laboratories. This approach requires conditions for students' communication, planning, exchanging ideas, carry out experiments. New rooms are equipped with magnet-highlighter boards, Internet access, access to the library resources, computers, and all necessary software. The students are involved in various creative contests, implying research and creative thinking. The obtained knowledge will transform into skills during in-service practice, the concept of which conforms to the "Regulations on practice for students of higher educational establishments of Ukraine". The practice is to develop students' skills and abilities to make independent decisions. The required practical skills are listed in the practice itinerary and their actual achievement is reflected in students' reports. Students' scientific training was performed in the research laboratories based on new technologies, employing development testing, computer-based designing of cutting tools, stereophotogrammetry, studying the ecology of mining, the problems of water resources, etc. this activity involves cooperation with leading industrial companies of the region. A very important feature of students' practical training is their participation in various vacancies fairs, workshops, round tables with the involvement of business culture representatives. It is possible through the collaboration of the departments with the Career Development Centre and the department for international relations. The university houses the only in the region business incubator YEP, among whose goals are the innovative system of promoting and developing youth and academic entrepreneurship. Companies' sponsorship enables students to work over their projects in teams, obtain necessary experience for future professional activity, possible for these companies. It helps students better understand the needs and problems of industrial processes, find the place for internship and further employment.

Furthermore, there is a great problem in the country of graduates' employment. The enterprises where students have their practice not always create necessary conditions for developing students' necessary competencies and the internship/practice is always only formal. This stimulates the university teaching staff to look for ways of improving students' practical training at university, using active methods and technical teaching aids. More and more students get involved in research work into indices and results of real production processes.

5. Conclusion

Changes in modern professional training are determined by the necessity to educate specialists ready to practical work, able to creativity, designing effective systems and items. This calls for the necessity to bring theoretical training and practice together which is possible both in the premises of the university (workshops, laboratories) and industrial enterprises. It is possible within the frames of CDIO Syllabus, which integrates theory and practical work, different subjects, and brings together teachers and students in collaborative activity, from which both parties benefit. Students participating in teamwork are more able to develop their critical and creative thinking, forecast and assess the outcome of their work, communicate their ideas, be flexible in cooperative work, make well-informed decisions based on effective communication. Practical work enhances students' motivation because they can deal with real products and processes, act in real or close to real production setting, can design and implement and discuss the results with teachers and other students. Moreover, embedding such courses as biology, physics, chemistry, and information science into the engineering curriculum and integrating

subjects raises the students' awareness about the impact of their products on the society and environment.

Professional technical training at universities of Ukraine based on CDIO Syllabus calls for studying the experience of other European universities such as Royal Institute of Technology (Sweden), The University of Leeds (Britain), Technical University of Turin (Italy) that developed and implemented engineering syllabi to meet the requirements of industrial enterprises and the society.

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