International Journal of Engineering Education Vol. 28, No. 4, pp. 831–844, 2012
Printed in Great Britain

0949-149X/91 $3.00+0.00

Towards Design-Centric Engineering Education: Capstone Course Reform in a Chinese University*

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The need for creative engineering to address the multi-faceted problems facing the world today has never been so great. The challenge for educators everywhere is to nurture world-class solution developers, despite local constraints in available resources or organization, by leveraging native strength and opportunities. At the Xi'an University of Architecture and Technology (XAUAT) in China, proposed reforms towards a design-centric learning environment featuring multi-disciplinary student teams for open-ended design projects from current public needs draw upon the existing academic specialties of this institution, and apply new ways of approaching education to enhance the existing Chinese undergraduate engineering curriculum. A design process is proposed that approaches those in professional firms, adjusted to maximize student acquisition of interpersonal (teamwork, conflict management, and negotiation), communication (written, oral, and graphical), and project management and design skills. The example institution's academic strength and industry connections suggest a number of possible projects, of which a wastewater treatment plant (WWTP) is chosen as a representative example allowing the detailed working out of a schedule of student deliverables (in this case, a feasibility study and a preliminary design) and a description of the learning process, starting with initial lectures and field trips, continuing through the discipline-by-discipline development of the project design, and culminating in reports and drawings evaluated on ability to satisfy the needs of the client by both faculty and experts from industry.

Keywords: engineering education; design-centric education, capstone design; inter-disciplinary design; waste water plant design

1. Introduction

Young engineers graduating today are entering a profession in flux, tasked with finding solutions to challenges so different in degree than those their parents faced, as to amount to a difference in kind. Climate change, ecological vulnerability, and water resource crises are among the most important global challenges for sustained development around the world. Global competition is rising as international barriers fall and knowledge diffuses to more countries, yet the winners are increasingly the most cooperative, those best prepared for multidisciplinary teamwork. In such conditions, educators are posed with the mighty task of developing engineers who combine deep technical skills with broad awareness of how to share them within unified projects advanced by diverse participants.

There are at present more than a thousand universities and colleges in China that offer college-level degrees in engineering, and the number of undergraduates is close to six million [1]. However, too many young engineers entering the work force are, according to a survey by the Mycos institute [2], inadequately prepared for their future careers. Among the competency gaps identified in these studies were oral communication, active learning, ability to interact with diverse multidisciplinary groups, teamwork, and business skills and knowledge. Recent trends in Klaus Schwab global competitiveness reports [3] are troublesome: Although the availability of engineers and scientists in China rose from 52nd to 35th in the world between 2008 and 2010, utility patents per million people did not increase significantly, and availability of the latest technologies actually decreased from 83rd to 94th during that period. Among the causes for these deficiencies is a lack of the applied, interpersonal, and holistic training. It might cultivate engineers capable of contributing their own deep technical knowledge and human insights to the broader understanding and team synergy. It is therefore

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* Accepted 4 March 2012.

time for schools of engineering in China to apply global best practice, including recent developments in design-centric education, to develop their traditional strengths in inculcating engineering fundamentals.

The reform plans and trials of educational programs in China are multi-step processes, and changes will not spread quickly to all universities nor will they take effect immediately. As China has transitioned towards a market-driven economy since the 1990s, traditionally-educated graduates of engineering colleges have been faced with growing difficulties in finding employment, and the issue has been exacerbated by growing enrollment since 2000 [4]. Governors [5], educators [6] and employers in China have recently recognized that decreased quality of graduated students is a key contributing factor. The Chinese Ministry of Education has triggered a series of reforming plans and education pilots for renewing engineering education programs, but some still are in progress and the subject of active debate, such as the CDIO [7] (Conceive, Design, Implement and Operate) engineering education in University of Shantou, and an Excellent Engineers program for promising undergraduates in 61 universities. These reforms, although promising, will take a long time to spread throughout the country. The pressing and immediate problem of the poor engineering career preparation in engineering in China therefore also requires that individual universities act now to further strengthen and reform their academic offerings, such as the capstone design course, within the existing national curriculum.

The senior capstone design course is the culmination of an undergraduate engineering education program, and offers the best opportunity to address the deficiencies cited by prospective employers. In developed countries such as the USA [8], it is central to the development and assessment of student professional competencies for program accreditation. In that country, senior capstone courses have been organized among many engineering departments for many years, further reinforced by support from the Accreditation Board for Engineering and Technology (ABET). Trends in capstone course design focus on providing a culminating design experience by allowing student teams to apply what they have learned in previous years on an open-ended project, developing their communication (written, oral, and graphical), interpersonal (teamwork, conflict management, and negotiation), and project management and design skills.

The instructional organization of capstone courses in many universities in China is currently falling behind best practice elsewhere and can be modified to great effect. Generally, the capstone is scheduled for the last semester before graduation and is the longest course in the current undergraduate programs. A typical capstone, which has not been changed significantly for around 60 years, involves an instructor responsible for one to eight students who major in the same discipline and often working independently on one portion of a design drawn from professional outputs thought suitable to their specialization. Because there is no design group and little, nor real peer collaboration during the capstone, students lack opportunities to practice multi-disciplinary cooperation, ideally in an open-ended project, and therefore lack communication, interpersonal, and integrative skills. All this said, the capstone, as detailed below, is an appropriate venue for reforms intended to address these deficiencies in graduating student by introducing realistic design processes and expected design deliverables in open-ended design project.

2. Capstone differences between global best practices and a target university in China

Historically, capstone courses have been implemented at one of three levels: the engineering school level, the engineering program level and the engineering stem level [9]. A design course at the engineering school level can include students from any engineering discipline within the engineering college, while a design course at the engineering program level includes students from just one discipline in the college, and a design course at the engineering stem level focuses on one area of a particular engineering discipline. The proportion of courses at each level has varied over time. The 2005 survey of engineering capstone design courses in the majority of ABET-accredited engineering programs in the United States showed a 14% decrease in single-discipline groups and the same increase in inter-departmental groups in the previous decade [10]. Although 18% of respondents reported using an individual student, 81% reported using groups consisting of students from several disciplines, and 35% included groups consisting of students from more than one department. The level of integration in student capstone designs has transitioned from engineering program to engineering school, as increasing emphasis is placed on strengthening students' interpersonal communication and the ability to contribute the knowledge of their own specialty within a multi-disciplinary group.

