Approach of Integrating Subject Matter Experts into Capstone Design Course

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Abstract

This paper discusses an approach of integrating subject matter experts in teaching capstone engineering design course. The approach requires the engineering student design teams to find at least five subject matter experts in the field of the defined project. The subject matter experts are committed to serve in the design and manufacturing discussions of the design concepts and participate during selection of the final design project. The design team taps into their technical and field experiences during the design discussions. A case study of this model is presented with the capstone project on 2021 Air Force Research Lab University Design Challenge. The integration of subject matter experts into the process of capstone design projects widens the scope of engineering design solutions that the teams accomplish. Also, the students gain better field engineering design experience by interacting with the subject matter experts. This approach supports the idea of increasing senior design or capstone design component in engineering curricula as part of the effort to better prepare graduates for engineering practice.

Keywords

Subject Matter Experts, Engineering Design, Engineering Capstone, Faculty Paper, University Design Challenge

1. Introduction

Engineering education continues to emphasize teaching engineering design at the senior level with industry-oriented projects. Engineering design is defined by Accreditation Board for Engineering and Technology (ABET) as “the process of designing a system, component, or process to meet desired needs. It is a decision making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet these stated needs” [1]. The ABET General Criterion 3, student outcome (c), requires that students demonstrate “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” [1]. The ABET General Criterion 5 states that “Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints” [1]. Therefore, capstone design courses and/or the experiences presented to students are both highly valued and required by accrediting organizations such as ABET. According to Paretti et. al, capstone design courses serve as critical preparation, providing students with confidence to learn new things and strategies for building new knowledge. The courses provide authentic industry experiences through open-ended projects that place students out of their comfort zone. And requiring students to seek and connect with subject matter experts supports this notion. Through capstone design, students assimilate the knowledge they have gained in education, and use skills in a setting that requires professional attitudes and behaviors. The faculty teaching capstone design can help prepare students for this self-directed learning through guided mentorship and modelling effective learning behaviors [2]. The implementation of the outcomes-based engineering accreditation criteria has heightened faculty awareness of the importance of the capstone experience and assessment instruments have been developed with nationwide common interest from colleges [3].

Conventionally, the engineering design process involves a series of twelve steps that engineers follow to design and create products. The process steps allow for applied science, mathematics, and engineering sciences to achieve a high level of optimization to meet the requirements of the design goal within the boundaries of design constraints. Sometimes, a couple of these series of design steps can be repeated before moving to the next step. The sequence of steps that are followed will depend on the type of project but allows lessons to be learnt from unsuccessful steps and improvements to be made. Literature shows that students would typically jump from problem definition to brainstorming to solve client design problem without taking into consideration the user’s opinion or expert’s technical experience. The design and manufacturing industries gather design feedback through customer surveys or social media to uncover their customers’ wants, needs, and behaviors. However, many of the product users are sometimes not experts and experienced enough to make advanced technical recommendations. In the design and engineering of unconventional innovative solutions such as products for special operation force applications, users of such innovative product are usually not handy. Previously, the design teams would work with the clients and professors to address an engineering design presented by the client.

In this paper, a model of integrating subject matter experts (SME) in the design process is presented to close the void in the design steps as shown in Figure 1. The SMEs are included in the engineering design interactions that occur between the student design team, clients, and professors. This approach provides opportunity for the design team to increase the scope of the functionalities and design features of the original clients’ requirements. A case study of the model is presented with a project conducted on Air Force Research Laboratory (AFRL) University Design Challenge and it illustrated that the approach enhanced the design functionalities stipulated by the AFRL.

