Integration of sustainability in metallurgical education: analysis of educational practices CDIO

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Abstract. Integration of sustainable development in education is now being addressed in numerous educational institutions across the globe. Based on different integration approaches, various teaching methods are being developed, applied and evaluated. A complex relationship exists between curriculum development and sustainable development. The goal of this paper is to present educational practices for integration of sustainable development in engineering education of metallurgy made by Siberian Federal University. We present in this study the results and reflections on the implementation of a specific teaching-learning methodology that has been designed to incorporate sustainability aspects in projects. These 12 ECTS-compulsory subjects are taught following the CDIO standards, according to which the students must develop a somehow innovative product or service from the conception and design to the implementation and operation. The results show that the students perceive that they have developed deep skills in sustainable development, as well as working across disciplines and with different stakeholders.

1. Introduction
Sustainability as a trend in engineering education is caused by fast global changes, the rise of dynamic nature and ambiguity level. The most important driving force of achievement of sustainability goals is education. Engineering education due to interdisciplinary and based-on-idea engineering plays the most important role in implementation and in becoming of an engineer as a personality, who has a leading way of thinking. Engineers for the future must foresee the impact of technical and technological decisions under discussion on sustainability aspects. We take into consideration ecological, economic and social aspects to say the least. Education for sustainable development is aimed at training of engineers, who can think in a new way [1, 2]. There are an ability and duty of a professional engineer to analyze ethical, social and ecological aspects of engineering among the most important goals of education for sustainable development [3].

The given article is aimed at the analysis of successful educational practices of sustainability in metallurgical education in CDIO ideology.

2. Literature review
The system of education is defined as a vitally important sphere of human activity, which plays a leading role in transition to sustainability. Education for sustainable development is concentrated on the way of thinking and action changes and is forced towards the formation of a human and the humanity’s as a whole new theory of mind [4]. Such kind of education must be systematic, spread over all the subjects...
and it isn’t considered as an alternative to modern education, but as a new level of its’ development [5]. There are following peculiarities of education for sustainable development: its’ leading nature, focus on future, transintegration, value-based orientation, problematical character, focus on study and solution of problems of life-sustaining activity in the environment, project development, modeling investigation, forecasting of possible ecological, socio-ecological consequences and ways of their optimization [5,6].

Aspects of education for sustainable development, when engineers are trained, include interdisciplinary content of education, involvement of students in the context of education, which is based on the experience and demands of educational process, practice of sustainability, partnership with local and regional communities [5, 6].

The most important contribution to conceptualization of engineering education for sustainable development was made by Barcelona declaration [7]. The given declaration indicated “the new type of an engineer, who is able not only to develop new technologies, but also to understand social aspects of these technologies [8]. Engineering education must take into consideration “contextual information”, the ability to see problems, actions and decisions in a broader context, that includes scientific, technical, economic, social and cultural aspects [9]. Engineers for the future must be ready to work in a more dynamic, transnational and intercultural, global working environment. The list of competencies for sustainability includes operational mindset and difficulty management, leading thinking, critical thinking, the ability to act in a fair and ecological way, collaboration in heterogenic groups, participation, sympathy, projected change, interdisciplinary work, communication and the use of Mass media resources, planning and realization of innovative projects, assessment and uncertainty, tolerance [10].

The most important role is played by interaction between society, industry and universities, when commitment and integration of sustainability processes and academic and managing features are formed. Learning must be considered as a social and interactive process, boundaries and development sectors play the role in creation and changing of the idea [12, 13].

The analysis of changes that are taking place in higher engineering education shows, that the implementation of aspects of sustainability is based on the experimental approach “action learning”. Successful cases of European universities (there are 50% of Scandinavian universities, 96% of British and Swedish universities) are introduced in leading universities of the USA and Canada [14, 15]. Russia is in urgent need of making the education system more sustainability-oriented. Syllabuses of leading universities are improved according to the aims of sustainability [16].

CDIO is the international project that implies reformation of engineering education. It was launched in 2000. The project promotes educational ideology “the idea comes first, then the product” [17, 18]. The abbreviation CDIO itself (Conceive-Design-Implement-Operate) shows the importance of practical approach in technical education. According to Edward Crowley, the CDIO idea means, that students have to study within the framework of professional internship, or as we say “true life context”. It is a means how to make students ready for their future job. This project helps students feel what it is really like to be an engineer [19]. The CDIO initiative is based on 12 fundamental standards, besides, there are some extra standards. Sustainability is an extra CDIO standard [20]. CDIO Syllabus 2.0 includes aspects of ethic and social responsibility and criteria of sustainability for each step of life cycle. Integration of sustainability and ethics in the CDIO context of engineering education is being analyzed within last 10 years as the programme is developing [21]. The necessity to work harder on transverse competencies, to increase the number of subjects in syllabuses, that has to do with sustainability is noted. The educational outcomes are highlighted, which are associated with sustainability. They are as follows: broad education, which is necessary to understand the influence of engineering decisions in global economic, ecological and social context, understanding of professional and ethic responsibility and
ability to design a system, an element or process in order to meet the necessary demands within the framework of restrictions of sustainability aspects.

A huge number of world-ranking universities has already joined the project, 10 of them are from Russia. Siberian federal university joined the initiative in 2014 and it helped to build the system of interaction of CDIO Metallurgy curriculum and metallurgical plants of our region [22]. The given interaction enables us to train the students according to the requirements of the company, it is currently important under conditions of rising competition.

