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Project Activities in the Development of Engineering Thinking

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The article discusses the problem of educating a next generation engineer, who is able to think in terms of process. The particularities of engineering thinking being analyzed, the project activities are considered relevant to develop engineering thinking. The discipline «Introduction to Engineering Design» is proposed as an element within the system of project-based education provided at the Siberian Federal University in accordance with CDIO international initiative.

Key words: engineering thinking, project, project-based education, CDIO.

The emergence of new work types causes the need for specialists who are able to think in terms of process, set the goals and then shift them when several alternatives should be considered or when the circumstances have changed. From year to year, the character of changes in engineer's responsibilities becomes more and more distinct: from solving certain professional tasks to solving the problems and managing the projects.

Today, a successful engineer is an engineer with systemic thinking, which allows the specialist to view a problem from different perspectives thus identifying it in general and to determine the ties between the problem elements [1].

Within the process of project management, one not only solves actual problems but also develops individual qualities such as engineering thinking. To detail the term of "engineering thinking", it is necessary to determine the notion of "thinking" which is an umbrella term here.

Thinking is the highest stage of cognition and comprehension of the world through theories, ideas, and human goals. Being based on feelings and perceptions, thinking overcomes their boundaries and gets into the sphere of supersensible and intrinsic world ties, in other words, in the sphere of world laws. We substantiate the claim of the scientists that thinking reflects invisible ties due to practical activities, which are tools of thinking. Thinking is connected with the brain work but the ability of the brain to operate abstract ideas is developed through gaining practical skills, studying language, logics, and culture. Thinking is embodied in different forms of supersensible and practical activities which summarize and keep the cognitive experience of people. Being the object of different scientific research, thinking is studied by almost all sciences. Thinking is the source and the tool of intrinsic human existence.

Many philosophers determined thinking as an essential characteristic of a human being. Thus, Descartes affirmed: "I think, therefore, I exist". As a method of cognition Descartes suggested the method of doubt that means that we should doubt everything whether it seems to be natural or supernatural. However, Descartes insisted that the method of doubt is applicable to find out the scientific truth while to understand the matter of thing or events in every day life, it is enough to use true or probable knowledge.

Spinoza determines thinking as a way the thinking substance acts and consequently interprets the notion of "thinking" as follows: to define thinking, it is necessary to explore the way the thinking substance acts and then compare and contrast it to the way unthinking substance does (exists and moves) [2].

Practical experience obtained from human activities contributes to emergence of different types of thinking.

For instance, logical thinking is a historical type of thinking based on the laws of identity and the consistency of arguments [3].

Technical thinking is stipulated by technical knowledge, speculation on activities results and endeavor to simplify the process of production.

Strategic thinking is directed to the goal of thinking, which is based on the forecast of the future. "I rush to the place where the puck will be but not to the place where it was several instants ago" – said Wayne Gretzky, a famous hockey player, and this was a motto of Steve Jobs as well. According to Kenichi Ohmae, strategic thinking is creative and active, it is an ability to produce dynamic ideas and goals. Strategic thinking is systemic observation plus the ability to detail the goal plus opportunity to get trustworthy and sufficient information.

Creative thinking is an ability to identify the problems and solve them using unconventional methods, therefore, one obtains something new, original and unique in terms of history and society [4].

As for "engineering thinking", we agree with the opinion of scientists, who define this phenomenon as a special type of thinking developed and revealed in solving engineering tasks. Engineering thinking allows finding quick, accurate, and original decisions for the tasks which are caused by needs for technical knowledge, methods, and skills and aimed at the design of new technical facilities and the development of new technologies. Engineering thinking is structured as follows:

- technical thinking, that is an ability to analyze content, structure, configuration and operation principles of technical objects under varied conditions;
- constructive thinking, that is designing the model of task solution, which is based on ability to combine theoretical and practical knowledge; exploratory thinking, that is a set of abilities, such as to identify a new constituent within the task, to compare the task with those of distinguished types, to give reasons for one's actions, interpret results, and make conclusions;
- economic thinking, that is reflection on quality of process and activities results in terms of market demands, so, an engineer is supposed not only to possess profound knowledge of the specialty but also to be able to present his or her potential and implement the activities results [5].

