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DEVELOPMENT OF INFORMATION COMPETENCIES OF ENGINEERING STUDENTS

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ABSTRACT

Intensive digitalization of the engineering profession imposes new requirements for the methods and approaches to the effective formation of information literacy. In Russia, this process is complicated by the strict state educational standards, which is not enough to train competitive specialists in the job market. The gaps that emerged while preparing the Bachelor of Engineering (BEng) are proposed to be filled with Conceive-Design-Implement-Operate (CDIO)-based tools. In the paper, the CDIO Syllabus project for BEng students is discussed as the methodological solution. The project includes a list of training results that are in line with Russia's Federal State Educational Standard (FSES 3++) and the DigComp 2.0 model. The practical application of the CDIO Syllabus project is demonstrated using the case of individual and/or group educational products based on a university's information-educational environment and resources. The study examines its structure, content, and implementation technology. To justify the applicability of the proposed solutions, we analyze the advantages of the CDIO initiative when building information competences for students of BEng programs. The research findings can be adapted to the orientation or educational profile of a university's engineering training.

Disciplinary: Engineering Education (Curriculum and Learning Development).

1 INTRODUCTION

The current system of higher education is undergoing changes caused by the emergence of new demands of digital society. The objective of universities is to train students capable and ready to perform their professional duties amid lifelong learning in the information environment using a creative approach (Mikhalkina et al., 2020; Makarova et al., 2019). This objective has become critically important in the context of delivering engineering education.

The conventional understanding of engineering education is associated with the issues of high technology that are resolved in accordance with a specific algorithm considering the specificity of a particular production process. The special features of the engineering activity predetermine the stringent requirements for student competencies (Vainshtein et al., 2016). These requirements are becoming increasingly relevant due to the rapid development of Industry 4.0.

The global trend towards integration of universities, scientific and industrial institutions contributes to the formation of practice-oriented project education and highlights the problem of finding novel methodological approaches and organizational tools that encourage the development of effective competences among students. For Russia, joining global trends is complicated by strict state educational standards, which is clearly not enough to train competitive specialists in the job market. According to the Boston Consulting Group (BCG, 2017), about 80% of the working-age population in Russia does not possess the appropriate professional competences. The issue of engineering education modernization is, therefore, among the acutest in the country (Chuchalin, 2014).

In contrast to the rigid model, a softer approach to education involves the use of the CDIO initiative (Conceive – Design – Implement – Operate) (http://www.cdio.org). It sets the targets for the quality of engineering education and its results. The CDIO initiative suggests organizing teaching in such a way that students could demonstrate in-depth theoretical and practical knowledge of the technical foundations of the engineering profession (Kutuzov & Shaposhnikov, 2012).

Thus, the purpose of the given study is to justify the implementation of the CDIO approach aimed at building information competences of BEng students in Russia. It is noteworthy that the stated goal requires Russian educational standards to harmonize with international educational practices (in particular, the DigComp 2.0 model). This condition imposes certain research limitations that need to be overcome.

2 LITERATURE REVIEW

Industry 4.0 determines the promising opportunities for the development of human capital based on open digital education technologies (Dellis et al., 2016). In this context, it is important to analyze the process of building competences.

Researchers emphasize that the concepts of proficiency and competence are interconnected. As Khutorsky and Khutorskaya (2008) put it, individual proficiency is not only knowledge of the actual material (information) and skills in a particular field, but also the experience that the student has gained. Among the components of individual proficiency are objectives and values, communication, experience, knowledge, and skills. Khutorsky and Khutorskaya stress that competence is an alienated and predetermined requirement (norm) for students' education, and proficiency in their personal quality (a set of qualities) and minimal experience in a given industry. This view is supported by Zimnyaya (2009), who regards competence as a structural unit of the process of proficiency formation. Litau (2018) views proficiency as an integral socio-personal-behavioral result of education in the aggregate of motivational-value and cognitive components.

Information competence, among other things, is distinguished by multifunctionality and universality (Smolyaninova, 2002). According to Smolyaninova, information competence is a set of universal ways of searching, receiving, processing, presenting, and transmitting information, as well as generalizing, systematizing, and turning information into knowledge. When investigating modern approaches to teaching under digitalization, Bates (2015) formulated a list of competencies that students need to acquire.

Currently, a common way to assess information competences is the DigComp 2.0 model (DigComp 2.0, 2018). According to the model, information competence is a necessary element of digital competence and is defined as the confident, critical, and creative use of digital tools to achieve the goals associated with work, employability, learning, as well as personal and professional development. The key components of digital competence are categorized into 5 areas: information and data literacy; communication and collaboration; digital content creation; safety; and problem-solving. According to the Joint Information Systems Committee (JISC, 2014), digital competence is a set of academic and professional situational practices supported by all sorts of changing technologies.

