Enhancing Engineering Education through Design-Driven Curriculum

Yanqiong Wu, Zhinan Zhang*, Junliang Zhang
School of Mechanical Engineering, Shanghai Jiao Tong University,
Shanghai 200240

Abstract

In China, there is a strong demand for reforming higher engineering education both from industry and tertiary education perspective. School of Mechanical Engineering (ME), Shanghai Jiao Tong University (SJTU) is ongoing developing design-driven curricula to enhance engineering education through project-based teaching, learning and assessment. More than 3000 students have completed over 600 projects in various courses since 2014. Of these projects, solving open-end problem accounts for about 25%, developing simple products about 25%, focusing on creative mechanism about 25%, and industry sponsored projects about 25%. Evaluation from industry at project showcase and students' self-assessment showed the positive effects of the undergoing reform of undergraduate courses conducted by ME, SJTU on the enhancement of engineering education.

Keywords: Engineering education, engineering design, project-based learning, design-driven learning, mechanical engineering

1. Introduction

Traditionally, mechanical engineering students took some courses separately to acquire professional knowledge which are relatively independent to each other. Take the design or manufacturing courses, engineering design courses mainly included engineering graphics, mechanical principles, and machinery design. On the other hand, manufacturing courses included engineering materials, machinery manufacturing technologies, manufacturing equipment, the principles and tools of cutting, etc. The design or manufacturing knowledge mastered by different students are thus vary a lot. As a consequence, they could not develop a global concept of mechanical products and systems, which further hinder them to develop the global optimization ability. However, the whole life cycle including the design stage and manufacturing stage for modern products is highly integrated. Therefore, it requires the reform and re-integration of the knowledge system and training mode of mechanical engineering courses.

According to the feedback from the employers of engineering graduates in China, the main problems of those graduates after being employed are as follows: 1) long training cycle, they usually lack the understanding of modern enterprise culture and the work process; 2) poor experience of team work, as a consequence of an unsatisfactory communication and coordination ability; 3) Their capabilities of solving practical problems are poor and they are short of creativity abilities; 4) They tend to seek job blindly and are not confident. What's more, they have few ideas about the work they will encounter in the future.

Through analyzing the problems mentioned above, the higher engineering education of China is facing urgent challenges: 1) to cultivate students with the comprehensive and innovative thinking, the systematic global concept development ability; 2) to further enhance the students' engineering practice and creativity ability; 3)to further strengthen the integration of engineering education and industry needs (i.e. Industry-University Collaboration);4) to further elevate the engineering capacity of the relevant education team, in particular, the involved young teachers; 5) to adapt to the trend of economic globalization and cultivate more engineering talents with international competitiveness.

In fact, developing countries like China but also many other developed ones (e.g. the US) are all facing the challenge of re-thinking of engineering education [1-3]. The CIDO stand is the reforming of engineering education with focusing on the evolution of requires of society and engineering [1]. Design thinking approach is also another learning and teaching approach with focusing on team-based real world problem-solving [4]. In all these examples of engineering education, Project-Based Learning was adopted. As summarized in [5] PBL cultivates students with several skill, e.g. team work skill, problem solving ability communications skill, self-assessment, etc. Literature examination and courses benchmarking also show that project-based learning (PBL) and teaching are widely applied in engineering education [6-9].

School of Mechanical Engineering (ME), Shanghai Jiao Tong University (SJTU) is ongoing developing design-driven curriculum to enhance engineering education through project-based teaching, learning and assessment. More than 3000 students have completed more than 600 projects in these courses. This paper reports on the experience of the authors on the design, organizing, management and teaching of design-driven courses at School of Mechanical Engineering, Shanghai Jiao Tong University in China.

2. Courses Design

2.1. Objective of Courses

The overall objective of reforming engineering education at ME, SJTU is to cultivate qualified innovators with focusing on the ever evolution of technical, social and natural environment, as shown in Fig. 1.