3. Materials and methods
The given paper analyzes the integration of education for sustainable development in training Bachelor`s degree students, who major in Metallurgy at the School of Non-ferrous metals and Material science of Siberian federal university. Organization of teaching process and educational achievements are regulated by competencies, which are presented in the standards of Federal state educational standards of Higher Education, CDIO standards and CDIO Syllabus [20]. The sustainability standard is pretty much focused on. This standard implies education for sustainable development and is aimed at forming the key competence of sustainability. Sustainability aspects are implemented through the analysis of cases given in the discipline “Introduction into Engineering” [23] and cross-cutting interdisciplinary projects [24]. The experience, that students get, is analyzed from 2 points of view: a) formation and development of competencies for sustainability; b) teaching and learning process itself.

The following research methods were used: theoretical - study and literature analysis on the research issue; empiric – synthesis of the experience, analysis of students’ activity results, observation, conversation, expert survey, questionnaire survey, testing; qualitative and quantitative methods of data processing – rescue, analysis and interpretation of research results.

An opinion poll was held in order to analyze the understanding of professional responsibility and impact of engineering on sustainability and self-perception of competencies for integration of sustainability into project. 45 Bachelor`s degree students were interviewed, there are 25 boys and 20 girls among them.

4. Results and discussion
Sustainability aspects are integrated into curriculum of the Engineering Baccalaureate CDIO, Metallurgy major, through the focus on interdisciplinary topics, ecological and social aspects are emphasized. Educational aims of education for sustainable development are aimed at understanding of the general idea of sustainability and its` importance, presentation of fundamentals, that let students take a critical look at sustainability in metallurgical industry and improve presentation skills.

The approach to teaching and learning was structurized in order to get aims of education for sustainable development according to figure 1.

![Figure 1](image_url)

Figure 1. The structure of classes within the framework of sustainability [5].
The given structure is combined with the aspects of Timpson [6]. Interdisciplinary content was observed, the process of active learning was based on practice-oriented learning and student-centered approach. Presentations and discussions promoted formation of students’ own points of view on sustainability. Assessment criteria were discussed with students. Educational process was edited according to the results.

The debate “Sustainability and metallurgy” is chosen to be one of the most successful educational practices. The debate was held within the framework of the discipline “Introduction into engineering”. Points under discussion are as follows: “Sustainability provides the development of metallurgical industry/ Sustainability holds back the development of metallurgical industry”. Discussions showed, that students can do critical thinking on sustainability in Metallurgy. If a student takes part in a debate, he will get key competencies of sustainability: systems thinking, critical thinking, empathy, tolerance, ability to work in a team, the style of public speech. Moreover, debate provides broadening of cultural outlook, development of intellectual abilities, research, organizational and creative qualities, communicative skills and oratorical abilities. Besides, students build up social positioning and skills of life in democratic society, which is very important for education for sustainable development. Students read up for the debate and were supported via electronic learning course of the discipline, they were divided into two parties: “for” and “against”.

Another successful practice is project-based learning, which was first tried in 2014 in the process of teaching Bachelor’s degree students, who major in Metallurgy, in CDIO ideology through cross-cutting interdisciplinary projects. An interdisciplinary project is a means to highlight the principle of wholeness of education and interrelatedness of disciplines under the conditions of interdisciplinary integration student has a deep understanding of the problem or provides the fresh view. Cross-cutting integrated interdisciplinary projects are focused on the solution of real problems of the united company “Rusal”. These projects are characterized by complexity, high level of uncertainty and they are oriented towards the key competencies of sustainability. The aspects of sustainability are well understood in projects, which are focused on recycling of different metallurgical wastes. The projects, that have already been finished, are as follows: “Technological decisions on the increase of efficiency of the use of secondary aluminium”, “Technological decisions on the recovery of electrolyte-containing materials and the secondary use in industry”, “Recycling of sodic- and potassium-containing wastes of foundry”. They show broad coverage of processing of aluminium production. Compulsory condition of project implementation is application of system approach for life cycle analysis of aluminium production (Life Cycle Assessment of Aluminium Production), model “waste management” (energy consumption, materials consumption and wastes disposal) [21]. System approach of Life cycle thinking is a compulsory condition for any well-thought assessment of sustainability, as it prevents from transition of negative effects to other phases of life cycle. The results of projects are defended by students, representatives of factories are present at the event. Students also present their project at the section “Green metallurgy”, which is organized within the framework of annual scientific conference. The work of this conference can be considered as one more example of successful educational practice of sustainability. If students take part in the conference, they are allowed to discuss the given solutions of interdisciplinary problems with the experts, get the skills of presentation and demonstration of their opinion within the framework of sustainability. Success of educational practices is assessed on the basis of pedagogical observation, expert assessment, interview, questionnaire survey, self-concept.

Fourth-year Bachelor’s degree students were interviewed on understanding sustainability, professional responsibility and the impact of engineering on sustainability aspects in order to study the influence of the abovementioned practices on the formation of competencies in the field of sustainability. The most important results of the interview are given on the figure 2.

The analysis of students’ key responses showed, that the majority of students understand the idea of sustainability in a correct way and social consequences of engineering decisions, both positive and negative. The results let us confirm, that such educational practices support the formation of sustainability competencies. Increasing number of successful practices upgrades the quality of the curriculum from the point of view of sustainability.
5. Conclusion

Literature analysis on the implementation of sustainability aspects in the curricula of universities let us point out key approaches and methods, that have already been tested at the School of Non-ferrous metals and Material science of Siberian Federal University. The results showed efficiency of educational practices (such as conduction of debate on sustainability in Metallurgy, organization of cross-cutting integrated interdisciplinary projects, in order to integrate aspects of sustainability into the training of Bachelor’s degree students, who major in Metallurgy, in CDIO ideology.

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