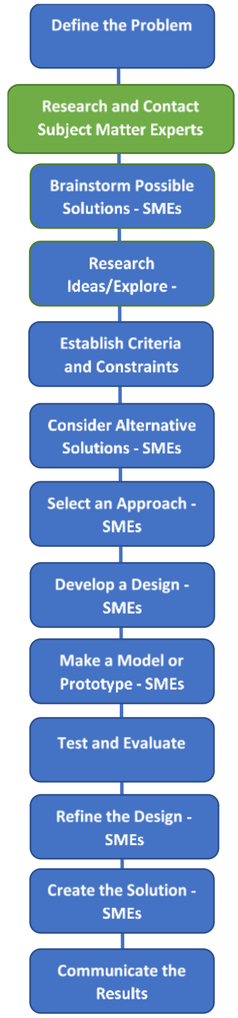

Figure 1 Subject matter experts (SME) integrated into the traditional series of steps in engineering design [4]

2. Description of the Program, Capstone Course and SME Integrated Approach

The curriculum in mechanical & industrial engineering (MIE) emphasizes design, manufacture, and automation while preparing students for careers in industry and continued education. A four-credit engineering design course is designed for the senior level mechanical and industrial engineering students. The course consists of an hour of lecture and three hours of laboratory work each week. MIE department has dedicated a large room capable of housing seventeen cubicles with each cubicle assigned to a capstone design team for team meetings and official documents. The course also has a laboratory space dedicated to lab work and a workshop equipped with a wide range of traditional manufacturing and testing equipment to support its practice oriented, hands-on, design-centered curriculum.

2.1.Capstone Course

The MIE senior design course uses real life engineering problems to teach design and project management skills to the senior engineering class. During the course, the students provide real consulting services to real industry clients and launch their long rewarding career as engineers. Traditionally, the student teams work with the projects' clients and the professors during the semester. In the model discussed, the student's team would be also required to work with SMEs and demonstrate their interaction with them during the project as shown in Fig. 2. The students work in teams learning engineering design skills, responsibility, and professionalism. Before the beginning of the semester, the instructors of the course solicit real life projects from industries, academic units, and research labs with commitments. The projects' brief descriptions with contact personnel are published on the course's platform for the incoming students to familiarize themselves with. On the first day of the course, the instructors would go through the projects and request students to formally apply for the projects that interest them with their resumes and cover letters. The students are instructed to indicate their top three choices of projects on their cover letter. This process of formally applying for the projects provides the students the opportunity to learn how to prepare professional resumes and cover letters while using the school's career and development office. The senior design course is taught in one semester and therefore requires that everyone involved (students, instructors, SMEs, and clients) would stay on top of the fifteen-week course timeline as shown in Table 1.

The enrolled students must have taken Two-credit course on Engineering Professionalism and Practice (EMGT 4110) a semester preceding this course. This pre-capstone course focuses on professional responsibilities of engineers and expectations of industry and society; ethics and law for engineers; codes of ethics and professional engineering societies; design, intellectual property, record keeping; environmental and safety issues in design; group processes; conflict management; and project management.