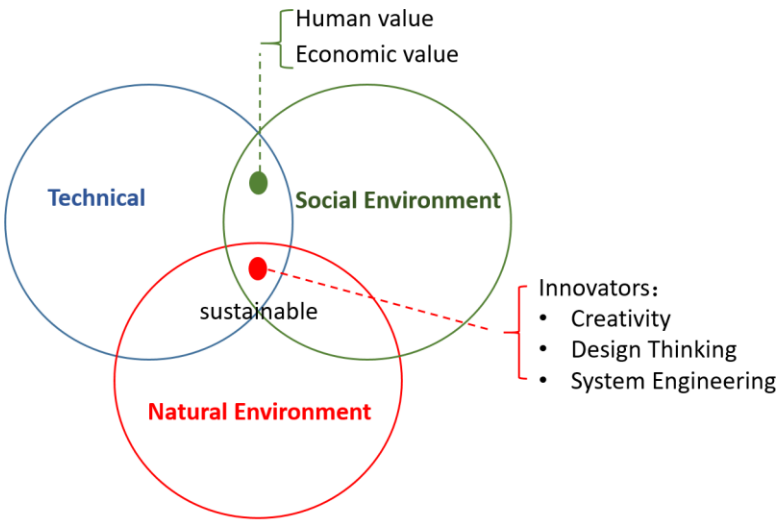

Fig. 1. Objective of enhancing engineering education at ME, SJTU

However, in the traditional curriculum-oriented training model, teaching plan is often treated as core and alterable. Teachers usually focus on the good arrangement of every class and the evaluation of class effect. As shown in Fig. 2, the goal-oriented training model (project-based learning and teaching mode), starts from the social needs with the purpose of making the graduates achieve certain requirements on abilities. The teaching plan clearly reflects the support of the graduation requirements. The meaning of "good" arrangement of classes is the actors effective completion of the corresponding task with given resources, which can led to achieve the goal of training qualified innovators.

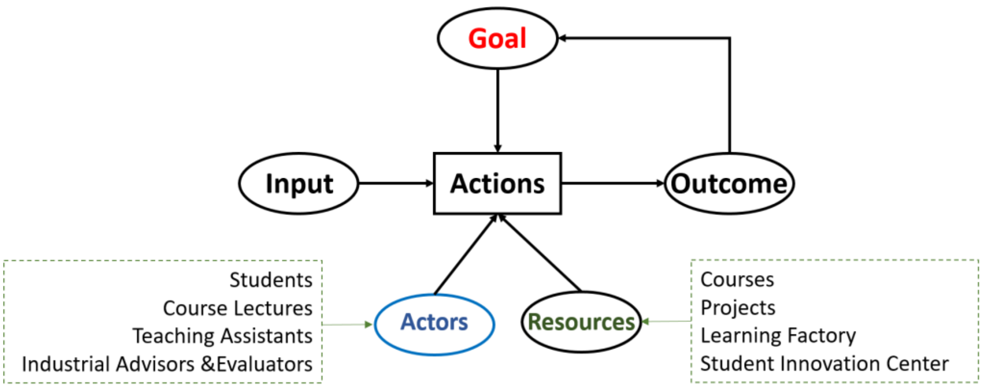

Fig. 2. New training model

2.2. The Overall Structure of the Design-driven Courses

The design-driven courses in ME SJTU consists of four step-by-step courses for the education of different levels of undergraduates, i.e. Introduction to Engineering for freshman, Design and Manufacturing I for sophomore, Design and Manufacturing II for junior and Design and Manufacturing III for senior. Fig.3 presents the overall structure of the courses.