Harrisberger et al. suggested that models of experiential learning activities be classified into two types: simulations and authentic involvement [11]. 'Simulations consist of contrived situations that are carefully designed to meet selected learning objectives and are under close faculty control. The Authentic involvement activities expose the student to real situations with totally open-ended outcomes, although the faculty may influence the selection of the situations and set performance criteria to assure that positive learning objectives are met.' The majorities of capstone projects in the 2005 survey mentioned above are from industry [10], and meet current market needs. As they are usually open-ended problems with a variety of realistic constraints such as economic factors, safety, and aesthetics, these courses fall within the 'authentic involvement' category. The compared surveys [10,12] go on to consider the details of capstone design courses in the United States. The course structure is most often a one-to-two semester course with simultaneous class and project components; most departments still assign one group per project, with an increased tendency toward 4 to 6 students per group and 2–5 projects per course cycle, and a fairly consistent majority maintaining a ration of student to faculty in the range of 1–5. However the specifics of structure, organization, and operation of capstone design courses vary more widely. Representative examples of capstone design courses, in the USA and elsewhere, are described below.

The Department of Civil & Environmental Engineering at MIT has two prepared curriculums for the final capstone course, both of which begin by taking Introduction to Civil and Environmental Engineering Design during sophomore year [13]. After completing their core curriculums, students are divided into separate civil engineering and environmental engineering science tracks, and then regrouped in their senior year for a unified capstone course consisting of a set of assignments that are not merely open-ended, but innovative. Students need to make and test a physical model of their designs and/or rewrite their reports to incorporate feedback they receive throughout the process, and finally make a formal presentation of their results.

The Ohio State University began a multidisciplinary engineering capstone design course in the mechanical engineering department in 2001 in cooperation with Honda [14]. It was specially programmed by an institute with a mission to enrich the students' experience and to strengthen the academic credentials of undergraduates in the College of Engineering. Over the years, projects have spanned a broad range of topics, to which more are added each year. It has evolved to include students from every engineering college, as well as from business, industrial design, and the MBA program. Students are grouped according to their interests in particular projects, so students interested in participating are able to find a project that will further their career goals and give them valuable experience in industry. There are three consecutive capstone courses scheduled before the 4th quarter of the senior year: Introduction of multi-disciplinary engineering capstone design and Multi-disciplinary engineering capstone design projects I and II. Additionally, project teams are expected to spend 4 ~ 6 hours consulting with their assigned advisor.

The engineering capstone at Brigham Young University includes a two-semester course that bring together seniors who study mechanical engineering, manufacturing engineering technology, electrical engineering, computer engineering, statistics, business, and industrial design. The design groups consist of four or five students, plus a faculty member or professional engineer serving as an advisor [15]. Capstone groups have completed 577 projects sponsored by 13 countries including China from 1990 to the present. The course is beneficial to both the students and the companies who sponsor them, as the companies get new, fresh thinking to solve their engineering problems and the students get the chance to put their engineering skills to practical, real-world use. Educators [16] also think industry sponsorship is of benefit to the sponsoring companies, the university, and the students.

The Design-Centric-Curriculum (DCC) is an alternative pathway for engineering students at the National University of Singapore [17, 18] representative of global best practice in interpersonal communication and teamwork development. Students apply from different departments and work together in multi-disciplinary groups centered on one or several projects for three years. During that period, modules focused on DCC projects, including lectures and seminars are provided for students in both the DCC and the traditional engineering curricula. A Design Summer School offers students in the DCC an opportunity to interact closely with undergraduates from a number of East Asian, South Asian, European, and North American universities to appreciate the cultural and social dimensions of design.

The Xi'an University of Architecture and Technology (XAUAT) is a target university for the capstone course reform in China. It was founded in 1956 with the responsibility of training the architects, engineers, and technicians essential to Chinese melting industry. Although it now also offers majors in the sciences, arts, law, and management, among others, it retains its historical focus on construction engineering: Architectural Engineering, Civil Engineering, Environmental Engineering, Water and Wastewater Engineering, Heating Engineering, and so forth. Undergraduate engineering

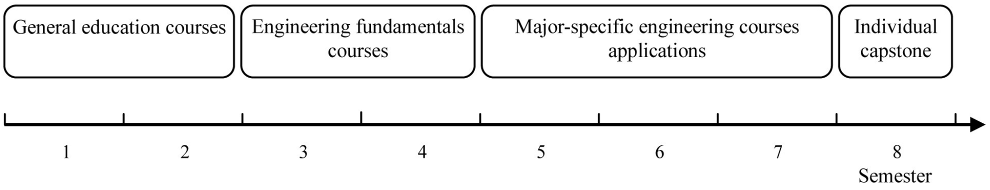

Fig. 1. Academic progression for XAUAT undergraduate students in engineering.

education in, the Xi'an University of Architecture and Technology (XAUAT), as shown in Fig. 1, consists of coursework in four levels, generally completed in succession: general education, engineering fundamentals, major-specific theory and applications, and the individual capstone. There have been no fundamental changes in course structure, organization, and required deliverables for about 60 years.

At XAUAT, the mandatory capstone design course is considered the culmination of the undergraduate engineering curriculum with the final (8th) semester devoted to it. At the beginning of that semester, students are assigned to instructors based on mutual selection. The instructor's responsibilities include scheduling tours to sites, developing and providing suitable project frameworks, and advising on project design. In order to prevent plagiarism among students sharing the same project, individual student usually has unique project. Projects provided in capstone are generally taken from a professional design created by engineers in industry or by the instructors themselves, and reduced to those portions deemed suitable for a semester's work by an engineering student of a particular discipline. Required deliverables consist of a set of design reports and diagrams, and grading is based on evaluations from the instructor, reviewers from other teachers in the same department, and the presentation committee.