One of the possible ways of developing digital competence in Russian universities is Kondakov's model (BCG, 2017), which incorporates three groups of competencies – socio-behavioral, cognitive and digital skills. The model is outstripping in nature and is based not on the traditional approach – requirements for the education level of graduates, – but on the labor market requirements for key professional and personal competences.

According to Davydova (2005), the central idea of the current development stage of the theory and practice of engineering vocational education quality management is to abandon the traditional approach, where the educational process is regulated according to the estimates of the final result. The focus of the new approach is on the creation of a universal quality management system that regulates the process through assessing its state and factors affecting the end result. The new vision of vocational education takes into account its scope since the latest studies highlight that a high rate of overeducated graduates is estimated to have a negative impact on economic growth at both short and medium terms (Sam, 2018).

Nowadays, engineering education is developing in several directions. The most important of them are oriented towards practice (Volchik & Maslyukova, 2017). They are most fully implemented in the CDIO concept. Maurya and Ammoun (2018) discuss the experience of implementing the CDIO approach in the integrated digital environment. They claim that internships at industrial enterprises help future engineers to put their knowledge into practice.

Bermus (2014) argues that the development and implementation of CDIO are roughly similar in meaning to that stipulated in Russian state educational standards: the key aspect here is not a specific set of competencies, but a holistic image of the future professional activity. It is also noteworthy that as early as at the ideological level CDIO implies gaining experience in individual and collective innovation activity, implementing the project in the open information-educational space, acquiring skills in interdisciplinary and interpersonal communication, and interaction, as well as examining and criticizing the ongoing projects.

At the moment, the CDIO approach is not sufficiently represented in Russian educational practice, which hampers the development of information literacy among Bachelors of Engineering. Educational standards in Russia are mostly focused on building the obligatory and universal professional competences. Against this backdrop, information competences lose in their significance. The cautious attempts to apply the CDIO concept in Russia were made by Arnautov (2014).

The literature review shows that the modern learning concept should be based on the methodology that involves an open and consistent cluster of pedagogical approaches (Shershneva, 2014). Its substance is the optimal use of methods with different didactic potential. One of them is the CDIO approach that has proved to be effective when resolving the problem of improving the quality of engineering programs. In the next section, we examine the methods for introducing the CDIO approach aimed at building information competencies of BEng students at Russian universities.

3 MATERIALS AND METHODS

In the current study, building information competences of BEng students is founded on the CDIO approach. Its methodology is premised on the core principles of the innovative educational environment – Conceive, Design, Implement, and Operate. When implementing the CDIO approach, it is also possible to utilize other metrics that detail the stages of preparation (Maurya & Ammoun, 2018) using: Inspire, Learn, Innovate, Create, and Evaluate (Table 1).

Table 1: Guidelines for implementing the CDIO approach in the training of engineers

Tool	Description
Inspire	Get inspired by the real world: contextual, semantic, in real life and the Internet
Learn	Focus on discipline, subject matter, design practice, and peer learning
Innovate	Learn through the interaction of different ways and forms of learning
Create	Apply a multidisciplinary approach and project management
Evaluate	Concentrate on continuous monitoring of the effectiveness of interaction, mentoring, peer management

The analysis of the given list of metrics demonstrates that the majority (over 60%) of the projected competences of BEng students is related to the preparation for integrated engineering activities at the stages of production and application of technical objects, processes, and systems (Implement & Operate); 25% of training results are focused on innovative activities (Design); and just over 10% of competences provide students with the opportunity to participate in research (Conceive). Such a structure of competences determines the priority area of professional activity (Chuchalin, 2016). It should be taken into account that the innovative component weakly correlates with higher labor productivity and living standards or may have negative relationships.

When introducing CDIO, the curriculum is subject to adjustments. In the curriculum of the principal engineering training program, there are both traditional modules and those that follow the CDIO method. As a rule, these modules are linked with project activities, focus on teamwork skills, the theory of the development of inventive tasks, design thinking, and the inclusion of economic, social, and environmental contexts (Crawley, 2011).

One of the important methodological components in the CDIO application for building students' information competences is the design of an adequate CDIO Syllabus. Many researchers are convinced of the need to adapt the structure and content of the CDIO Syllabus according to the state educational standards (Chuchalin & Daneykina, 2017).