The problem of engineering thinking development stipulates the necessity to explore the particularities of engineering thinking.

The phenomenon of "engineering thinking" is the object of exploration in many sciences: philosophy, psychology, pedagogy, humanities and technical sciences.

The solutions of creative engineering tasks have been analyzed, it is possible to claim that the foundation of engineering thinking rests on creative imagination and fantasy, "multiscreen" systemic reflection on knowledge, technical creativity, which allows operating the process of ideas generation.

What should engineering thinking be like? Which types of thinking it should it comprise? Engineering thinking should be based on highly-developed imagination and include various types of thinking: logical, creative, theoretical, technical, special, as well as practical reasoning and eye-mindedness. The most important ones are creative thinking, technical thinking and eye-mindedness.

Previous researches conducted by psychologists and educationalists (E. de Bono, S.M. Vasileysky, N.P. Linkova, V.A. Molyako, N.M. Peysakhov, K.K. Platonov, Ya.A. Ponomaryov, A.F. Esaulov, G.S.

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Altshuler, M.M. Zinovkina) showed that the most important characteristic of creative engineering thinking is its consistency.

Engineering thinking is systemic technical thinking which allows viewing the problem from different perspectives and analyzing the ties between its elements. Engineering thinking makes it possible to observe the system, the supersystem and the sub-system, the connections between and inside of them, moreover, to see past, present and future of all three systems. In other words, engineering thinking should be "multiscreen": the more "screens" a student observes, the more original and simpler solution will be suggested. The characteristic feature of "multiscreen" observation is the ability to identify and overcome technical contradictions as well as physical contradictions hidden inside, and intentionally generate ideas, which are paradoxical and heretical in terms of formal logics.

The following abilities are considered characteristic for engineering thinking: the ability to identify technical contradiction and initially direct one's mind to the ideal solution, when the basic function of the object is performed, so to say, on its own, without any expenses on energy or resources; the ability to specify such a direction of the thought that is the most promising in terms of technical system development; the ability to cope with psychological factors and deliberately intensify creative imagination [1].

Another characteristic feature of engineering thinking is the intention to submit the idea, which has been intentionally generated, to engineering study, i.e. to implement the idea into a real project on technologies development, facilities design etc.

As a result, the global task of a technical institute is to develop systemic creative engineering thinking in order to use the bulk of scientific and professional knowledge on different technological processes in the most efficient way.

One of the most promising ways to solve this task is to introduce project-based learning aimed at internal and professional development of personality through intensive involvement into the planned activities.

Firstly, project activity is a link between the theory and practice in education. Secondly, this type of activity allows operating the whole technological cycle of production.

Project is an original process comprising a complex of activities with the effective and termination dates being coordinated and operated to reach the goal which meets definite requirements such as terms, costs and resource limits.

Any project possesses a set of characteristics. These characteristic features have been identified, one can define this or that type of activity as a project one:

- temporariness: any project is limited in time, which does not refer to its results though; so, if there are no effective and termination dates, the activity is considered an operation and may last any time;
- original products, services, results: the results of any project are original outcomes (results, achievements, products); otherwise, the enterprise becomes serial production;
- consistent development: any project develops in time and passes through definite stages planned in advance, while the design of project specification is restricted to its initial content.

The technology of project education is a complex of methods, processes, and educational materials, which are used to organize project education, as well as a set of activities, operations, and methods to get the project results which meet definite quality, content, and expenses requirements (term of implementation, facilities rent etc.). The requirements, in their turn, are stipulated by the stages of science, technology and society development in general.

Project activities are considered important in terms of pedagogy if their aims are:

- to get profound technical knowledge and practical skills in definite specialty;
- to develop the skills of designing and operating new products and systems;
- to understand the importance and strategic significance of scientific and technological development of the society;
- to acquire the knowledge on the chosen profile/specialty.

