Designing a Senior Experience in Mechanical Engineering: Culmination of an Undergraduate Program, Preparation for Professional Life, and Reinforcing the Foundation for Continued Learning

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Abstract

The senior experience in an undergraduate engineering program should accomplish at least three main objectives: to serve as a culmination of the undergraduate program, to prepare students to begin their professional life and to ensure that students are on a path of life-long learning. The first objective must include synthesis and application of knowledge acquired in the first three years of the program, namely application of advanced analysis techniques to design. The second objective involves exploration of important issues needed to prepare graduates for professional practice and/or graduate school. The third objective needs to instill student confidence in their ability to learn on their own. The mechanical engineering program at Union College accomplishes these goals through four complementary components of the senior year curriculum: (1) a required two term senior research/design project, (2) required capstone design courses in mechanical systems and thermal-fluid systems, (3) a required weekly senior seminar program, and (4) upper level elective courses. This paper explains these aspects of the curriculum along with the rationale and motivation for their development and provides several examples of the content of each of these components.

Introduction

Union College is a private, predominantly undergraduate institution with principal focus on curricula in liberal arts and engineering. The mechanical engineering program is one of four engineering programs at Union College. In the early 1990’s mechanical engineering and the other engineering programs at Union College undertook a major effort to design an engineering curriculum for the 21st century. This was done with the help of a major grant from the GE Foundation (now GE Fund). Most of this effort was directed at taking advantage of the existing strengths of the technical side of the program and capitalizing on the fact that engineering is taught in a liberal arts environment at an institution with a strong international component in the curriculum. Therefore it is well-positioned to produce broadly educated engineers for the global engineering community of the 21st century. In the new mechanical engineering program there is a strong emphasis on fundamentals in both thermal/fluids and mechanics. This is reinforced by significant hands-on laboratory and design experiences in each of these areas. Communication skills and design are reinforced and practiced across the curriculum. As a college committed to liberal education, Union requires that a substantial part of each student’s education be devoted to study outside the area of the major. This is attained through a General Education Curriculum that adds breadth of learning to the expertise acquired in the major. In addition, all students are
required to fulfill an international component of the curriculum that usually entails some type of foreign experience or study abroad. The undergraduate program concludes with senior year experiences designed to accomplish three main educational objectives: (1) to serve as a culmination of the undergraduate program, (2) to prepare students to begin their professional life, and (3) to ensure that students are on a path of life-long learning.

To serve as a culmination of the undergraduate program the senior year should include synthesis and application of knowledge acquired earlier in the program. Students should conduct engineering design that includes application of advanced analysis techniques and consideration of the impact of engineering solutions on society (including economic, environmental, and sustainability issues) to evaluate design alternatives. The senior experience should also include opportunities for upper-level advanced engineering course work that helps the students gain technical breadth and/or depth. These may include graduate engineering courses to help prepare them for graduate school. Finally, the senior experience should also include opportunities for additional non-engineering coursework to pursue other interests such as preparation for post-graduate professional study in a field other than engineering or to pursue a minor.

Preparing students to begin their professional life should involve exploration of important issues needed to prepare graduates for professional practice and/or graduate school. This can be accomplished by attending seminars from practicing engineers; preparing for the FE Exam; attending lectures on codes and standards, ethics, intellectual property, and safety/product liability; undergoing project planning/scheduling experiences; and developing an awareness of different career paths. This is also accomplished through teamwork exercises where students learn to work on disciplinary and multi-disciplinary teams.

To ensure that students are on a path for life long learning the senior experience needs to lead students to realize that they must continue to learn on their own after graduation to remain current in technological world that is rapidly changing. The senior experience should help students develop confidence in their ability to learn on their own. It should stimulate their intellectual curiosity. These things can be accomplished when students manage a project, learn to work independently, and are connected to the profession through membership in a professional society.

These objectives are consistent with other practical requirements that must be fulfilled in the senior year curriculum. These include satisfying ABET EC 2000 requirements for accreditation of mechanical engineering programs, satisfying the College requirement of a major senior writing experience, satisfying the College mission to promote undergraduate research, and satisfying the mechanical engineering department program requirements of having a capstone design experience in both mechanical systems and thermal fluid systems with multidisciplinary teamwork and oral presentations.

The senior year curriculum in mechanical engineering at Union College is designed to achieve all of these objectives. The basic curricular components of the senior year include: (1) a two-term senior project, (2) capstone design courses in each of thermal/fluid systems and mechanical systems, (3) senior seminar in mechanical engineering, and (4) engineering and free electives. This paper describes each of these aspects of the senior curriculum along with the rationale and
1. Senior Project

The senior project is the cornerstone of our program. It has been part of our program for over 25 years. It is a required two-term (trimester) experience where students complete an engineering project. The experience is designed to be flexible, and can be based on the individual student’s personal interest and goals. Students may choose to work on a design-oriented project or on a research-oriented project. They may work in small teams or they may work individually. Its flexibility and focus on individual contributions sets students up for life long learning.