For example, a capstone design course in Water and Wastewater Engineering in XAUAT that the author took as an undergraduate retains the same format today. All teachers in the department were involved in the course, and in the recent past years the number of students per instructor had varied from 4 to 10. To develop projects suitable for capstone courses, instructors usually solicited engineering design reports and drawings from friends and classmates in professional design companies, then selected information from these materials and wrote mission statements laying out design objectives for capstone. One of the three main options for a capstone project within the specialty was a wastewater treatment plant (WWTP) design. Students choosing this project had to justify the selection of a wastewater treatment process, calculate the size of wastewater treatment units, and supply drawings of both the overall design of and specific units within the plant.

Even in the capstone, although students in a specialty may choose among several different projects, some important gaps become noticeable when comparison is made with international best practice: Because capstone design projects are expected to adopt similar methods as did the reports from which the material was derived, XAUAT capstones are closer to directed design than open-ended designs. The duration of the capstone is only a semester instead of a year or more, and students work individually, rather than in a team, let alone one comprised of students from multiple departments. Therefore, essential professional 'soft skills', such as teamwork, conflict management and negotiation with colleagues in a multi-disciplinary setting, are not inculcated. These deficiencies are the subject of increasing concern among employers in professional consulting and design companies hiring XAUAT graduates. Similarly, it has often been the case that new graduates exhibited a narrow range of engineering knowledge, unrealistic ideas and poor implementation of project design, and a lack of collaboration and conflict resolution in a multi-disciplinary design team. As a result, these new graduates are been conceived as many as three years of training in firms to reach professional engineers.

3. Presentation: the reformed capstone structure and project features

As it is common practice in professional firms served by XAUAT engineering graduates to be developed by small teams of professional engineers of several different backgrounds for projects design, this work proposes a framework for capstone design courses featuring multi-disciplinary student project design groups. Four modifications in the capstone structure are planned: An increase in length from 1 to 4 semesters, additional lectures and seminars aimed at the capstone project, the development of complete, rather than partial, engineering designs, and a shift from an individual to an interdepartmental student design group. As required by the reform, the features of capstone projects described in the below project example include market demands for graduate, student group composition and deliverables, which are basically different in many industries projects.

3.1 The structure of the reformed capstone

As design projects developed in real-world conditions are often complex and time-consuming, particularly for inexperienced engineers, a single semester is not enough for students to understand the technical background, appreciate the client's needs and expectations, form an effective team, and carry a project through to completion. Early exposure to each of these elements of successful design development is vital. The increase in length means that capstone-related work will also occur in the 5th through 7th semesters; assignments in these semesters will be extracurricular to minimize impacts on the authorized sequence of courses, which themselves will be more meaningful for students inspired by real, immediate projects. Figure 2 illustrates the new XAUAT academic progression.

Potential real projects for capstone would be based on strengths in specialties and capabilities of faculty in the University. Most of the engineering specialties in the University are shown in the left of Fig. 3. XAUAT's strengths are in architecture, civil, mining and other forms of industrial engineering, and many faculty research projects always focus in those fields. As a result, the potential capstone projects also come from these industrial projects, such as public building projects (stadium, museum, school, supermarket), real estate projects (apartment, house), mineral projects (cement plant, smelting plant), and urban infrastructure projects(road and bridge, water supply plant, wastewater treatment plant). A list of available projects for capstone projects in the University is publicized at the end of the 4th semester from which students choose one and form groups for a project according to their interests.

XAUAT's strong industrial connections and experienced faculty enable a series of lectures and seminars to be provided outside of the standard course sequence to meet the needs of student design groups. The central part in Fig. 3 shows the layout. Lectures will be mostly offered by invited experts from the industry with design experiences similar to the capstone project. A lecture will be followed by a seminar delivered by XAUAT faculty, taking the form of a discussion between teachers and students on how to adapt lecturers' experiences to student needs.

A design project in industry requires a great deal of specialized knowledge from a number of different fields, and is generally completed by engineers having diverse professional backgrounds. Students intending to become professional engineers should not care only about their own responsibilities, or think about the design only in the terms of their own specialty, but they must take into account how their work is connected to others within the context of the project as a unified whole. Team meetings provide opportunities for students to communicate with each other about ideas and outcomes, learn from and teach students in other specialties, and together

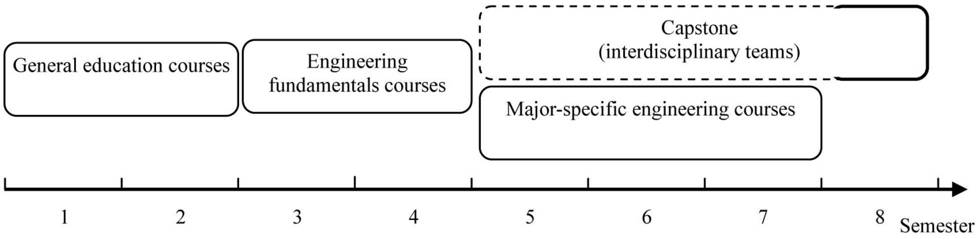

Fig. 2. Academic progression for XAUAT undergraduate students in engineering, with extended capstone.