Students' interest in project activities is stipulated by project feasibility and its importance for particular individuals: the project matter should be connected with solving a realistic task which results in clear and tangible outcomes, whatever the degree of complexity and level of education are.

Development of engineering thinking is stimulated by mastering technologies which are in demand and which are successfully applied in modern companies. Another promotive factor is the possibility to explore project technologies at different stages of the whole cycle: reflection and identification of the task, possible solutions overview and analysis, suggestion of original solution, implementation, testing, preparation of report documentation, defense of results, and, if possible, application of the results, with raising the requirements from project to project.

High qualification of project managers (teachers and academic staff), who are experienced in real projects, as well as mutual work with companies, which, if possible, participate in projects, and employment assistance for graduates are the factors to motivate all participants of project activities. The motivation is caused by mutual interests.

Teamwork as well as short-term practical research or application tasks in the process of education develop the project skills which can be applied in hands-on production projects.

The results of the project are represented in the project design passports, analytical reports and public defense of projects to which the third party interested is invited.

Every student can participate in a project due to different degrees of complexity for the student to choose:

- Basic level projects. During the first and second years of bachelor's program projects are supposed to provide students with basic knowledge and to develop basic cultural competences such as project work technologies, project activities management and self-management, conventional ways of performing results, project results documentation in accordance with applicable laws and regulations. The most important requirement to projects is for the results to be applicable to solving engineering problems or tasks.
- Advanced level project. Here there are SSRPs (Student Scientific Research Projects), in which the degree of complexity is increased, scientific research is considered to be an essential part, scientific novelty is an important requirement and the solution is to be original.
- Practical training and work experience internship for most of the specialties may also be project-based. They may become either a project or a part of the project, for example, a stage of collecting data, studying technologies or exploration of work environment.
- Graduate qualification work. The result of the project is the solution of an engineering problem which should undergo external evaluation (reviewing).

Project-based learning has been successfully introduced in "Metallurgy" education program provided at Siberian Federal University in accordance with CDIO international initiative [6]. From the first year of studies students participate in projects of different complexity degree.

To give an example of project-based activity, let us turn to the project within

the discipline «Introduction to Engineering Design». The project includes different stages which can be passed through either in the classroom or as self-study work. The term of the project is one semester and to complete the project successfully, one should get basic knowledge prescribed by the course syllabus.

The working title of the project is "Designing a Mechanical Element". Students are suggested to design a mechanical element from several (from two to four) assembly parts with the help of the program of three-dimension design.

The project includes two stages: the first one is texting and calculating, the second one is graphic. At the first stage the student gets the task for design (or suggests the task and discusses it with the teacher) and then describes the project stages in the terms of references. After that, the student calculates geometric and other technical parameters of the element and in the result makes a traveler for manufacturing procedures. At the second stage, the student using the obtained parameters designs a three-dimension model of the element and provides virtual assemblage. The result of this stage is an animated render-element. At the last stage the student makes a technical drawing and specifies it in accordance with the united system of design documentation. All the documents including the terms of references, traveler for manufacturing procedures, technical drawing, specification, calculations and the model, are discussed during public defense.

While working on a project the student obtains the skills of using basic and specialized computer programs, gets the knowledge prescribed by «Introduction to Engineering Design» syllabus. It is possible to increase the complexity degree of the project, which depends only on the student's wish and ability to design more complicated, technically-based and diversified stuff.

The student in the process of project work passes all stages including planning, analyzing, and synthesizing, etc. Project activities can be provided not only by individuals but also by groups, which makes it possible to develop communicative skills. Identifying tasks and solving problems increase motivation to project activities and stipulate goal setting, concreteness, initiative, originality in solving cognitive tasks, ingenuity of approaches, intensive brainwork, and exploration experience.

The majority of experts admit that the development of engineering thinking is caused by problems in operating manufacturing and technical processes, i.e. solving engineering tasks through different options.

Thus, passing through all project stages the student not only obtains practical skills but also develops engineering thinking.

CDIO: FROM HIGH SCHOOL STUDENT TO A SPECIALIST

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