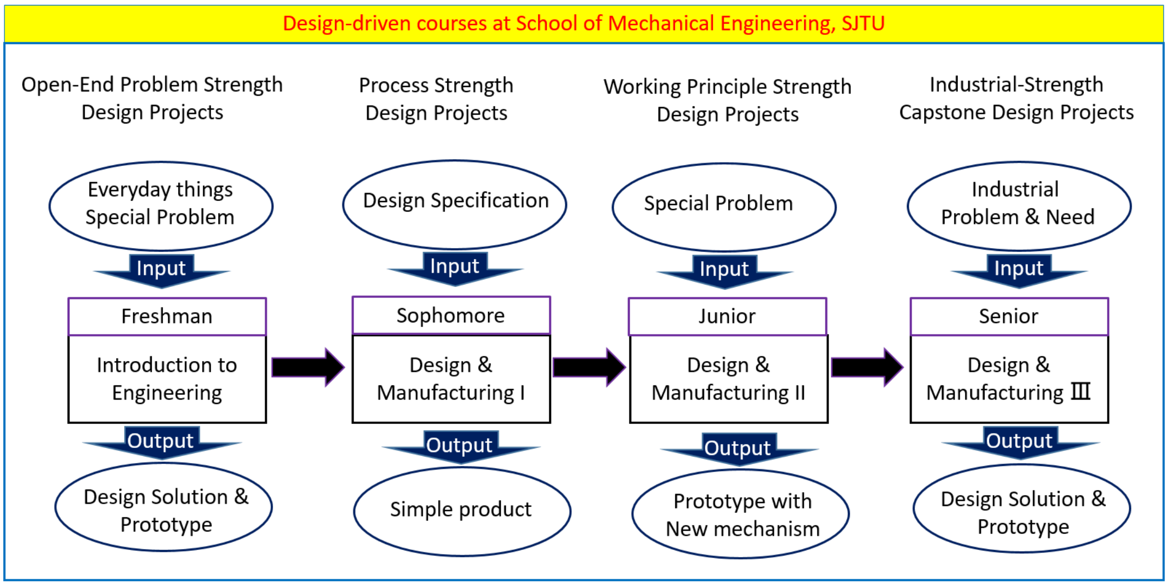

Fig.3.Overall structure and function of design-driven courses

Details description of the objective and key topics of the core design-driven courses are:

- **Introduction to Engineering**

Course objective: to focus on engineering cognition and cultivate the engineering thinking ability

Key topics:

– The responsibilities and challenges of engineers

– The ways and standards of scientific and technological exchanges

– The concepts and process of engineering design

– The fundamental concepts and process of manufacturing

- **Design and Manufacturing** I

Course objective: to focus on the design and development of simple products

Key topics:

– Methods and tools for engineering design

– Design representation and engineering drawings

– Fundamental knowledge of processing and materials

– Understanding and drawing of production diagram

– 3D modelling and related software

- **Design and Manufacturing** II

Course objective: to focus on the design and development of mechanism systems

Key topics:

– Characteristics and design methods of common mechanical structures

– Dynamic analysis of mechanical systems

– Characteristics and design methods of common components

– Requirements, methods and steps of mechanical design

– Production, assembly and debugging of mechanical systems

- **Design and Manufacturing** III

Course objective: to focus on the design and development of composite mechanical and electrical systems.

Key topics:

– The process and organization of the product design and development
– Coordination of multi-disciplinary tasks
– The protection of patents and intellectual property
– Economics issues in product design and development
– Industrial design process management

2.3. Assessment

In the four categories of design driven courses, the following assessments of leaning outcomes are developed.

- *In course assessment*. Blend assessment approach is adopted in course, which consists of process review from teachers, teaching assistant, peer reviews on several millstones (e.g., clarifying the requirements, conceptual design, prototype and final showcase) among teams.
- *Project showcase assessment*. In the showcase, more than 150 selected projects are exhibited in the stadium of SJTU. The learning outcomes of each project are assessed and validated by key stakeholders, i.e., experts from industry, teachers from courses and other university, and peers from showcase projects and the online reviewers from all the courses. Three level of Outstanding Project Award and the Best Creative Award and Best Student Favorite Award will be selected.
- *Reflections from students.* Students evaluate their personal gains after taking part in the design driven course.

