Redesign of capstone design for improving engineering students with multidimensional capabilities

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Abstract: Capstone design, as the last and vital teaching procedure for students, provide opportunities for them to comprehensively apply knowledge and skills they have learned and therefore is widely conducted by colleges and universities to enhance students' integrative competence. A well-designed capstone design course plays a vital role in meeting both the criteria of ABET and the New Engineering Education in China. This paper introduces the former capstone design course and presents the function, structure and a three years operation of the redesigned capstone design course at Shanghai Jiao Tong University.

Keywords: capstone design, engineering design, engineering education; project-based learning

1. Introduction

The higher engineering education in China is reforming (e.g., New Engineering Education) for producing high-quality engineering talents with multidimensional capabilities, i.e., both professional skills and technical skills. The Accreditation Board for Engineering and Technology (ABET) in the USA also emphasizes the importance of senior students to attend at least one design-oriented (project-based) course [1]. It is widely acknowledged that capstone design plays an essential role in the design curriculum for engineering students to construct their ability to meet the requirements of industry and sharpen their integrated design skills, and meanwhile, to meet the ABET criteria.

However, the most common form of capstone design course in China is research-oriented. It is based on students' individual projects mainly supervised and sponsored by professors, in which students are expected to acquire in-depth knowledge. However, this kind of capstone design has some significant drawbacks, such as lack of teamwork, design communication, problem identification, and system engineering thinking, etc., which are

ranked as top of core competencies by industry. It exists a gap between industry need and engineering education. At the same time, many leading universities have carried out capstone design courses, e.g., Georgia Institute of Technology [2], The Pennsylvania State University [3], etc. In their capstone design course, students in one class are divided into several groups. The size of each group is usually up to 5 students and 2-4 students in general. In this kind of capstone design courses, which are project-based, design-driven and student-centered, students have access to gain a number of abilities, e.g. teamwork, design communication, project management, etc. However, this kind of capstone design contributes less to help students to gain deep knowledge both in how to do research and write a thesis.

To overcome the aforementioned drawbacks of different capstone design patterns, the reform of the capstone design course was conducted at the School of Mechanical Engineering, Shanghai Jiao Tong University. This reform focuses on cultivating engineering students by paying attention to both individual and team abilities. This paper presents the methodology of the redesign of capstone design course in Shanghai Jiao Tong University, and the results of a three years' practice of the capstone design course are also analyzed.

2. Related Works

Prior research reported capstone design and courses' positive impact on developing engineering students' both professional and comprehensive quality and ability, including more competitive employability skills [4], engineering project management skills, ability to work in a multidisciplinary team [5, 6], higher-stage cognitive development [6, 7], and the like. For example, Liu's qualitative research towards industry and community organization professional staff identified lots of expected employable skills should be trained through capstone design to help students transform from school to workplace smoothly, such as interpersonal skill, project management skills, feedback and presentation skills. What's more, professional ethics, global awareness, and civic responsibility were also emphasized [4]. Walker et al. introduced Studio Culture into engineering capstone design courses and the pilot case reported a significant boost in students' cognitive development [8]. To be specific, interactive communication and learning between teachers and students in the classrooms under Studio Culture deepened engineering students' self-

realization and raised their confidence to communicate and solve problems in their professional fields.

With continuous exploration and practice, the trend of capstone design and relevant course have changed over time, such as from single oral presentation to a combination of oral and written presentation, increased number of students in each capstone cycle, more diversified source of the capstone project and students' longer devotion to project [9]. For instance, the Penn State Univ. Department of Materials Science and Engineering launched a new capstone design curriculum with a two-course sequence in 2012, which contains a writing and speaking intensive gateway course and a senior year capstone experience. During the senior year, students can select to execute an individual research thesis or an industry-sponsored team project [10]. In accordance with the new trend, scholars put forward a great many advanced experiences and recommendations for future reform and implementation of capstone design. James and Paretti established a nine-function model of capstone design teaching [11], by summing up the experience of 42 capstone design instructors, which was composed by challenge, secure, supervise, improve employable capabilities, accept and confirm, advice, and shape relationship and provide exposure and role models. Goldberg suggested a new model where instructors incorporate more active and student-centered learning methods into capstone design courses, including methods like collaborative, cooperative, problem-based, and project-based learning [12].