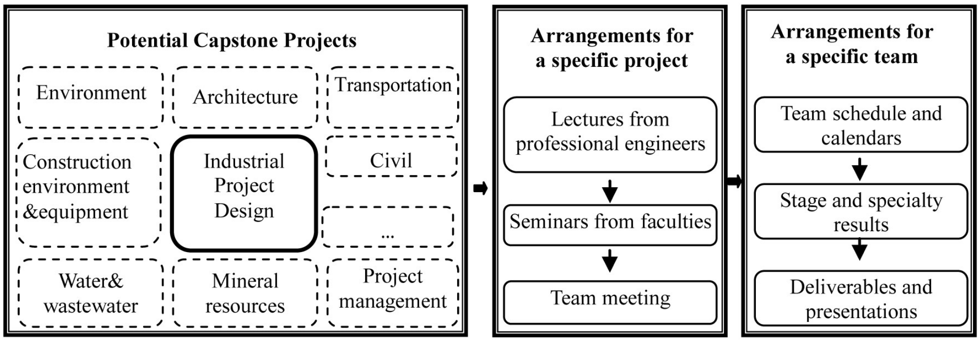

Fig. 3. A model of multi-disciplines capstone toward project design-centric engineering education in XAUAT.

negotiate each step in the design process for the overall design aims. Whether team meetings will be joined by instructors or other outside parties will be determined by the students.

As shown in the right-hand side of Fig. 3, a schedule of interim project objectives and assignments will be planned under the suggestion of teachers in team meeting, and a group calendar will record the progress of group design for individual student assessment. As in a professional firm, each specialty is responsible for delivering a set of results that are confirmed and signed for the next specialty. Final results of a team will include project reports and drawings by each involved specialty. The final oral presentation will be reviewed by a committee composed of members of the faculty and professional engineers.

The purpose and result of these changes is to provide a capstone experience more closely aligned to a professional engineering assignment, involving a multi-disciplinary project design team, which will promote integrated collaboration and communication, and improve teamwork and conflict resolution. Because the projects are developed by sources in industry and by faculty with close connections to outside professionals, the particular technique practices trained in graduating students are highly responsive to social and market demand. The design of the capstone, because it approximates circumstances in professional consultant and design firms, will enable graduating students to adjust more quickly to professional settings—to be both more employable and more retainable. Although many potential projects above can be chosen as capstone projects, among them, we consider the wastewater treatment plant (WWTP) as an example for further explanation.

3.2 The features of capstone projects described in an example

A great many WWTPs projects will be designed and built within Shaanxi province, China. The purpose of municipal waste water treatment is to prevent pollution of receiving waters or to reclaim water for reuse. A conventional WWTP process consists of preliminary units (pumping, screening, and grit removal), primary settling units to remove heavy solids and floatable materials, and secondary biological aeration units to metabolize and flocculate colloidal and dissolved organics. Waste sludge drawn from these units is thickened and processed for ultimate disposal. To better protect the decreasing surface and underground water resources in China, wastewater from households and industries in a city or town are increasingly collected in a sewer system, transported to a WWTP, and there treated before disposal. According to China's National Development and Reform Commission [19], as of 2011 60% of county capitals have WWTPs. However, in underdeveloped Shaanxi province where XAUAT is located, not more than 10% of county capitals in 2008 had this infrastructure. It is estimated that at least 100 additional waste water collection and treatment systems will be needed in the province by 2020, and XAUAT graduates will be responsible for designing a great many of these.

WWTP design is a complex, multi-step project and many of the best designs are devised by remarkably creative solutions to problems that contain open-ended elements. The complexity arises at least in part from the multiple, often contradictory, demands placed on any such public utility: the nature of influent waters in future, the environmental and social sensitivities related to effluent discharge, client demand for high performance at low cost, government regulation, robustness in disaster or under usage stress, even the expectation of the community regarding building aesthetics. In China, it is standard practice to divide the design of WWTPs into three phases: feasibility study, preliminary design, and construction design. The product of a WWTP feasibility study is a report that comprehensively details building necessity, economic rationality, and technical feasibility, then lays out one or more implementation possibilities. After the report is peer reviewed and given official approval, it becomes the basis for the preliminary design. Documents included in a WWTP preliminary design consist of a design manual, a project budget book, a set of drawings, and tables of construction materials and equipment, which together include the designs of specific wastewater treatment units, the overall layout, the flow diagram of the plant, and a more exact cost estimate. The construction design report is a much more detailed set of written materials that can guide actual construction of treatment units and building, the installation of equipment, and the planning construction budget. Generally, a preliminary design on a traditional WWTP having a Daily Capacity of $0.5 \sim 20 \times 10^4 m^3/d$ is completed by 7 ~ 10 engineers in 1 ~ 6 months. However the required time and engineers for a feasibility study report and construction design vary greatly depending on conditions complexity around the WWTP and the involved experiences.

WWTP design is a collaborative, multi-disciplinary task. For instance, a preliminary design for a traditional WWTP (Daily Capacity of $0.5 \sim 20 \times 10^4 m^3/d$), as handled by a professional municipal engineering consultant or design firm or institute, may be carried out by a team composed of 1 ~ 3 water and wastewater, or environmental engineers, 1 ~ 2 civil engineers, 1 architectural engineer, 1 cost estimation engineer from Project Management Engineering, 1 electric power engineer, 1 automated control engineer, and (in cold regions) 1 air conditioning engineer from Construction Environment & Equipment Engineering. Because the appropriate treatment processes depend on raw wastewater characteristics, weather and geological conditions, the economic and technical base and other factors, personnel specializing in water and wastewater engineering usually are responsible for the selection of the treatment process and they determine the function, size, and layout of specific units. They are called process engineers, whose work is often the basis for the efforts of workers of other specialties. Fig. 4 illustrates the overlapping sequence which is typical in the WWTP design process in a professional firm China. For illustration, consider an ordinary pumping station, typically a unit and sub-design within a WWTP. When the basic concept about the pumping station has been discussed and approved among engineers involved in a seminar or meeting, its size should first be calculated and its functions should be arranged by process engineers. The results become the conditions governing architectural design, and the next results from process and architectural engineers in turn guide civil engineers as they calculate and draw the structure of the pumping station. The structural designs in hand, air conditioning engineers may then select and position the ventilation and heating equipment in the building, and electrical and automated control engineers may lay out the wiring and pumping control systems. Finally, engineering management specialists estimate the expenditure for each sub project. When unresolvable difficulties emerge during transitions, or non-conformant specifications are provided, all involved parties will gather to discuss the necessary alterations.

