# A unique and effective way of teaching a capstone/senior design course

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ABSTRACT: A senior design course should provide engineering students the opportunity to solve real-world problems. As such, it is, a part of the curriculum of most engineering programmes worldwide, including the curriculum of the Industrial and Management Systems Engineering (IMSE) programme at Kuwait University (KU), which is an ABET (the Accreditation Board for Engineering and Technology) accredited programme. The senior design course of the IMSE programme at KU is unique and effective. In particular, at the stage of problem identification, students identify problems as opposed to the common practice of faculty members identifying them. In this article, four questions are addressed; how an organisation is selected, how a problem is identified, how the senior design course outcomes map to the ABET student outcomes and how a project is evaluated. The answers to the four questions are provided as a result of the author's experience of teaching the senior design course in the IMSE programme for more than a decade. Important factors to discern in selecting an organisation are stated and essential aspects to observe in identifying a problem in the organisation are specified. Programmes from other universities may benefit from the lessons learned.

Keywords: ABET, capstone/senior design, education, industrial engineering, problem identification

## INTRODUCTION

A capstone/senior design course provides engineering students the opportunity to solve real-world problems and, hence, it is a part of the curriculum of most engineering majors worldwide. Todd et al provided a survey of capstone design courses in engineering departments throughout the USA in order to understand current practices in the capstone design courses [1]. Moreover, Dutson et al described the standard practices and state of capstone design education as revealed through a literature search of over 100 papers related to engineering design courses [2].

The issue of design in engineering education was addressed by many researchers, including Odora [3], Katz [4], Storbel et al [5], Mahmud et al [6] and Davis et al [7]. Teaching design in senior/capstone courses has increased recently as a result of an effort to better prepare graduates for engineering practice.

It is reported that engineering graduates are increasingly expected to work in team-based projects and, hence, employers are looking for graduates with strong teamwork capabilities (Natishan et al [8] and Willey and Freeman [9]). As a result *…an ability to function on multidisciplinary teams* is included as a student outcome in the ABET Engineering Criteria.

A concern that the senior design course students have is the amount of time, work, and stress and its impact on the students' academic performances on this and other courses. Therefore, Nobes et al investigated the effect of senior design project workload on student performance and reported that students have typical workloads of 15 hours/person/week, on average, and it may be as high as 25-40 hours/person/week [10].

Furthermore, Gruenther et al investigated the influence of prior industry experience and multidisciplinary teamwork on student design learning in a capstone design course [11]. Moreover, Zou and Ko assessed the teamwork development process for capstone design course [12]. They assessed the intended learning outcomes of teamwork skills by both qualitative and quantitative methods. On the other hand, Cooper et al proposed a method of evaluating different senior design projects against common outcomes [13].

Shin et al discussed the benefits of developing capstone design course and internship in combination with industry [14]. They also stated that it is not easy to check the progress and status of students periodically during the period of internship. However, they stated that during the capstone design course, it is easier to check each student's progress.

They further stated that the students have the opportunity to deal with real world problems and to prepare their future profession during the capstone design course.

The capstone/senior design course is part of the curriculum of the Industrial and Management Systems Engineering (IMSE) programme at Kuwait University (KU). The IMSE programme has been accredited by the Accreditation Board for Engineering and Technology (ABET) for many years. In the senior design course, students have an opportunity to utilise the methods, techniques and tools that they have learned from different courses in solving real-life problems. ABET emphasises the need for engineering courses providing engineering design, teamwork, communication skills in addition to other skills. The senior design course of the IMSE programme provides the students the opportunities to develop skills including design, teamwork and communication.

Savsar and Allahverdi presented a detailed description of the senior design course of the IMSE programme [15]. They also described the course role, its objectives, learning practices, and its relation to the other courses in the curriculum. Furthermore, they provided a brief list of the selected organisations and statistics about the tools that the students utilised in the completion of their projects. In the current article, the answers to four questions are sought: how is an organisation selected? How is a problem identified? How do the course outcomes map to the ABET student outcomes? And how is the course evaluated? The author, an ABET evaluator, has been teaching the senior design course for more than a decade. He believes that the way the senior design is being conducted in KU's IMSE is unique and effective, and that programmes from other universities may benefit from it.

All the students in the senior design course select a single organisation. The students are divided into three to five groups, depending on the size of the class, where each group addresses a different problem. The selection process of an organisation is defined in the next section. The problem identification phase, the mapping of the senior design course outcomes with the ABET student outcomes, the evaluation of the senior design course are presented and discussed in the following sections, and concluding remarks are made in the last section.