Based on the recollections of experiences in senior design courses by engineers already employed, Abdullah suggested that schedule time, instructors' guidance role, content, and form in senior design courses should be improved. For example, the project should be divided into distinct phases to ensure the project can be completed on time [13]. Furthermore, Walker et al. proved the feasibility of bringing Studio Culture and the cognitive apprenticeship method into traditional senior design courses, which completed the transition from curriculum-center to activity-center [8]. In this kind of collaborative and interactive environment, engineering students can consolidate professional knowledge and skills by applying and practicing what they have learned in the actual engineering design process and strengthen self-reflection about projects by considering how to make further adjustments in the next period of projects. In response, Liu also indicated that collaborative, experiential, project-based and service-based learning forms in capstone

design and its courses could contribute to improving engineering students' employability [4]. In addition, numerous studies also explored mutually beneficial strategies for both industrial sponsors and students in school-enterprise cooperation capstone design [14, 15, 16]. For example, Pezeshki and Beyerlein held that consideration should be given to project motivation, professional experience, interactivity, and project design process when building partnership with industrial sponsors [15].

As mentioned above, although there are a number of feasible reform measures, capstone design needs to be redesigned to train students equipped with the breadth of ability, the depth of knowledge, and cross-level thinking ability.

3. The framework of redesign of the capstone design course

Figure 1 shows the capstone design course model of the School of Mechanical Engineering, Shanghai Jiao Tong University. Only the senior students in their last semester are allowed to register for the course. Currently, a team-taught course is offered with 1 credit in the spring semester and 3 credits project-based learning started in the middle of November in the autumn semester. The projects are carefully chosen from all the project proposals proposed by industry sponsors. Only the projects selected both by students and academic supervisors can be finally determined as capstone design projects. The lectures on engineering design and creative design methods are given by instructors of a group of project, and the lecturers on intellectual property and the capstone design at Pennsylvania State University are given by a professor from law school and Pennsylvania State University, respectively. The head of the capstone design course together with the teaching affair office and instructors continuously improve the syllabus. The 2020 spring syllabus consists of a detailed description of how to conduct the outcome-based design of the course.

This reform of capstone design course is featured by the following characteristics: a) Completing practical design task with engineering background through teamwork to realize the transformation of teaching method from closed to open, from knowledge to ability; b) Introducing enterprise into capstone design and training students to view and solve problems from multiple perspectives through solving practical engineering problems sponsored by industry; c) Establishing a multi-channel industry-university-research cooperation platform and forming a new model of joint efforts to foster engineering talents

by inviting enterprise engineers or experts as capstone design project mentors, holding capstone design achievement exhibitions.

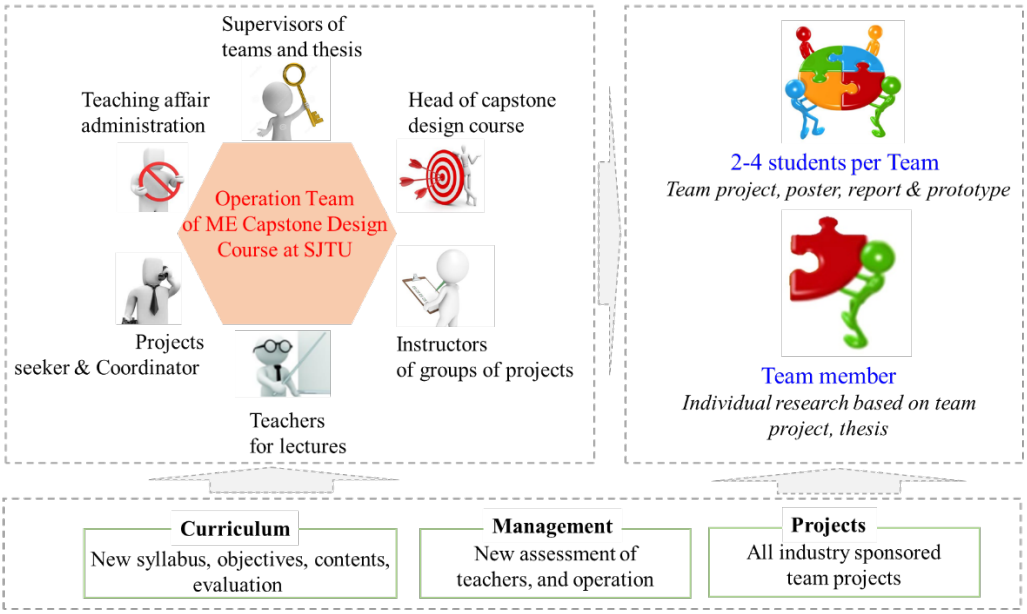

Fig. 1 Framework of the redesign of the capstone design course

3.1 Setting of capstone design faculties

The faculties in the capstone design course consist of project managers, lecture teachers, project and thesis supervisors and project mentors from industry sponsors. As showed in Fig. 2, these four kinds of faculties act as different roles in the capstone design process, providing students with various help.