The whole designs for built WWTPs in China cannot totally completed in capstone. As the objective of the capstone course is to complete the academic preparation of a young engineer for the workplace, we emphasize veracity in professional circumstances. However, we do not attempt to perfectly replicate them. Because the final stage in engineering project development, the construction design, is more time-consuming and demands more experience, a feasibility study report and a set of preliminary design documents will be set as targets consistent with industrial criteria for WWTP designs in China [20]. That is, the capstone is divided into two phases: a feasibility study and a preliminary design. Required deliverables in each phase will be similar to those in a professional design firm and two presentations are required, one at the end of each phase.

The WWTP capstone designs are a little different with one in a firm. As the needs of students performing a single task for the first time differ from those of more experienced workers involved in more than one project at a time, a capstone designed as a learning experience may profitably have a different progression of work than that is typical in engineering firms. Outcomes, delivered efficiently, are most important in a professional environment. As is shown in Fig. 4, professional engineers are only intensively involved during their portion of the design process. At other times they merely remain on call to provide their explanation and skills when needed. Students, however, lack both skill and practical experience, particularly about the interactions of their own discipline with others, and will benefit from participating at each step in the design

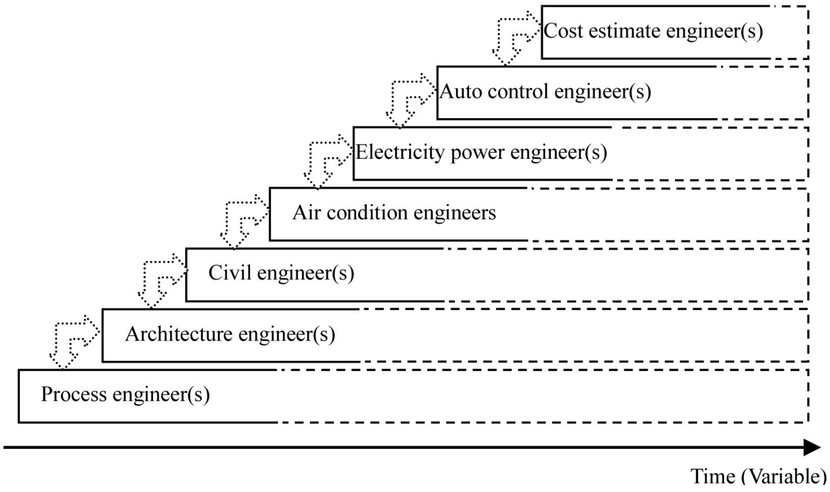

Fig. 4. Staged cooperation within a firm during the preparation of a WWTP design; Arrows show communication between engineers.

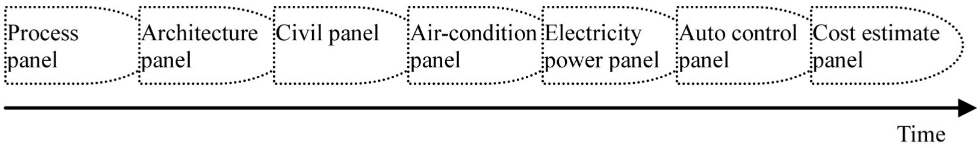

Fig. 5. Sequential WWTP design process for a student group in the modified capstone.

process. Figure 5 illustrates the sequential ordering of inter-disciplinary discussion and decision-making during the design process in a capstone course. Semi-structured feedback from other engineers in a firm will be replaced in a student design group by frequent, structured communication and rapid modifications at each design step. All members in a capstone design group should take part in every step in the process, discipline by discipline; each step is led by a student studying that specialty. For example, water and wastewater students lead the process engineering panel; this leader is collectively responsible not only for treatment process selection and treatment unit size calculation, but also for the allocation and review of tasks to all members. Later, at the end of the sequence, the same students will form a project cost estimation panel, whose members have different assignments related to planning treatment unit costs, all of which are reviewed by a project management student.

4. Discussion: an organization and schedule example of a WWTP capstone project

Although the implementation details of the reformed capstone will vary by project type, in most cases they should reflect current practice in industry, therefore should be modified as necessary to enhance learning opportunities. In the case of a WWTP design project, the schedule of the capstone course resembles the workflow in firms. The deliverables required are developed in a series of group and individual assignments completed after lectures and seminars in the plan. Two rounds of design processes, the feasibility study and preliminary design, are planned below. The discussion concludes with a consideration of benefits and potential difficulties.

4.1 Project background

A small municipal WWTP is planned for Zhenping in Shaanxi Province as part of an intended water pollution control and soil conservation initiative around Danjiangkou Reservoir, the source for one of the largest south-to-north water diversion projects in China. At present, sewer and storm water from the city flows untreated into the Danjiangkou reservoir by way of the Nanjiang River, a minor tributary of the Han River. There are expected to be 27,000 persons living in the city by 2020, according to the Zhenping city plan, but no major industrial development is anticipated. Therefore, previous experience suggests that a small municipal WWTP, with a capacity less than 5,000 m^3/d and most likely using a traditional (biological-based) treatment process will satisfy projected demand.

Approximating the mix of specializations, design process, and outcomes found in a professional firm for a similar project will enable future engineers to mature and adapt more quickly to real-world office circumstances.

4.2 Structure of student groups and faculty advisory committees

The author's design experience indicate that a small WWTP design can be completed by six to eight engineers with approximately six different specializations. The corresponding mix of disciplines within a student capstone group for such a WWTP is illustrated in Table 1. One substitution is that an automatic control major will be responsible for electrical design, as there is no electric power major in XAUAT, but all automatic control majors take a course in power engineering. Two students are chosen as treatment process engineers, one from water and wastewater engineering and the other from environment engineering. Likewise, the mix of specialties in the faculty advisory committee matches the structure of required engineers in a firm: six professors from as many different schools in XAUAT. Choosing the number of student groups that may work on the same project type will involve tradeoffs, as fewer groups increase educational costs, whereas more groups decrease the ratio of teachers to students. Based on experiences in the USA, three to six such groups are appropriate.