## SELECTION OF AN ORGANISATION

The selection of an organisation is an important first step for problems to be identified and solutions to be proposed for each group of the senior design course team. However, the team is not aware of this issue at the beginning of the semester. Therefore, the instructor emphasises this issue in the first lecture of the semester. The instructor requests that the team members identify some potential organisations to be discussed in the next lecture. The instructor recommends that the students should keep three considerations in mind, while searching for an organisation.

The first one is that a private organisation is preferable to a government organisation since getting some of the required data from a private organisation is usually easier and faster, based on earlier course experiences. Another advantage of working with private organisations is that they usually either have one day off as the weekend or working seven days a week. This makes it possible for students to observe the organisation and collect the required data in a relatively shorter time. One more advantage is that some private organisations work in two or three shifts and this allows students to visit them more often, including after their classes. Certain milestones of the project, such as the final presentation to faculty members, cannot be postponed, which is another advantage of choosing a private organisation. It should also be noted that some groups may need to observe the system and collect the required data themselves. However, for example, if the required data is monthly demands or sales, the students do not have time to observe the data and, hence, need to get the data from the organisation. It should be noted that some government organisations have been selected in the past and important improvements have been suggested for them.

The second consideration is that a manufacturing organisation is preferable to a service organisation, since students can observe a manufacturing organisation better and that more problems can be identified in a shorter time. On the other hand, service organisations have been considered in the past and significant improvements have been obtained. Moreover, the vast majority of students in the Department are women, and female students prefer *cleaner* organisations that are closer to the city.

The third consideration is related to the size of the organisation to be selected. There are three to five groups in a senior design team and each group needs to identify a problem to be addressed. If the size of the organisation is small, then, it might be difficult to identify several different problems, where usually interrelated problems are desired. Hence, the bigger the size of the organisation, the better it is.

The organisations the students come up with, are considered in the next lecture, with the pros and cons of each being discussed. The groups of the senior design team are formed, where the number of groups changes from three to five depending on the number of students registered for the class. The maximum number of students in the class is 15.

The number of candidate organisations is reduced and each group is assigned with the task to visit each of these few organisations. The most important factor to observe is the willingness of the management of the organisation to help and facilitate. Of course, another factor is to be able to identify enough problems for each group, where at this stage only a rough guess can be made.

In the subsequent lecture, each group gives a short presentation about the organisation visited, and discusses the pros and cons. If unanimous agreement cannot be reached, the decision is made by voting. The students are given a formal letter from the instructor to the selected organisation requesting that the students would like to conduct their senior design project at their organisation, including the number and name of students. It has been observed that some organisations may not accept so many students, as they mistakenly think that the students will be trained at their organisation. However, the organisations are informed that students will be conducting analysis to improve the system and, usually, the organisations agree.

## PROBLEM IDENTIFICATION

Shin et al (2013) stated that finding proper real-world problems is not easy. They further stated that faculty members could find potential projects when participating in conferences, training, and at any event at which they meet new people. Therefore, many universities and industry strategic partnerships have been reported to find proper real-world problems by Fornaro et al [16] and Kornecki et al [17]). The literature review reveals that in general, faculty members find problems for senior design students. However, in the senior design course in the IMSE programme, students identify problems themselves in consultation with their instructor. The author believes that it is crucial that students identify problems themselves.

Once the organisation is selected, the next two to three weeks are spent in identifying the problems to be addressed by the various groups. In general, during the first week, students just observe the organisation for identifying a problem and ask different questions to employees, engineers or managers. The team meets during lectures and members discuss their observations and findings. The groups in the team are recommended to look for more than one problem, if possible. During the following week, each group presents the problem they came up with, and the instructor guides them and asks many questions about the problem that they have identified. Some problems that the groups have identified may not be feasible for reasons, such as:

a. The time is not sufficient to solve the problem. It should be noted that the students only have about two months to solve the problem after it has been identified.
b. The identified problem requires data that is either not available or is confidential. For example, if the identified problem requires monthly demands or sales, and the data is not available, then, students do not have time to collect these data. It should be noted that some organisations provide confidential data with the assurance that the data will not be released.
c. The instructor estimates that the students cannot solve the identified problem.
d. The solution of the problem is too easy. The objective of the course is the application of industrial engineering methodologies, techniques and tools to solve real-life problems. Therefore, the students should use some IE methodologies, techniques and tools.
e. After getting some initial data, it becomes clear that the solution of the problem is not significant. For example, if the problem is to reduce the number of rejected products in a production line and the reduction of the rejected products results in a saving of $20 per day, then, the problem may not worth being addressed.
f. The cost of the proposed methodology may be too high. For example, the cost of reorganising a finished product warehouse may be large compared with the savings from shutting down the production line as a result of not having enough space to store finished items. However, if the organisation is in the phase of opening a new warehouse, then, the design of such a warehouse is important.
g. The instructor estimates that an improvement cannot be achieved. The students, at the end of their project, may realise this fact. However, it would be too late to change the problem.