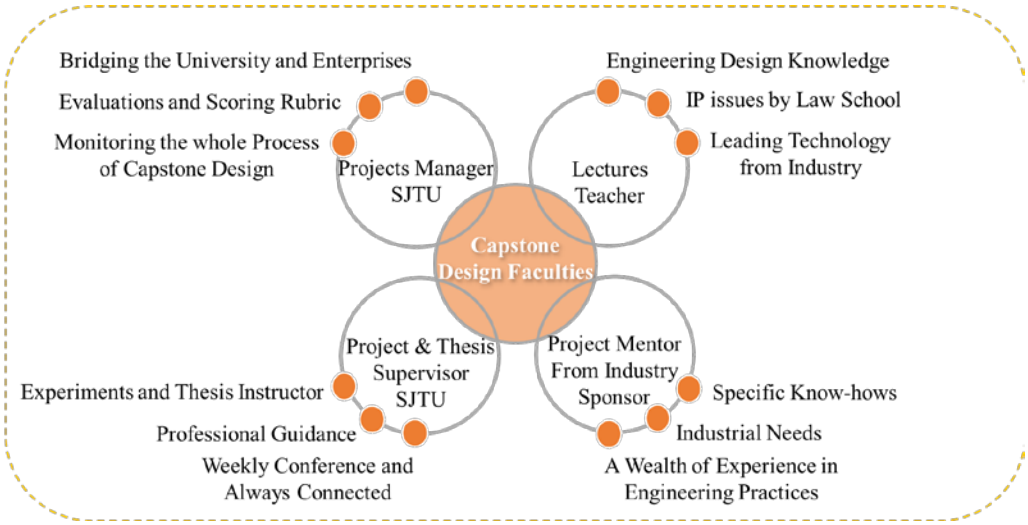

Fig.2 Setting of capstone design faculties

Project managers (i.e. instructors of groups of projects) are not involved in every stage of each project, but they do periodically check the progress of all teams in their group. Also

they are in charge of the evaluation system, and they usually make official contacts with enterprises before the settlement of new projects.

Generally, the project and thesis supervisors are those who connect with the project team most closely.

Fig.3 Engineering Design Syllabus

Instructors (the instructors are the lecture teachers since 2020) are responsible for a 1-credit, 16-hour engineering design course. As shown in Fig. 3, the lecture offers students interdisciplinary and comprehensive knowledge needed in the capstone design. Students are required to attend a closed-book exam at the end of the lecture, in which their theoretical knowledge and abilities to provide solutions towards actual cases are examined. The score will be a part of the final evaluation of the capstone design course.

Unlike the traditional capstone design courses, this new model attaches project mentors from industries to the faculties from university, combining theoretical knowledge with actual practices. Some experienced mentors from small and medium-sized companies promote the project topics from their actual needs, and thus they are willing to help students to complete these projects. In other cases, large enterprises which have signed cooperation agreements with the university will assign these projects to engineers, and the HR assistants will coordinate the tasks, ensuring the effective support from engineers.

3.2 Basic procedure

The reformed capstone design course in SJTU is consisted of 5 stages (See Fig.4). Project selection begins at the 7^{th} semester and it requires the mutual selection between project supervisor, industry sponsor and the students. The team members need to come up with a preliminary plan and clear each one's work in the whole project. At the end of the 7^{th} semester, students will attend a dissertation proposal in the form of team defense. Then the project officially begins as an one-week-loop: The team members will meet with their project supervisor and industry mentor each week, reporting their weekly progress, discussing the present problems and set up a plan for next week. The mode of one-week-loop guarantees the high-efficiency of the project, and allows the teammenbers to make timely adjustments before it is too late.