4.3 Stages of the capstone and required deliverables

The deliverables same with one by professional engineers are expected of students in a feasibility study and then a preliminary design; the first by the end of the 6th semester and the second at the end of the 8th. Because all students are required to take part in the whole process, and each in turn will take charge of the group in a sequential series of discipline-by-discipline design steps (as shown in Fig. 4), design time for a given project will be much longer in

Table 1. Specializations included in a student WWTP design group

Design group		**Faculty advisors**			
Student Engineers	**Quantities**	**Teachers**	**Quantities**	**Majors**	**Schools**
Process	2	Process	1	Water and wastewater Eng Environmental Eng	Environment & municipal engineering
Architecture	1	Architecture	1	Architecture Eng	Architecture engineering
Civil	1	Civil	1	Civil Eng	Civil engineering
Electric power	1	Electric power	1	Auto control Eng	Information & Control
Control	1	Control	1	Auto control Eng	Information & Control
Project costs	1	Project costs	1	Project management Eng	Management

the modified capstone than in a firm. Although the preliminary design generally requires more workloads than the feasibility study, two semesters are allocated for each, as students will need time to establish effective team dynamics and develop a basic knowledge of wastewater treatment systems and WWTP design at the beginning the capstone. The feasibility study report will be reviewed by three professional engineers, and a presentation on it is scheduled at the end of the 6th semester. After approval, the report becomes the basis for the WWTP preliminary design documents. The cycle of knowledge-acquisition, design development, and report preparation and presentation repeats in the senior year, with the 7th semester devoted to learning how to make the preliminary design documents, and the 8th to the detailed and formal design.

4.3.1 The stage of feasibility study

The development of a feasibility study report in the capstone will draw upon the procedures found in professional firms, which customarily include four steps. Firstly, all involved engineers visit the city and make a survey local climate, geology, infrastructure, water environments, sewer systems, etc., to establish suitable WWTP specifications. Secondly, the WWTP will be conceptually designed, from process planning to electrical layout, in the order given in Fig. 5. Thirdly, an integrated conceptual project design, yielding an estimated investment and economic cost and an analysis of environment impact, will be developed by process engineers and engineering management engineers, with input from engineers of other specializations. Finally, the report will be compiled by process planning engineers, and formally presented before a committee of experts chosen by either the customer or government.

As illustrated in Table 2, the junior year is divided into basic instruction in the 5th semester, and the four-step design process described above in the 6th. Students begin the capstone with two tours, the first in the neighborhood for the local information about potential receiving water bodies and urban infrastructure, and the second at a similar WWTP in order to develop a general idea. Both activities, plus an individual report on the city and WWTP will encourage students to start thinking at an early stage on about how to apply the knowledge they synchronously acquire in their major-specific courses in the semester. As at this stage none of the students will possess the specialized information required to complete the feasibility study, technical instruction begins early, with three lectures on wastewater treatment systems by a professor from XAUAT. From the 7th week, all students will attend a lecture presented by an invited expert from industry once every two weeks, each topic on WWTP design from the perspective of a particular discipline with a total of seven. Seminars, hosted by professors from each involved school in turn, allow students to discuss the application of techniques and knowledge to their joint project and practice oral communication in a goal-oriented, team environment. Assessment of student progress is made frequently through evaluation of participation in seminars and assignments; not only does this provide a grading rubric, but it also permits instructors to quickly identify and reinforce material that students are struggling with. A detailed schedule on the feasibility study should be made with the help of faculty at the end of learning. Additional unguided group meetings and any necessary tours to the city will be planned by students themselves, allowing them more relaxing opportunities to communicate and build group dynamics.

The 6th semester begins with a lecture on wastewater treatment plant feasibility studies—what they are, and how to generate them—featured by an invited speaker from the industry. Groups then plan and conduct a faculty-guided tour to the city of Zhenping to collect documents, characterize the construction site, determine influent characteristics and other environmental conditions, and follow this up with a whole-group summary report on the WWTP site, required plant capacity, influent characteristics, and effluent standards. Once reasonable WWTP specifications are established, students are then able to choose wastewater treatment processes

Table 2. Feasibility study development schedule, junior year

Semester	Weeks	Objective	Methods
5th	1 ~ 6	Understanding of overall WWTP system.	• Site visiting: a tour to get a general idea of water bodies and urban infrastructure around Zhenping. • Lecture 1 ~ 3: wastewater treatment systems, by a XAUAT professor. • Study tour: visit to a similar WWTP guided by a professional operation engineer in the WWTP. • Personal assignments: a report about the city and the WWTP.
	7 ~ 20	Study of WWTP design, considered from the perspective of different disciplinary, tailored for a feasibility study phase; scheduling for the WWTP feasibility study report next semester.	• Lecture 1 ~ 7: WWTP design: design and construction phases, treatment processes selection, architectural engineering, civil engineering, electric power engineering, auto control engineering and project investment estimation, by professional engineers from firms or institutions. • Personal assignment: report on design assignments based on one's own major, evaluation of how to cooperate with other engineers during design preparation. • Seminar 1 ~ 6: a discussion on WWTP design from the perspective of each discipline; a member of the faculty should be involved in disciplinary order. • Group assignments: a draft schedule for the a feasibility study.
6th	1 ~ 4	Determination of the site, plant capacity, influent characteristics and effluent standards, based on the feasibility study criteria.	• Lecture: What is a feasibility study and how to do for a WWTP? By an experienced process engineer. • Seminar: planning an information-gathering tour to Zhenping. • Study tour: collecting materials and information for the WWTP project. • Group assignments: a summary report about the WWTP site, capacity, influent characteristics and effluent standards.
	5–12	Wastewater and sludge treatment process selection.	• Seminar 1 ~ 4: wastewater and sludge treatment processes, process design, architectural and civil design, electric power and control design. • Group assignments: a summary report of all involved disciplines and a design calculation draft of all involved disciplines.
	13 ~ 16	Development of a construction schedule, estimating and economic evaluation, planning administration and employment, environment protective design, safety and economical operation design.	• Lecture: What is a project investment report? How to estimate a project investment and evaluate it economically in a WWTP feasibility study? By an invited investment estimated engineer. • Seminar 1 ~ 6: Making a construction schedule, estimating project investment, economic evaluation of the project, planning administration and employment, environment protective design, safety and economical operation design. • Group assignments: a summary report including the construction schedule, estimating and economic evaluation on the project, the administration and employment, environment protective design, safety and economical operation design.
	17 ~ 18	A feasibility study report.	• Seminar 1 ~ 2: discussion of content of a feasibility study report and division of the tasks, collection and aggregation into a report. • Deliverable: A feasibility study report on the WWTP.
	19	Presentation on the report.	• Lecture: What makes a good presentation? By a member of the faculty. • Group assignments: preparing a PowerPoint.
	20	Presentation.	