In such cases, the instructor recommends that students look for an alternative problem that can be identified in a short time. The students are recommended not to use the word *problem* at the organisation since the management at many organisations do not want to hear this word. Therefore, the students state that they are looking for opportunities to improve the organisation.

It should be noted that the problem identification is the most difficult and stressful phase of the project and, hence, students are anxious during this phase. Therefore, during the lectures, the students are frequently reminded that this phase is the most important and difficult, and that once the problem is identified, the remaining part of the project is not going to be as stressful.

It is important for students to identify problems themselves rather than the instructor proposing problems for each group. This is an important component of the senior design course since the problem should be open-ended. The identification of the problem is graded.

## MAPPING OF THE COURSE OUTCOMES AND ABET STUDENT OUTCOMES

Student outcomes are defined by ABET as …*Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviours that students acquire as they progress through the program.* ABET student outcomes are: a) an ability to apply knowledge of mathematics, science,

and engineering; b) an ability to design and conduct experiments, as well as to analyse and interpret data; c) an ability to design a system, component or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability; d) an ability to function in multidisciplinary teams; e) an ability to identify, formulate and solve engineering problems; f) an understanding of professional and ethical responsibility; g) an ability to communicate effectively; h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context; i) a recognition of the need for, and an ability to, engage in life-long learning; j) a knowledge of contemporary issues; and k) an ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

A brief description of how the ABET's *a-k* outcomes are addressed in the senior design course is given below. The utilisation of each outcome may vary from project to project even though some of the outcomes are heavily utilised in all the projects, as will be explained later.

While working on a solution for an identified problem, each group needs to apply the knowledge of mathematics, science and engineering. Some of the required data can be collected from the organisation, while other data need to be observed and collected by the students, where the students are required to design their data collection environments in order to have a meaningful analysis. Once collected, the students analyse and interpret the data in order to propose a solution to improve the system.

The concept of design is heavily used in the course. The author believes that in no other course is the design concept used as much. Moreover, since the students address real-world problems, their proposed solutions have to be within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.

As stated by Zou and Ko [12] and Dutson et al [2], in general, students are not receiving enough training that enables them to function effectively in a collaborative environment. However, a collaborative environment is provided for the senior design students in the IMSE programme of KU. Specifically, the senior design team consists of three to five groups, all working in the same organisation. Therefore, all groups have to work together; especially, when their problems are interrelated. For example, one group identifies that as a result of not efficiently using finished product warehouse, the production is shut down for few days in a month. A second group works on the minimisation of the number of setup times in the production line due to flavour changeovers, and comes up with a schedule, which results in reducing the number of setup times. This makes using the finished product warehouse more efficiently even more important. Furthermore, a third group works on reducing the error between the actual and forecast demands. This also affects the utilisation of the warehouse. Therefore, the course provides a collaborative environment where the students have to function effectively since each group has to come up with an improvement for their identified problems, which are usually interrelated.

The identification of problems was addressed in the previous section. The instructor does not identify a problem for a group, rather each group needs to observe the system and identify its problem. Of course, the identified problem is discussed with the instructor and some initially identified problems may not be feasible for the reasons stated earlier. Each group needs to formulate the problem and propose a solution. The groups have to show that their solutions indeed improve the system and the proposed solutions are cost effective.

All the groups are in contact with employees, engineers and managers of the organisation throughout the semester, and have to understand professional and ethical responsibility. For example, no organisation would like its information and data be leaked to outside. Moreover, some data are confidential. Therefore, students are often reminded about their professional and ethical responsibility.

Each group has to deliver ten oral presentations, where each time the instructor gives detailed feedback for improvement. Moreover, groups have to submit two written reports that are also evaluated comprehensively, and feedback is provided for enhancing the group's written capabilities.

The impacts of the proposed solutions on global, environmental and societal contexts are discussed with the instructor, and company designate, who is usually an engineer or manager. Cost analysis is conducted for all solutions to account for economic feasibility.