3. Facilities for Design-Driven Courses

The information asymmetry between managers and students leads to the problem that a lot of teaching resources and facilities are not used in a timely manner. In order to integrate teaching resources so that the service can be offered to teachers and students to the greatest extent, the internet based resource information management platform (http://me.sjtu.edu.cn:8095), the learning factory and student innovation center are developed to help users (students and teachers) to find the right resource in supporting their course or projects, see Fig. 4.

(a)Learning factory (b) Student innovation center

Fig. 4. Learning factory and student innovation center

Only for the learning factory, since the official start in October 2012, the factory received 192 students in 2012, 1094 people in 2013; about 1400 visitors in 2014. With the operation of the appointment system for the information management service platform "learning factory" and the promotion of project learning, the "learning factory" is expected to serve more and more visitors in the upcoming years.

4. Implementation

4.1. Course Development

The core objective of ***Introduction to Engineering Course*** is to cultivate students' engineering cognitive abilities and design abilities. It's also aimed at improving their innovation abilities, inspiring them to experience the creative way of thinking and stimulating their creativity. This course will help the first year engineering students have a general knowledge of engineering, get to know the relationship between science and engineering, understand the basic concepts and general process of the preparation, manufacturing or construction of some engineering project. They will constantly try to find solutions to open-ended questions through Project-based learning approach. Fig. 5 presents different level of targets of the Introduction to Engineering course.

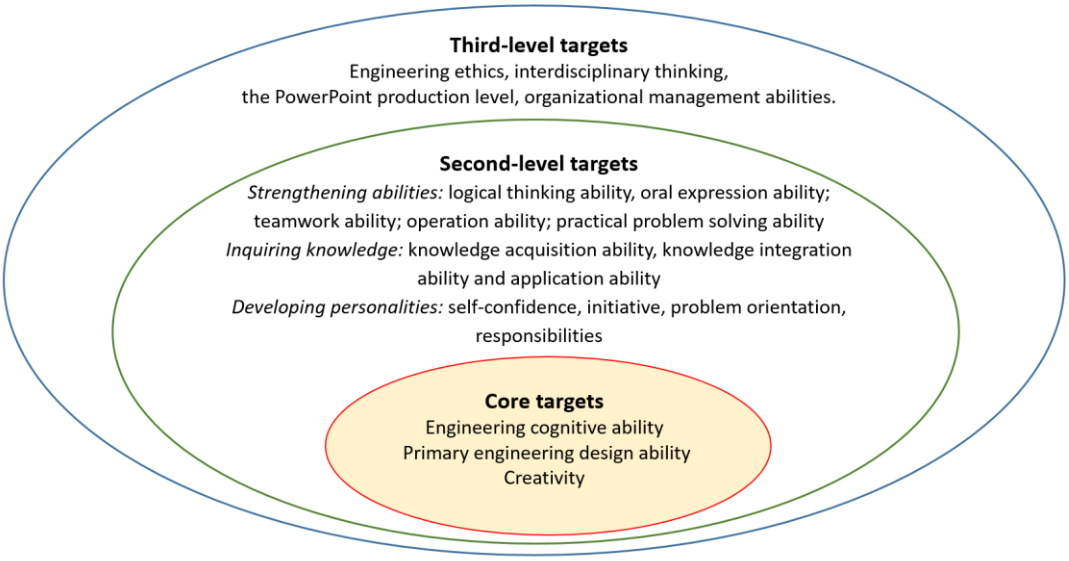

Fig.5. Three level objectives of Introduction to Engineering

Figure 6 outlines the organization of design drive course. As shown in Fig. 6, students are working together through project-based learning approach for problem solving with the support of teacher, teaching assistant and other resources. Their outcome will be assessed by multi-stakeholders.