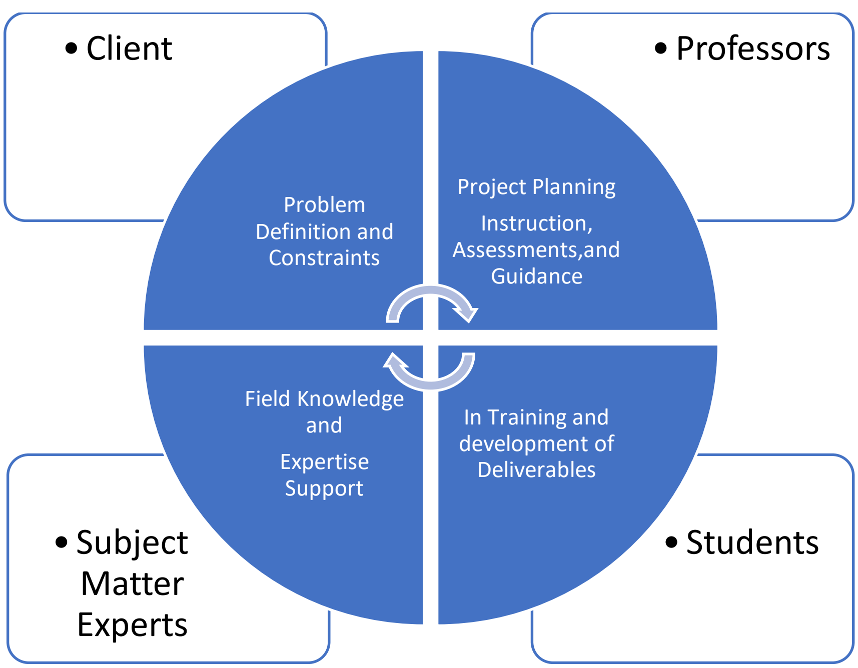

Figure 2. Model of Capstone Design Course Integrated with Subject Matter Experts

Table 1 Fifteen-week schedule for the Capstone Design Course

Weeks	Design Steps to Cover	Description of Outcomes
One and Two	Define Problem and establish Subject Matter Experts	Students meet with client to define problem. Students prepare a charter and send back to client. Constraints and deadlines are documented. Team member roles are selected. Project manager of team is elected by team members. ***Minimum of five subject matter experts (SME) in the field of project are contacted and documented***. Client and Professors okay teams' charter document.
Three, Four, Five	Brainstorm Alternative Solutions	***Minimum of three alternative solutions to the problem are documented and discussed with the SMEs***. Decision making criteria is established. Decision matrix table is used to recommend optimal solution.
Six	Select Solution and Baseline Report	Baseline report is prepared for the client and baseline presentation is scheduled with client. Client agrees with recommendation or makes changes as desired. Professors and client evaluate presentation and report.
Seven and Eight	Develop a design	Full engineering design is prepared on the selected conceptual solution. ***The SMEs feedback are incorporated in the final design.*** Engineering analysis and numerical models are conducted to support design.
Nine	Critical Design Review	Final design review is presented to the client and professors before big financial commitment to the project. Submit part list. Order parts considering lead time. ***SMEs are encouraged to participate***.
Ten and Eleven	Manufacture a model, prototype	Manufacture, consider outsourcing, additive manufacturing.
Twelve and Thirteen	Test and Evaluate	Test the prototype and evaluate performance. ***Discuss with SMEs and gather input. What did SME say?***
Fourteen	Refine Design	Make refinement if necessary.
Fifteen	Communicate Results	Prepare final report, presentation, manuals for clients and professors.

2.2. Objectives of the Course Model

The technique of integrating SMEs into capstone design course presents unique opportunity for the students to learn new materials and strategies for building innovative knowledge and enable them to perform the design tasks upon completion of the course. The listed course objectives below are designed to meet the ABET engineering design goals and they are used in the Mechanical & Industrial Engineering program's ABET goals assessment.

a. Solve a significant real-world problem for an industrial sponsor using engineering design.

b. Apply engineering skills and techniques to determine the root cause(s) and develop recommended solutions of the key problem(s).
c. Develop skills to work on a multi-functional team.
d. Develop skills in data gathering and interaction with production and management level employees, in a professional and ethical manner and recognizing the need for lifelong learning.
e. Hone communications skills for oral presentations and written reports.

2.3. Subject Matter Expert Involvement

The subject matter expert (SME) is an individual who has a high level of expertise in performing a specialized job. The SME would bring expert or technical assistance to the project and they would be involved as members of the project and advisors throughout the project engagement. Table 2 lists typical technical supports that a design team would anticipate to receive from a SME, especially during the brain storming and analysis phases of the project **[5]**. The SME involvement throughout the fifteen-week schedule of the capstone design project in MIE program is also highlighted in Table 1.