and their ramifications for architecture, civil engineering, and electrical power and control in a series of four seminars, and generate an integrated summary report and a design calculation draft. In the second half of the semester, groups turn their attention to project cost estimation and economic evaluation, which is one of the most important sections of any feasibility study, beginning by attending a lecture by an invited engineer with experience in these fields. In four weeks, a student design team participates in six faulty-led seminars covering each major category of economic cost, as detailed in the Table 2, and uses these to build and justify a written cost analysis. In week 17, with most individual parts of the report now prepared, students take advantage of two seminars to detail the content of a feasibility report, divide up tasks, collect materials, and aggregate them into a unified written work. This report is due at the end of week 18. Just as written communication is trained here, so public oral communication is practiced in the following two weeks, as the teams attend a lecture on effective presentations, then prepare and deliver their work, with each student participating in the final oral presentation.

4.3.2 The stage of preliminary design

The second half of the capstone (shown in Table 3) is, like the first, divided into two steps and lasts two semesters. In the 7th semester a series of lectures by invited experts from industry, followed up by faculty-run, student-led seminars, consistent with the development of a preliminary design report from the perspective of each discipline involved. Lectures introduce components and process, not in isolation, but as parts of an integrated design. It also include practical advice on how coordinate one's own efforts with those of other specialists. Through

Table 3

Semester	Weeks	Objective	Methods
7th	1 ~ 14	The basics on WWTP preliminary design from the perspective of different disciplines.	• Lecture1 ~ 6: How to go about a professional preliminary design of a WWTP? One each by a professional process, architectural, civil, electrical power, control, and project costs engineer. • Personal assignments: a consideration of how to organize a group for a professional design, as a manager of a specific discipline. • Seminar 1 ~ 6: discussion on WWTP design from the perspective of each discipline involved. Faculty members are involved in disciplinary order.
	15 ~ 20	Tables, drawings and the design manual in preliminary, and a schedule in next semester.	• Lecture: an WWTP overall design from an experienced professional processes or architectural engineer. • Seminar 1 ~ 2: how to generate tables of construction materials and equipment; effective drawings and design manuals. • Group assignments: a detailed schedule for the preliminary design.
8th	1 ~ 2	Treatment units processes design and drawings.	• Seminar: discussion on treatment units processes calculation and drawing in a WWTP design. • Group assignments: treatment process drawings, a report on design calculation process and a design manual covering process engineering.
	3	Treatment units architecture design and drawings.	• Seminar: discussion on architecture diagrams in a WWTP design. • Group assignments: architecture diagrams, a report on design process and a design manual about architecture engineering.
	4 ~ 5	Treatment units civil design and drawings.	• Seminar: discussion on treatment units civil calculation and diagrams in a WWTP design. • Group assignments: civil diagrams, a report on design. calculation process and a design manual about civil engineering
	6	Overall design considerations and plant layout drawings.	• Seminar: discussion on WWTP water level calculation in a series units and general diagrams. • Group assignments: diagrams, a report on design calculation process and a design manual about the plant plan.
	7	Electric power design and drawings.	• Seminar: discussion on WWTP treatment units electric power design calculation and diagrams. • Group assignments: electric power diagrams, a report on design calculation process and a design manual about electric power engineering.
	8	Control design and drawings.	• Seminar: discussion on treatment units, auto control design calculations, and diagrams in a WWTP design. • Group assignments: control drawings, a report on design calculation process and a design manual about control engineering.
	9 ~ 10	Project budget book.	• Seminar: discussion a project budget of a WWTP. • Group assignments: a report on the project budget and a design manual about the budget.
	11 ~ 13	Design manual and tablets of construction materials and equipments.	• Seminar1 ~ 2: discussion of content of a design manual and division of the tasks, collection and aggregation into a design manual and tablets. • Deliverables: a design manual in the WWTP preliminary design and tables of construction materials and equipments.
	14	Printing all materials.	• Seminar1 ~ 2: student review of drawings. • Deliverables: All drawings and a project budget book.
	15	Preparing a presentation.	• Group assignments: preparing a PowerPoint and a simplified design manual.
	16	Presentation.	

guided discussion as a group in seminars, student engineers can develop a sense of how to generate a WWTP preliminary design as a team. Two major assignments are due in the 7th semester: an individual perspective on how to manage a team working on that portion of the design related to one's own specialty, and a detailed, item-by-item preliminary design schedule prepared by the group as a whole.

The 8th semester is the culmination of the capstone design project; no other courses are scheduled, and the intensity of work increases as student applies everything they've learnt to generate two deliverables: A written preliminary design report, a set of drawings, and a presentation approximating those delivered by professional engineers. The design process is partitioned into eleven parts based on the author's experience. Seminars guided by faculty are a vital forum for settling difficulties and resolving questions during this process. Eight group assignments in Table 3 involve the preparation of documents included in the final report; each build on those before it. For example, once the previous assignments have been finished and handed in, a set of drawings and a design report can be prepared conveniently. All deliverables in this phase of the capstone, including a set of drawings, a design manual, a project budget book, and tables of construction materials and equipment, are the same as those prepared by a firm, according to WWTP preliminary design criteria.