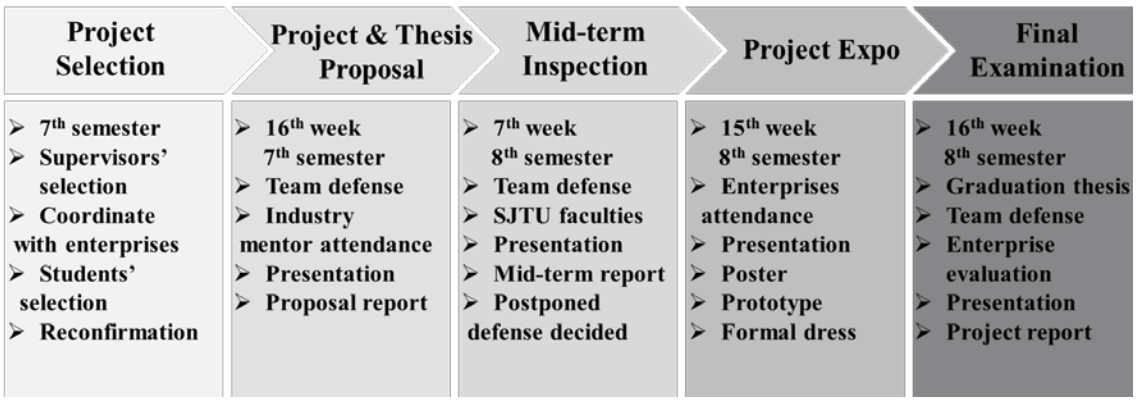

Fig.4 Basic procedure of the capstone design project

The mid-term inspection is a critical point of the capstone design course, when students who need to attend a postponed defense will be decided. The bottom 10% projects need to attend a secondary inspection and then, after the supervisor's evaluation, whether the project can be continued or fail is determined. Meanwhile, the top 10% projects will get the opportunity to attend the conference in the project expo, where these projects will compete for the *Best Design Award*. Other projects could compete for the *Best Presenting Award* in the expo. At the final examination stage, all students will get their final score for the capstone design course, considering their performance in the whole process.

Figure 5 is a showcase of the comprehensive evaluation of the capstone design project. All team members have to present in their oral defense and attend the project expo to introduce their project to the guests and answer questions of judges.

Fig. 5 A showcase of comprehensive evaluation of capstone design projects

4. Results and Discussion

Through three years' continuous reform of capstone design, an outcome-oriented and student-centered curriculum system, operation mechanism, teaching team, and stable

industry-sponsored project source have been formed. Students' integrative competencies have been improved and they stand out in various competitions after capstone design (See Fig.6). For example, all 17 participating teams trained under this new model of capstone design were awarded in the Capstone Design Competition by *Chinese Mechanical Engineering Society*, including one sole gold award, two silver awards and four bronze awards. Besides, the first prize of PSU International Joint Capstone Design Competition was also pocketed.

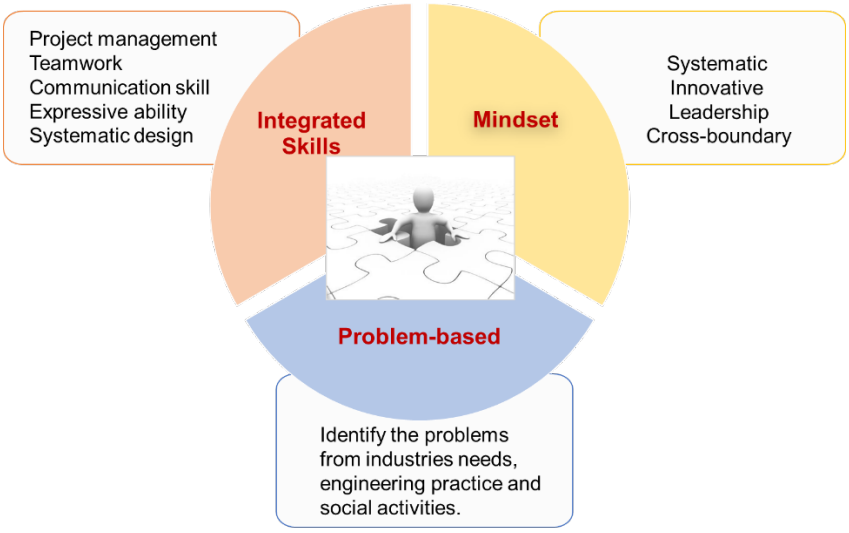

Fig. 6 The redesigned capstone design brings students multiple improvements

There is an example of 2019 capstone design project of School of Mechanical Engineering, SJTU. Four students from the department of nuclear engineering and technology conducted this project-*Visualization Study on Heat Transfer Characteristics of Droplet Impact on Heated Surfaces*. In this project, two students in the experiment team adopted high-speed photography to observe the process of droplet impact on high temperature surfaces, and the other two students in the statistic postprocessing team analyzed the result in two different ways: a uNet neural network model and a commercial image processing software. Based on the topological changes of droplet during impinging, this project showed four different flow patterns in the process of droplet impact on high-temperature surface based on Weber number and surface temperature and clarified the mechanism of related phenomena according to the transition of boiling mode. Moreover, this project developed the tool of automatic extraction of droplet morphology and motion feature(See Fig.7).