Table 2. SME Activity on the Project **[5]**

Activity	Design Output
Advise project manager and design team on technology strategy	Offer technical advice and recommend strategy
Review current architecture	Review and document findings
Plan and motivate for technology	Offer technology support and motivations
Design the future technical architecture	Establish the future technical architecture
Build and assemble technical solution	Build and present the feasibility of the solution
Test the technical solution	Prepare test cases and scenarios and perform testing of the technical solution

2.4. Communication

Communication between the student design team, professors, clients, SMEs, team members is ubiquitous. The students in a senior design team elects a project manager and the project manager holds the responsibility of all communication that take place during the project. This is a critical aspect of the project management and provides unique opportunity for the project manager over the course of the project. In the case of communicating with the SMEs, a team member may lead the interaction between a particular SME who has been connected to the project by the team member. The team is required to gather design suggestions and maintain communication with the SMEs throughout the project. They should document specifically why the SMEs like or dislike certain designs.

2.5. Assessment

The goal is to be able to assess the course goals achieved by the student design team and the individual students. This is accomplished by diving a project into components and making sure that each student is assigned a primary leader in a division while maintaining secondary contributor in other divisions as illustrated with Fig. 3. Each student in the team is required to speak during all the three major oral presentations over the course of the projects. This allows the instructors to monitor individual and team progress with oral communication. Each team presents one final report that have been prepared through coordinated efforts of all team members. Again, the instructors monitor the efforts from the team's design folder. An example of evaluation form used to evaluate the students individually and as a team during presentations is shown in Table 3.

Table 3. Senior design oral presentation evaluation

Evaluation of Content

	Not at All			Very Much
The team provided a clear introduction to the problem	1	2	3	4
The approach to the problem was reasonable	1	2	3	4
The team provided good explanations of the decisions they made	1	2	3	4
The final design was clearly presented and explained.	1	2	3	4

Evaluation of the Presentation

Team Overall Evaluation

	Poor			Excellent
Content of presentation – addressed major issues in sufficient detail	1	2	3	4
Clarity of presentation – provided clear explanation of content	1	2	3	4
Visual aids – easy to read, helped clarify specific points	1	2	3	4

Individual Evaluation

Presentation Skills – posture, eye contact, voice, appearance, body language

	Poor			Excellent
Team member ___________________________	1	2	3	4
Team member ___________________________	1	2	3	4
Team member ___________________________	1	2	3	4
Team member ___________________________	1	2	3	4

3. Case Study – Air Force Research Lab (AFRL) University Design Challenge

3.1. Client and Project definition

Air Force Research Laboratory selected UMD to participate in the 2021 University Design Challenge in the development of innovative design solution to automatically insert awareness sensors such as surveillance camera in different defined scenarios to simulate denied areas. There were about fifteen national colleges involved in the engineering design challenge. This project was employed as one of the senior design capstone projects in MIE and electrical engineering departments for fall 2020 and spring 2021. The mission of capstone team was to research and develop a method for the placement and operation of remote awareness sensors in denied hostile environments.

3.2. Design constraints

The AFRL specified that the designed solution should consider size, weight, and power (SWAP), cost, flexibility, durability, adaptability, usability, maintainability, trainability, mobility, deplorability in a covert operation, discoverability, securability, and timeliness. The budget for the project is limited to $25K which included cost of travel to the Air Force base where the design challenge would take place.

3.3. Design functionality

The AFRL stated that the design teams would anticipate test scenario around an obstacle course covering the areas up to and including from 6 inches deep below the surface (soil or water) to 100 feet above the surface (building, tree, light post) to maneuver and place awareness sensors. The prototype should be able to remotely monitor a wide area (up to 200 ft away) and easily transported by the special operation force (SOF).

3.4.Student Team

After collecting cover letters and resumes of all students registered in the course, the project teams were formed to have multidisciplinary characteristics; as a result, providing opportunities for the students to learn engineering from varying perspectives. The phase one of the project in Fall 2020 comprised of two mechanical engineering and two electrical engineering senior students. The final phase of the project in Spring 2021 was comprised of four mechanical engineering students, three electrical engineering students, one engineering physics, and one computer science. The project is decomposed into five major units to allow for design assignments to students, accountability and final assessment of individual students learning as illustrated with Figure 3.