4.4 Benefits and potential difficulties

The instructional design of the modified capstone will allow undergraduate students to complete a feasibility study report and a set of preliminary design documents for a real WWTP project, in circumstances approaching the inter-disciplinary collaboration within a firm. Students from different departments and schools in XAUAT are grouped into inter-disciplinary capstone design groups, members of which learn and work together towards shared objectives, by communicating, discussing, and resolving conflicts in seminars and group assignments during capstone design. Tailored lectures and seminars will supply the technical knowledge and human skills required for these future engineers to contribute effectively to diverse multidisciplinary groups. Undergraduates, who participate in a design group and generate a WWTP feasibility study report and preliminary design, will become familiar with design processes in professional firms, and develop abilities as an engineer in particularly high demand by employers in professional municipal institutions or firms, due to the enormous expansion of WWTP projects in China in recent years.

There are advantages for student engineers and disadvantages in efficient designing following such a capstone designing process. Taking an active part in each step of the design multiplies student opportunities to both practice teamwork skills and appreciate how each discipline fits within and contributes to a developing whole. Students take on different functions as the design progresses, serving in turn as design lead, local expert, or panel member, creating additional opportunities to exercise leadership, settle conflicts, and communicate with colleagues. These learning efficiencies outweigh the output inefficiencies.

There are also several potential difficulties and challenges that may arise. The education cost of the undergraduate capstone per student will definitely increase. New expenditures due to the modified capstone instructional design at XAUAT largely fall into three categories: lectors' fees, the expense of tours, and faculty salary. However, perhaps the most significant challenge is that a prolonged capstone may conflict, in student workload and in scheduling, with the courses studied in the 5th, 6th and 7th semesters, due to additional lectures, seminars and assignments for students. The capstone design will initially be open for particularly strong and interested students, and the capstone teaching plan should be modified flexibly to suit changing needs and address any identified weaknesses or omissions.

5. Conclusions

As shown by recent surveys of both technical development and employer satisfaction, the existing structure of Chinese engineering education is increasingly ill-suited to the rapidly changing, market-based, customer-oriented, globalizing economy of modern China. The present proposal is presented as an actionable example for a reform within the undergraduate curriculum authorized by the Chinese government, the existing one-semester capstone can serve as the basis for an expanded course that adds three semesters of extra-curricular preparation, concurrently with the major-specific courses. In place of the existing one-semester's worth of individual work on that sub-set of a project design belonging within a single discipline, the reformed capstone will involve students working, as a group drawn from multiple disciplines, on an entire project, to prepare the same materials expected of a team of professional engineers. In the case of construction projects, these are the feasibility study and the preliminary design (the construction design is omitted in the interests of time).

The specifics of course design draw upon the existing academic specializations and industry connections of the Xi'an University of Architecture and

Technology (XAUAT) in Xi'an, Shaanxi province, which here serves as a case study, one representative of Chinese conditions, of how local and institutional strengths and constraints, and anticipated employment opportunities, shape a proposed reform of undergraduate engineering education. This institution retains its historical strengths in construction engineering and has identified a particularly strong demand for public utilities. Specifically, a great many waste-water treatment plants (WWTPs) will be needed in Shaanxi Province to protect human health and the environment. WWTPs are complex, multi-stage projects balancing numerous and often contradictory demands from builders, operators, neighbors, users, activists, and governments; many of the best designs are devised by creative responses to problems that contain open-ended elements. Selecting a WWTP design as the initial project category in the reformed capstone also eases the transition for XAUAT. WWTP design is a multidisciplinary exercise in a professional municipal design firm. The array of engineering specializations in such a project matches XAUAT departments quite closely, and members of the faculty of several departments have considerable experience in designing WWTPs. This means that a diverse, well-informed group of instructors from different departments and schools are immediately available to support student teams.

A small municipal WWTP, located in Zhenping, Shaanxi province, serves as a capstone design project case, allowing for the detailed planning of a teaching program including a design process, a group structure, a sequence of learning opportunities, and a description of required deliverables. The design process is divided into two parts, consistent with the first two steps: A feasibility study report of the WWTP in the junior year, and preliminary designs for the WWTP in the senior year. Specifics of these deliverables are based on WWTP design industry criteria and written, graphical, and oral materials submitted in support of the design proposal are reviewed by engineers from industry and university professors.

These changes to the capstone component of the undergraduate curriculum at XAUAT represent only a very preliminary stage of comprehensive reform. Accumulation of experience over time will allow for repeated cycles of experimentation and course-correction to both better fit the reform to conditions applying at XAUAT, and to improve student learning outcomes by better understanding how to guide, mentor, and engage future engineers. A single project type is presented here, but in order for students to truly become engaged in their learning, they need to at least be able to choose among several different projects—and, ideally, once faculty are sufficiently skilled in guiding multidisciplinary designs for diverse projects –also be free to develop any idea they can convince professors and/or engineers from industry to support. These reforms consider only one university, yet the advantages in information sharing, mutual faculty support, and student competition that a network of cooperating universities can generate will do much to transform a local initiative to an example of global best practice.

Acknowledgements—We would like to thank Professors Tim Wolfe, Hal Walker and Motomu Ibaraki for providing the opportunity to experience a capstone in The Ohio State University, the original inspiration for this paper. We also very much appreciate the communicative, explorative, and critical efforts of our colleagues from the XAUAT training team in OSU. And of course, we are most grateful for this support of the Innovative Trail District (2010–2012) and the Teaching Demonstration Center (2010–2012) within the Chinese Ministry of Education and the Training program from State Administration of Foreign Experts Affairs of China.

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