Establish a correlation between the competences of the Russian educational standard and CDIO Syllabus within the same discipline of the course, and also discuss the possibilities of implementing an active practical approach. The course of Mathematics for engineering is used as the case study. The competences of the educational standard are identified according to the relevant work program of the discipline. The correspondence of the competences is illustrated in Table 2.

Table 2: Correspondence between the competences of the state educational standard and CDIO Syllabus.

Competences of the state educational standard	CDIO Syllabus
General cultural competences: OK-1 (ability to form a modern picture of the world based on a holistic system of natural-scientific and mathematical knowledge and to navigate the values of being, life, and culture); OK-7 (knowledge of the culture of thinking, the ability to generalize, analyze, critique, systematize, forecast, set goals and establish ways to achieve them, be able to analyze the logic of reasoning and statements)	1. Disciplinary knowledge and basics – Basic knowledge of mathematics and natural science; – Mathematics (including statistics)
Professional competencies: PK-2 (ability to independently gain new knowledge and skills using IT and put them into practice, including in new areas of knowledge and not directly related to the field of activity)	2. Professional competencies and personal qualities – Data search (print and electronic publications); – Persistence in achieving goals, ingenuity, and flexibility
Professional competencies: PK-4 (ability to organize their work based on scientific grounds, be independent in assessing their performance, mastery of independent work skills, including in the research domain)	2. Professional competencies and personal qualities – Lifelong learning; – Time and resource management
Professional competencies: PK-3 (ability to work in a multinational team on interdisciplinary and innovative projects. As a department head or team leader, s/he can set the team's goals, take decisions under risk bearing in mind the consequences of a mistake, provide training and assist their subordinates)	3. Interpersonal skills: teamwork and communication – Building an effective team; – Team management; – Team growth and development; – Team leadership
General cultural competences: OK-5 (fluency in written and oral business reporting in Russian, public and scientific speaking skills, ability to produce and edit professional texts, fluency in one of the foreign languages as a means of business communication)	3. Interpersonal skills: teamwork and communication – Communication strategy; – Written communication; – Electronic/multimedia communications; – Graphic communications; – Oral presentation; – Interviewing, listening, dialogue
Professional competencies: PSK-1.5 (ability to use application software to compute units, assemblies, and systems of cars and tractors)	4. Planning, design, production, and application of products (systems) within an enterprise, society, and the environment – Using knowledge in design; – Disciplinary project; – Interdisciplinary project

As shown in Table 2, the relationships between the competences comprehensively describe the acquired personal, interpersonal, and professional competencies established according to the program's goal, which meets the requirements of CDIO Standard 2. The CDIO method allows using the main technical and engineering contexts in the learning process at various stages of the life cycle: development, design, introduction, and operation of real systems and products. Currently, 12 CDIO standards are approved. Each standard corresponds to a certain stage of the approach, from regarding CDIO as a general context for development to an integrated evaluation system for the entire program for various participants in the educational process to ensure its continuous improvement.

Within the framework of the present study, for the effective CDIO adaptation, we look at the specificity of preparing BEng students for innovative and research engineering activities using information competences. Moreover, when developing CDIO Syllabus for Bachelors of Engineering, level-sensitive characteristics and practice-oriented directions for building information competences according to the DigComp 2.0 model were used.

4 RESULT AND DISCUSSION

In this section of the research, we present the results of the CDIO Syllabus development aimed at building information competences of BEng students taking into account international educational practices in the field of digitalization.

The advantage of the CDIO Syllabus is that, in contrast to the requirements of the accreditation criteria, the requirements of the CDIO Syllabus for graduates' competencies are decomposed at several levels (Crawley et al., 2014), see Figure 1.