3.5. Subject Matter Experts Involvement

The approach requires the team of students to research and identify a minimum of five SMEs in the field of the project. The SMEs contact information is shared with the instructors for confirmation of their commitment to the project. Over the period of the project, eleven SMEs were involved, and their related expertise can be seen in Table 4. The involvement of the SMEs can be remotely or in-person.

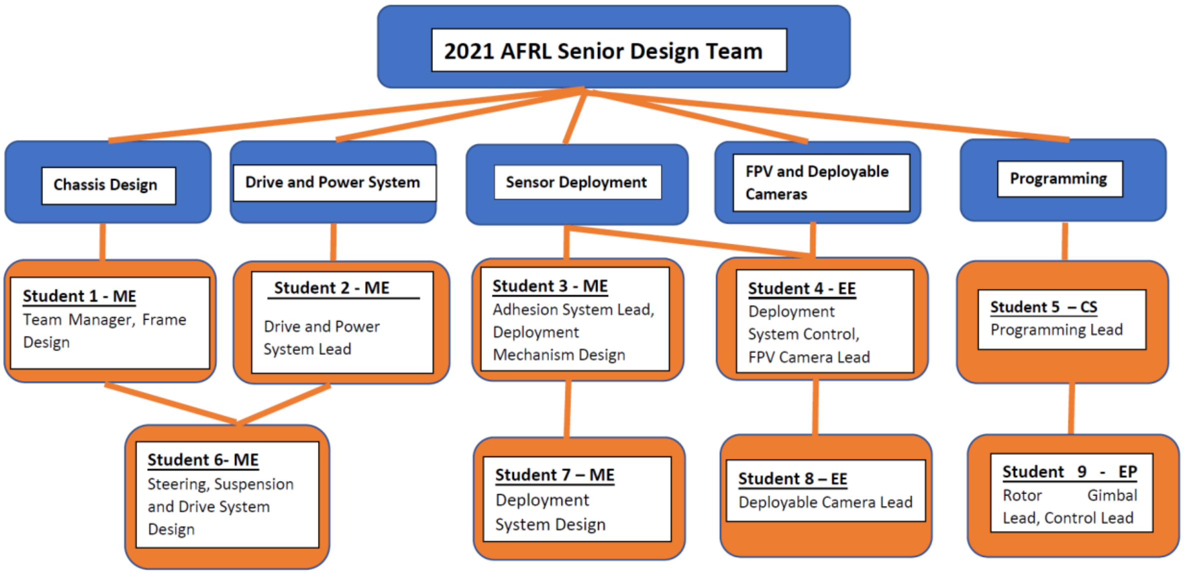

Figure 3. Project system decomposition diagram

Table 4. SMEs Involved in the Project with Expertise

SME	Expertise
X1 (Capt.)	Strategic Level Operational Officer, 20-year military veteran
X2 (SSgt)	Special Tactics Operator/SpecialReconnaissance, 6-year veteran
X3 (Dr.)	Adhesives & Composites Materials Engineer, SystemSupport Division at Wright-Patterson Air Force Base
X4	Master Adhesive Lab Technician,3M Corp
X5	Field Service Rep for ContropUSA Drone Surveillance,USMC Veteran
X6	Off Road Systems Engineer atPolaris
X7 (SSgt)	Infantryman inside US Army
X8	Electrical Engineer Specializingin Power Conversion Design
X9	Mechanical Engineer at COHU Corporation Specializing in TestFixtures
X10	Designer at CPP Specializing inAirplane Parts
X11 (Major)	UMD ROTC and AerospaceStudies

3.6. Interactions between SMEs and Students

The original project definition was design and build a prototype solution for remote insertion of awareness sensor in a remote denied area. The student design team is required to present three or more alternative design solutions to the SMEs, professors, and clients. The four design solutions considered and analyzed by the design team were: use of a quadcopter, wall climber, adhesive projectile, and individual flying sensor systems. A set of design criteria was used to arrive at the wall climber as the recommended design solution to the client, AFRL. After the presentation of the feasible design concepts by the design team, the SMEs provided numerous feedbacks to the design team on desirable design characteristics for a prototype and synthesized into summary Table 5.