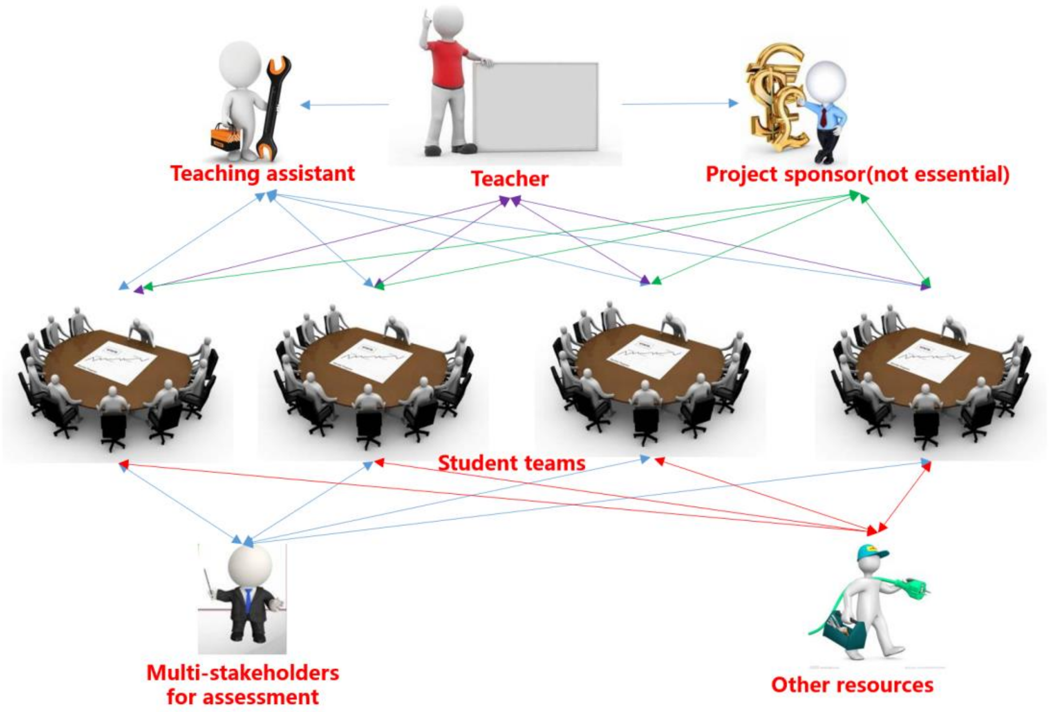

Fig. 6. Organization of course

4.2. Implementation of Design-driven Course

Figure 7 presents process of student centered learning and abilities cultivating in one of design-driven course. As shown in Fig. 7, four types of learning approaches are developed, i.e. learning by observing, learning by doing, learning by sharing and learning by discussing.

Fig. 7. Team and project-based learning approach

As shown in Fig. 8, four kinds of abilities are promoted in the design driven courses, i.e., presentation ability, prototype and showcase ability, communication skills and peer review assessment.