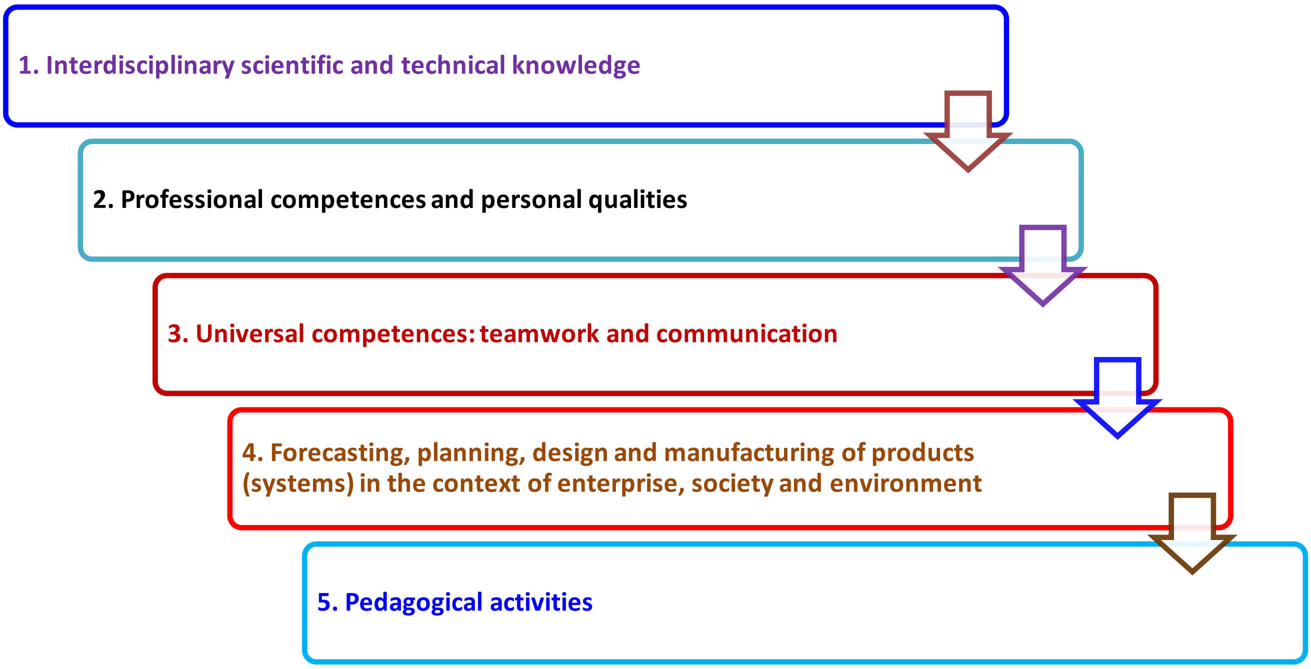

Figure 1: CDIO Syllabus for training students of BEng programs.

This allows educational program designers to effectively implement a competency-based approach, i.e. to determine in detail the initial data for program design, to set tasks for university teachers, and to carry out deep modernization of educational programs based on CDIO Standards.

Table 3 presents the CDIO Syllabus which includes the list of training results that take into account the requirements of the Russian state educational standard (FSES 3++) and the DigComp 2.0 model.

CDIO Syllabus design provides a system-related description of the innovative activity results of Bachelors of Science in Engineering. Evaluation of student competencies can vary according to the educational profile of engineering training. In this case, it is acceptable to manipulate the ratio of CDIO Syllabus components. When designing level-sensitive engineering training programs, CDIO Syllabus requirements should be differentiated with regard to the peculiarities of engineering activity.

The research limitation of the study is the lack of an integrated educational platform for using the CDIO method in Russia. Universities practice this approach in different ways, which hampers the exchange and replication of experience while implementing educational programs, modules, or specific disciplines. Strict state educational standards do not allow one to fully implement the CDIO approach. It should be realized that only cooperation between universities, companies, and research institutions can make it possible to project graduates' competences and realize the full CDIO-based training cycle in an effective manner (Toomsalu et al., 2019).

Table 3: CDIO Syllabus for training students of BEng programs

Bachelor's degree program of CDIO Syllabus
1. Interdisciplinary scientific and technical knowledge
1.1. Knowledge of mathematics and natural science. 1.2. Knowledge of innovative engineering. 1.3. Information and operational literacy
2. Professional competences and personal qualities
2.1. Analysis and solution of innovative problems. 2.2. Experimentation, research. 2.3. Systems innovative mindset. 2.4. Critical analysis and creativity. 2.5. Ethics, justice. 2.6. Network etiquette. 2.7. Digital cooperation and interaction
3. Universal competencies: teamwork and communication
3.1. Leadership. 3.2. Digital communications. 3.3. International communications. 3.4. Copyrights and licenses
4. Forecasting, planning, design, and manufacturing of products (systems) in the context of enterprise, society, and environment
4.1. Eco-friendly professional activity. 4.2. Technical-economic and social context. 4.3. Forecasting and innovation management. 4.4. Planning and design. 4.5. Production. 4.6. Innovative technical entrepreneurship. 4.7. Protection of health and well-being. 4.8. Protection of personal data and confidentiality
5. Pedagogical activities
5.1. Development and implementation of electronic educational resources and products. 5.2. Identification of needs and technological responses. 5.3. Creative use of digital technology. 5.4. Determination of deficits in the maturity of information competences

In this respect, the stage of creating individual and/or group educational products using the university's electronic information-educational environment and its resources is gaining in importance. When considering the significance of engineering education, students can be asked to undertake a group project on the topic "Open Engineering Space". It should be noted that projects can be of various directions: social, industrial, and general engineering. It is possible to adjust the implementation mechanism according to the type of the project. For instance, implementing engineering projects requires additional calculations. Students are given a form to fill in the project passport, which includes the main elements: the list of participants, the project's name and abstract, stages of project implementation, problem statement, deadlines, goals and objectives, target audience, implementation schedule, team, partners, results and methods for their evaluation, as well as further steps in project implementation (Table A1).