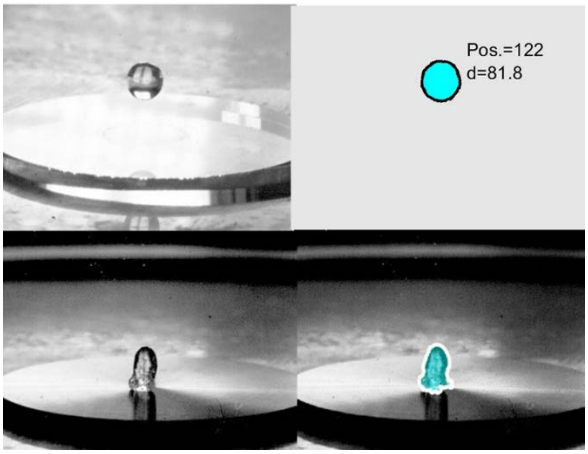

Fig. 7 The automatic extraction of droplet morphology and motion feature based on uNet neural network

As shown in Fig.8, the capstone design course contributes to the cultivation of future engineering leaders by a comprehensive evaluation of capstone design projects and guidance from both academic and industrial supervisors.

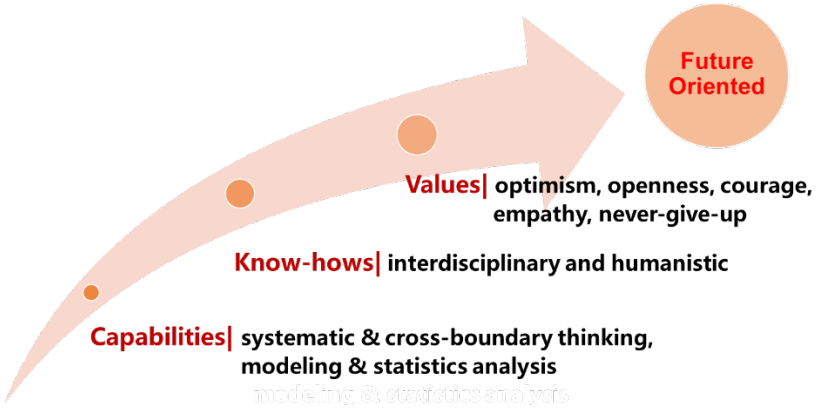

Fig. 8 The redesigned capstone design cultivates future engineering leaders

At the end of the capstone design course, forums and surveys are conducted to find out problems and search for improvement potentials. The survey questioned different aspects in the whole process of capstone design from the students' side including the communication within team members and with instrutors, oral presentation and thesis writing, project management and leadership and so on. Pre and post survey to 85 graduates in 2018(sample questions and results are shown in Table. 1) show that there still exists communication bias between team members and mentors from industry, etc. Therefore, it still needs effort to analyse the factors (e.g., the communication and trust) that affect the outcome of the capstone project and to continuously improve the content and operation of

the capstone design course.

Table 1. Sample questions and results in the survey

Items	Attitudes
Which of the followings best describe your team? a) Everyone depends on others to complete the tasks. b) Social loafing. c) No difference with single work. d) A win-win game and mutual learning.	 a) 2.35% b) 16.47% c) 22.35% d) 58.82%
How much do you think the school instructors helped you in following aspects(score from 1 to 5)? a) lifelong learning b) solving problems c) teamwork d) innovation e) communication and coordination f) leadership and team building ……	Average score a) 3.88 b) 3.98 c) 3.6 d) 3.53 e) 3.84 f) 3.53
How much do you think the project mentor form industry sponsor helped with your project? a) not helpful at all b) less helpful c) neutral d) helpful e) quite helpful	 a) 35.29% b) 11.76% c) 20% d) 21.18% e) 11.76%
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5. Conclusion and Future work

A new structure of the senior capstone design course of School of Mechanical Engineering, Shanghai Jiao Tong University has been developed. The unique feature of the original structure consists of all industry-sponsored projects, both team projects and an individual research thesis. The capstone design course at SJTU continues to be a work in

progress new content to meets the New Engineering Education and ABET requests and concerns, fully considered the feedback of graduates and the requirements of the industry. This paper set up the redesigned model of capstone design course, which is recognized as important to the development of student's multidimensional ability to integrate domain knowledge and real-world concerns and industry constraints into team projects and individual research. This model effectively brings students multidimensional engineering talents, both professional and technical. The ongoing research focuses on conducting capstone course based engineering education research, which can support continuously improve the outcome of the course. The quantitative measurement of the capstone design course on the improvement of engineering students with multidimensional capabilities is also our concern.

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