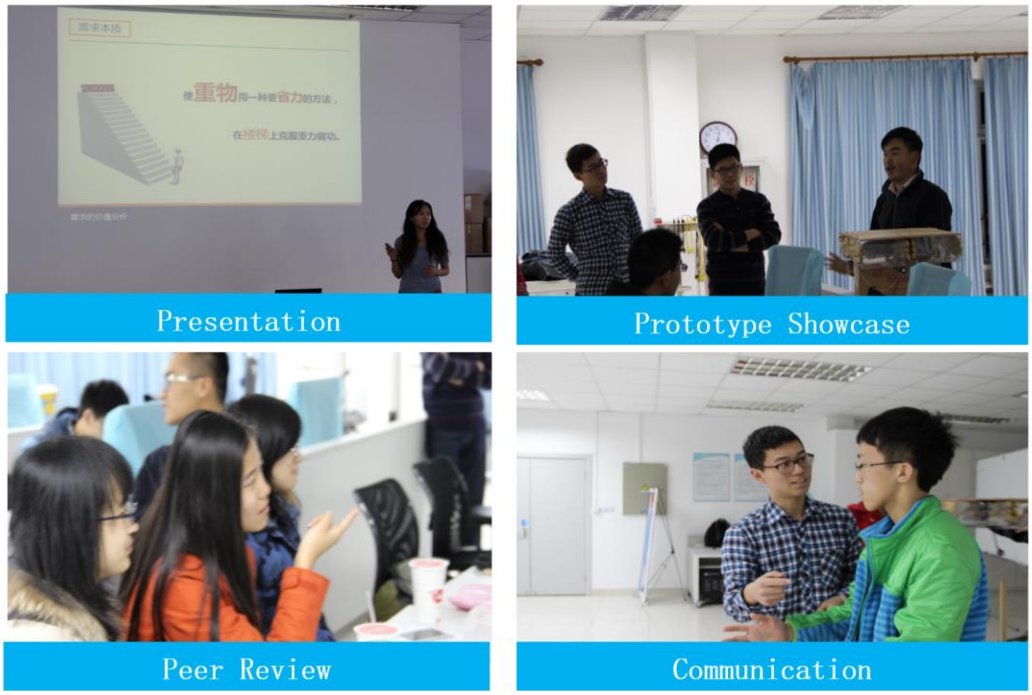

Fig.8. Cultivate abilities based on student centered approach

4.3. Outcome and assessment

- Outcome

The design of a planet lamp (the team has filed a national patent application) is presented to showcase of the outcome of an innovative product. In operation, the motor drives the output shaft 1 to rotate the helical gear 2 at an equal angular speed, thereby driving the gear ring 4 to perform unequal angular rotation. The friction ring 8 is fixedly connected to the gear ring 4 and the friction convex ring 8 Friction between the friction wheel 5 friction transmissions, due to adjacent friction convex ring rotation angular velocity is different, it can drive the friction wheel for rotation and revolution. The friction wheel 5 revolves around the center of the lamp, and the sub-lamp 6 connected with the friction wheel 5 makes the rotation of the friction wheel 5 as the center, and the rotation and revolution of the sub-lamp 6 are realized. According to the assessment of experts, this product got the Third Prize of Outstanding Project.

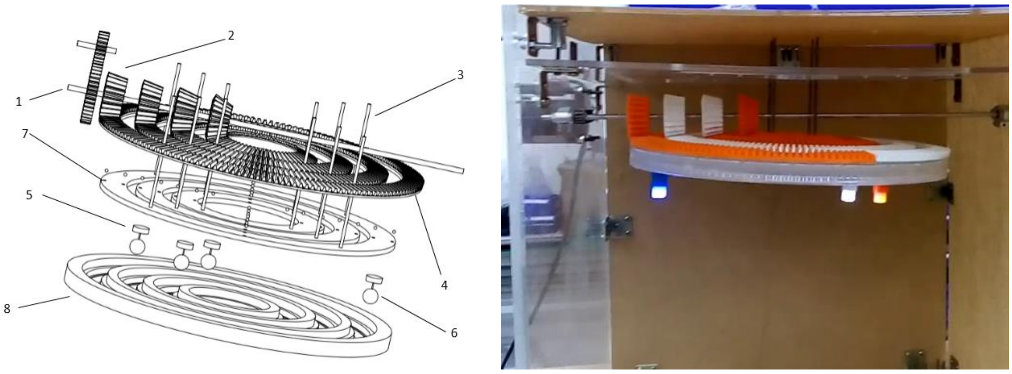

Fig. 9. Outcome of teamwork

- Reflections

Senior Student A, "These subjects are quite different from traditional subjects, which mainly use test and homework to judge a student and give the final grades. Most of us are supposed to be a good researcher or engineer, so it is essential for us to join and organize a project, to train the skill that used in real project. Some of us who may not be good at exam can find their talent in taking projects, and it can arise our confidence in research. What's more, we can realize that in a project, which role are we playing, a leader, a tech superior or somebody who always has brilliant idea. We find what we are good at, both what we are short of."