Some of the identified problems cannot be solved using only the methodologies, techniques or tools students have learned in their courses. Therefore, students may need to search the Internet and learn new methodologies and techniques. Furthermore, students may need to search the literature to find solutions to similar problems that they have identified, so that they may come up with feasible solutions. Occasionally, students need to benchmark their solutions where again they need to search the literature. This is where students recognise the need for life-long learning.

Given that students solve real-world problems in an organisation, they face contemporary issues and learn about them. Students use the techniques, skills and modern engineering tools that they have learned throughout their undergraduate education to solve the identified real-life problem, which is an engineering practice. On the other hand, if they need

some techniques and tools that they have not previously learned, they learn them on their own, with realising the importance of life-long learning.

While conducting their senior design project, students of the senior design course need to have the ability of the aforementioned ABET *a-k* outcomes in order to satisfactorily complete their project. Although the degree of utilisation of outcomes *a, b, h, i* and *j* may vary from one project to another, the utilisation of outcomes *c, d, e, f, g* and *k* are essential in successful completion of all the projects.

## EVALUATION OF THE COURSE

It has been observed that meeting during lecture times throughout the semester puts pressure on students to work harder. Having regular meetings is also good for the instructor to follow-up progress. It has also been observed that it is better to have the lectures on three days rather than on two days per week, since if the lectures are on two days a week, there is only one day between the two lectures, so not much progress can be achieved. During the first six weeks, all groups of the project team meet during the lecture times. For the following weeks, the instructor meets each group separately, at least twice a week. However, all the groups of the team also meet together during some of the lectures.

Each student is evaluated throughout the semester during the meetings and a personal grade is given to each. Once an organisation is chosen, the next important step is the identification of the problem. This is graded as a group.

The capstone design course allows students to practice their communication skills via written reports and presentations (Shin et al., 2013). In the senior design course, the students have a chance to practice their communication skills since at least two comprehensive reports and three main presentations are required, where other faculty members in the Department are also involved.

Students have three general presentations; first technical presentation and final technical presentation to faculty members, and final technical presentation to the public. Students present the problem that they have identified along with their proposed methodology during the first technical presentation, while they present the solution during the final technical presentation. During both first and final technical presentations, faculty members evaluate students as groups, while the instructor evaluates them individually. Moreover, students have to present their work to the public during the final technical presentation where faculty members from other departments in the College, representatives from the organisation where the students conducted their project and parents/relatives of the students are invited. The instructor grades students individually, while they are graded by other faculty members as groups. Students have to present their first and final technical presentations two or three times to the instructor in order to get feedback and get ready for those presentations. During these preparations, the instructor evaluates the students individually, as well as a group. The presentations are evaluated based on organisation, subject knowledge, visual aids, surface features, eye contact, and elocution on a scale of 1 to 4 for each specified component.

Students are also evaluated based on rewritten reports. There are two reports for each group: the first and final reports. The first report includes identified problems along with proposed methodologies, while the final report includes the detailed solution for the identified problems. The reports are evaluated based on ease of understanding, appropriate use of visual tools, logical presentation of ideas, quality of technical information, quality of outcomes and overall report quality. The students are taught how to write good reports during the lectures. Both the first and final reports are evaluated thoroughly by the instructor. The final report is also evaluated by two other faculty members in the Department.

The instructor has the group members evaluating each other at the end of the semester. Each student evaluates every other student in the group on a scale from 1 to 5 in terms of quality of the work, quantity of the work, creativity, reliability, teamwork and team norms.

To summarise, each student receives a grade consisting of two components: individual (distinct grade for each individual), denoted by I, and group (same grade for each group member), denoted by G. The graded items consist of: meeting performance (I), problem identification (G), first technical presentation preparation (I, G), first technical presentation to the faculty members (I, G), first written report (G), final technical presentation preparation (I, G), final technical presentation to the faculty members (I, G), final technical presentation to the public (I, G), final written report (G), group member evaluation (I) and meeting deadlines (G).

## CONCLUSIONS

Students in the IMSE programme at KU, like most engineering students, are required to complete a senior design course during their final year of undergraduate studies. The students in the senior design course are typically divided into three to five groups where all the groups address different problems for the same organisation in order to come up with improvements. Unlike the majority of programmes, the students of the senior design course at the IMSE programme identify problems themselves in consultation with their course instructor. As a result of teaching the senior design course in the IMSE programme for more than a decade, the author identified important factors that should be taken into

consideration while selecting an organisation. Essential factors to consider while selecting a problem are also described. Moreover, the mapping of the course outcomes with the ABET student outcomes is described along with the evaluation of the course. Programmes from other universities may benefit from the lessons learned in teaching the course in the IMSE programme at KU.

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## BIOGRAPHY

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