Students are provided with evaluation criteria for the project. They should be informed that the developed educational product will be comprehensively evaluated, including self-assessment and expert reports. Once the project is defended, a group discussion is planned to analyze its results, which will help to reveal the difficulties in understanding the educational material and putting the acquired knowledge into practice. Table A2 presents an example of a group educational project description.

In the course of the study, we have found that the application of the CDIO approach in the training of engineers contributes to the practical implementation of design and experimental competences both in classrooms and modern educational laboratories using the electronic information-educational environment and its resources. In our view, this makes building information competences more effective.

The prospects for future research are to lay down the criteria for assessing the stage of information competencies development of BEng students and to adapt the designed CDIO Syllabus according to the peculiarities of the senior levels training – Masters's degree and postgraduate school. Also, to organize the interaction of all participants in the educational process, it is expedient to create an electronic educational platform that consolidates the resources in this field.

The obtained results can be used in the development and implementation of curricula of the major engineering training programs. It is possible to apply CDIO Syllabus design in the implementation of advanced training programs in several related disciplines and educational modules. These can be such disciplines as Information Literacy, Design Thinking, Information, and Digital Technologies in Professional Activity, Digital Competence in Professional Activity, Method of Innovative Projects, Computer Modeling, etc. Thus, the use of the CDIO approach is one of the possible solutions for the effective building of information competences among students.

5 CONCLUSION

Current trends in the sphere of vocational education set specific requirements for the practice-oriented knowledge of university graduates. In the context of digitalization, it is of primary importance to train specialists with sufficient information competences. We have found that in the process of BEng training it was necessary to use the CDIO approach. A formative stage in the development of an educational program is the design of the CDIO Syllabus, which includes a list of training outcomes considering the standards and requirements of the DigComp 2.0 model. For that purpose, we have developed the CDIO Syllabus project that can be applied when training Bachelors of Science in Engineering in Russian universities. The widespread adoption of the CDIO approach can be more effective if provided with the relevant organizational-methodological support and interactive cooperation between the members of the educational process with the help of resources of the information-educational environment.

6 AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding author.

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8 APPENDIX

Table A1: The CDIO project passport form.

Project information	Project code	
	Name, Surname of the person in charge	
	Project name	
	Project abstract	Provide the project's abstract
	Project stage	Preparatory stage
		Implementation stage
	Problem	Describe the problem that the project concentrates on and relate it to the development of engineering education
		Describe the applied problem(s) the project is designed to resolve/reduce the severity of it
		Describe the problem while focusing on the main CDIO principles
Execution period	Provide the deadlines for the project implementation	
The goal of the project	Formulate one goal of the project. It should be specific, measurable, achievable, realistic, timely (SMART)	
Objectives of the project	Formulate no more than three objectives that, if accomplished, will help to attain the project's goal	
Resources	List the resources used, including ICT resources and those of the electronic information-educational environment	
Target audience	Groups at which your project is aimed at. Indicate social groups and participants' age	
Project implementation schedule:		
Name and description of the event	Start and end dates	Expected results
…	…	…
Team	Specify the people involved, their positions and responsibilities; how many volunteers, if any, you are going to recruit	
Partners	Specify the current partners and those who you plan to engage in the implementation of the project, including public agencies and industrial enterprises	
Results	Describe what changes are expected as a result of the project. Indicate the qualitative and quantitative results and indicators	
Results assessment methods	Specify the indicators that, if achieved, point to the successful realization of the project	
Further implementation	Describe the perspectives of continuing work after the project is completed	

Table A2: Example of a group CDIO-based educational project description

Project's section	Section's content
Name of the project	Project on open engineering space development
Developers	Name of group members
Activity description	BEng students develop a project and present it to the expert panel
Goal	To create a project according to the CDIO ideology
Objectives	Fulfill the Conceive, Design, Implement, Operate requirements Prepare a group project's presentation
Project implementation tools	Resources: – e-learning courses; – websites; – forums; – webinars; – online conferences; – interactive online services (creating mental maps, Google Docs, Google Slides); – etc.
Self-assessment / expert evaluation / group discussion	Completing an individual self-assessment form, expert evaluation, group dialogue based on the results of a completed project

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