Senior Student B "As a mechanical engineering student, I think the courses such as Introduction to Engineering and Design and Manufacturing are the most challenging but also the most important courses for an engineering student. In these courses I learnt how to sufficiently analyze engineering specifications, apply basic engineering knowledge and mathematical analysis into practice, come up with appropriate solutions and solve unexpected problems during the process of design or manufacturing. In addition, I also learnt a lot of communication and group work skills which are very useful for engineers. Actually, in each project, we may meet various problems that are hard to be solved, but team work can help to enhance the speed of resolution. Finally, these courses helped me improving my self-confidence after finishing each project and achieving each objective."

After taking one of or all of the design-driven courses, the awareness of students to participate in the technology innovation activities was raised year by year. In recent years, students have won prizes for many times in the national and international competitions of science and technology, such as the National College Student Competition for Energy Conservation and Emission Reduction.

5. Conclusion and Future Works

This paper presents the latest experience of engineering education reforming in China, i.e. designing a series of courses with focusing on project-based teaching, learning and assessment. Four years practice at

School of Mechanical Engineering, Shanghai Jiao Tong University show that design-driven course has positive influence on the cultivating of engineering students with system thinking and creative ability, problem solving-ability, teamwork and communication skill. Assessment from industry showed that the reform of engineering education can bridge the previously existed gap between industry and university.
The ongoing work focuses on four directions. Firstly, more relevant teaching methods and facilities will be employed and developed to improve classroom teaching. Secondly, to keep on negotiating with industry to find more proper projects and external lectures. Thirdly, to incorporate emerging technologies into design-driven courses. Fourth, to develop more scientific assessment approach for student and outcome assessment.

Acknowledgements

The authors would like to acknowledge the Center for Teaching and Learning Development Project at Shanghai Jiao Tong University（Grant No. CTLD16B1006）. They would also like to thank Mrs. Xin Wang, Mr. Nian Yin, Mr. Li Wang, and Mr. Rong Jiang and for their feedback and discussion on the paper.

References

[1] Edward F.C., Sören Östlund J.M., Brodeur D.R., Edström K. Re-thinking Engineering Education: the CDIO Approach. Springer International Publishing Switzerland 2007, 2014.
[2] Tomiyama T., Gu P., Jin Y., Lutters D., Kind Ch., Kimura F.. Design methodologies: Industrial and educational applications. CIRP Annals - Manufacturing Technology 58 (2009) 543–565
[3] McAloone T.C. A competence-based approach to sustainable innovation teaching- experiences within a new engineering program. ASME Trans. Journal of Mechanical Design, 2007, 129:769-778.
[4] Brown T. Design thinking. Harvard Business Review, 2008, June 1-9.
[5] Hosseinzadeh N, Hesamzadeh R.M. Application of project-based learning to the teaching of electrical power systems engineering. IEEE Trans. on Education, 2012, 55(4): 495-501.
[6] Dym C.L., Agogino A.M., Frey D.D., Leifer L.J. Engineering design thinking, teaching, and learning. Journal of Engineering Education, 2005, 103-120.
[7] Chang V. MNC-sponsored multidisciplinary industrial-strength capstone design projects in China. International Journal for Innovation Education and Research, 2014, 2-10:54-65.
[8] Paretti M., Layton R., Laguetter S., and Speegle G. Managing and mentoring capstone design teams: Considerations and practices for faculty, International Journal of Engineering Education, 2011, 27(6): 1–14.
[9] Wodehouse A.J., Grierson H.J., Breslin C., Eris O., Ion W., Leifer L.J., Mabogunje A. A framework for design engineering education in a global context. Artificial Intelligence for Engineering Design, Analysis and Manufacturing (2010), 24, 367–378.