Table 5. Summary of SME feedbacks interactions with the student design team

	Design Characteristics	SME 1	SME 2	SME 3	SME 4	SME 5
1	Portability (< 35lbs)	x				x
2	Covert	x	x	x	x	x
3	Trainability	x				x
4	Smart Battery Life	x				
5	Rugged (Durability)	x				x
6	Repairability	x				
7	Easy Battery replacement	x				
8	Switch Battery Modes: game camera to a normal camera	x				
9	Not less than 200 ft camera view	x	x			
10	Solar power for battery charging	x				
11	Pack for easy battery charging	x				
12	Aerial Sensor Placement (ground is obsolete)		x			
13	Remote toggling of camera		x			
14	Detection of low and high radio frequency		x			
15	Detection of enemies' sensor		x			
16	Smallest Camera size			x	x	
17	Mavic Air 2 Drone capacity of 800 grams lifting capacity.			x		
18	Kinect – video game console that is able to detect human shape				x	
19	Sensor monitoring modes					x
20	Infrared rays – night vision					x
21	Simple battery pack AA					x
22	Cell phone triangulation					x

3.7.Design Solution

The team developed a remote-controlled Sensor Deployment Rover (SDR) with the ability to traverse the ground as well as scale up walls using drone-type propulsion, see Figure 4. The SDR is equipped with 4-wheel drive, 4-wheel steering, two gimballed thrust propellers and an onboard sensor deployment system that allows the operator to deploy multiple sensors on ground terrain and vertical surfaces such as walls and buildings. All these features combined into one rover allow for sensor deployment in an array of locations, giving SOF optimal surveillance capabilities.

The SDR can be fully controlled by one operator via the Herelink digital transmission system. The SDR has two cameras that provide the operator with first person-view (FPV) video of the rover on the Herelink controller during operation and sensor deployment. The SMEs stressed the importance of simplicity in operation, therefore the operation and control of the SDR is designed to be as straightforward as possible. The flight data and rover FPV video are displayed on the large touch screen embedded in the controller. Additionally, the FPV video is streamed to the Android Team Awareness Kit (ATAK) network, providing all operatives with the most up-to-date information. Deployment and camera reloading can be carried out with a press of a button once the SDR is in position. Once the sensors are deployed, the camera feeds can be monitored on a separate wireless display.

Figure 4. Final Prototype of the Sensor Deployment Rover (SDR) Design

4. Discussion

The engineering capstone team completed the project within the mandated timeframe and design constraints using the project management tool taught in the course. Originally, the AFRL design challenge required that the prototypes will be tested and evaluated against other design solutions from other colleges in the scenarios and obstacle courses covering up to and including from 6 inches deep below the surface (soil or water) to 100 feet above the surface (building, tree, light post). The AFRL required that the prototype should remotely monitor the area (up to 200 ft away). The team met all the required functionalities demanded from the AFRL. The SMEs inspired the team to consider applications of their SDR solution beyond what was required such as in the urban area's operations by the SOF. As a result, there were additional characteristics to the SDR design that included ability to climb stairs and capability to stream first person view (FPV) video to the ATAK network, providing all operatives with the most up-to-date information. The biggest challenge associated with this approach of teaching senior design is the extra pressure put on the student teams to find at least five SMEs that will commit to the project over the full project time. Some of the SMEs were more involved and contributed to a greater extent than others. This is anticipated as they don't all have the same levels of professional career responsibilities.

5. Conclusion

The approach of integrating subject matter experts into capstone design course was discussed and a case study on the use of this approach to accomplish 2021 Air Force Research Lab University design challenge was presented. From the result of the case study and interaction with the students, it is concluded that:

- Integrating subject matter experts in a capstone design course created more exposure to real life experts and learning opportunities for the students.
- This approach presented an opportunity for the design team to engage with and consider potential user needs in the design alternatives.
- The case study showed that this approach can help to widen the scope of original client's design function demands by up to 50%.

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