The design projects typically involve students working individually or in small teams designing, building and testing mechanical components, devices or systems. Some of these projects have been centered on the projects sponsored by the different professional societies such as SAE and ASME (Mini Baja, Formula SAE, and Air Cargo). Other senior projects are done as part of the International Virtual Design Studio (IVDS), an innovative program initiated in the mechanical engineering department at Union College in 1996. This program teams ME, EE and CSE students at Union with EE and ME students at foreign institutions (currently with the Middle East Technical University in Ankara, Turkey and ESGILEC in Rouen, France) to work on a design project. The projects have been in the area of mechatronics design and each of the multinational/multidisciplinary teams must design and construct a competitive device within certain design constraints to meet a challenging set of objectives.

The research projects typically involve individual students working closely with a faculty member (on occasion these are team projects). The project topic is generally related to the faculty member’s research but not exclusively. Undergraduate students are generally not sophisticated enough to develop their own research projects and instead choose a faculty sponsored project because they are interested in the particular topical area. This type of project is often chosen by students planning to go to graduate school. Most of these projects involve some aspect of design in that the student generally works in a lab and must design an apparatus to carry out experiments. However, the focus is more on “research” i.e. learning something new, than it is on design. Over the past five years 15 student co-authored papers have been published (many with presentations by students at national engineering conferences) and 15 students have presented their work at the National Conference on Undergraduate Research.

Students choose a project at the end of their junior year and submit a proposal to the department for approval. As part of the senior project experience they are required to attend the weekly department seminar series; to participate in required weekly meetings with the project advisor; to keep a laboratory/design notebook (journal) that is available for review by the department; to apply for internal funding for the project if necessary; give a minimum of two oral presentations; submit a written progress report at the end of the first term and a final report at the end of the second term to department chair and project advisor; to set up a project web page; and complete a senior project evaluation at the end of the project.
Over the past two years, out of 33 completed projects, 70% were individual projects (of these approximately 56% were research oriented, while the other 44% were more design oriented). Further, approximately 40% of the individual projects were student initiated (developed from student personal interest) while 60% were faculty initiated. A higher percentage of the design projects stem from personal student interests than do the research (66% for design projects versus 23% for research projects).

A smaller percentage of students choose to work in teams for the Senior Project (only 30% of the 33 projects). Of these 80% of the team projects involved interaction with a foreign team member (under the IVDS experience described above) to design something, while the other 20% worked individually, on a particular piece of a larger project (i.e. as part of a robotic club, or SAE car).

The senior project is, by its very nature, a culmination of our undergraduate program. Students build on previously learned engineering topics and apply them to these design/research projects. The senior project also helps to prepare them for professional life. In the project students reinforce their communication skills by giving multiple presentations, writing proposals and writing interim and final project reports. The project also builds their time management skills. At the start of the term they have to plan and keep to a schedule to complete the project. They must learn to balance their time between all of their senior year activities. Results of alumni surveys point to the senior project as the highlight of their undergraduate experience by preparing them for graduate school or for managing projects.

However, we believe that the senior project’s greatest impact is to help prepare students for life long learning. The individual nature of the project (versus large team approach) is important and in fact promoted. It provides the student with an opportunity to gain confidence in his or her own abilities and it stimulates his or her intellectual curiosity. This is particularly true for the average student who has not otherwise had an opportunity to excel. In committing to a project, the student takes sole responsibility and sole credit for its success. They complete the project through their own individual efforts and cannot hide behind a team. The authors can cite numerous examples of students who really “blossomed” when they did their senior project. For many students, it is the first time they are able to work on their own on a project that truly interests and excites them. The experience builds their confidence in their own abilities. This confidence is an important factor in setting up students for life long learning. They (in general) have succeeded on their project and can do so again in the future. They learn that they can learn on their own.

2. Capstone Design Courses

In 1996 we revised the Mechanical Engineering curriculum and added two senior level design courses (Design of Thermal-Fluid Systems and Design of Mechanical Systems) which are designed to diversify the senior capstone design experience. These required courses are project-based design courses which complement each other so as to ensure: (1) coverage of design in both mechanical systems and thermal fluid systems, and (2) a wide range of teaming experiences.

In the Design of Thermal/Fluid Systems (DTFS) course students work in teams (typically five students per team) on design projects that involve the design of piping systems, heat exchangers,
thermodynamic cycles, and other thermal/fluid systems. The primary objectives of this course are to teach students to work in teams, lead projects, communicate effectively, apply design principles to the design of thermal/fluid systems and to apply principals of engineering economic analysis. The course is organized into five two-week projects. The instructor serves as both “manager” and “advisor” to the projects by assigning each project and then mentoring the students through the project. Each student in the DTFS course is required to complete the five assigned design projects with both group written and oral report formats, to maintain an individual design notebook, to evaluate the work of team members, to evaluate the oral presentations of all class members, to complete project evaluations for each project and to write a final 2-3 page course evaluation paper.

The Design of Mechanical Systems (DMS) course is a capstone project based design course in machine design. The course was designed to give students: (1) experience in solving challenging open-ended problems in mechanical design consistent with the ABET definition of senior capstone design and (2) a practical working knowledge of basic machine elements such as motors, gears, belts, bearings, shafts, flywheels, and fasteners. The DMS course is organized around three projects: an industrial sponsored project and two calculation-intensive machine design problems. The industrial project spanned the entire semester. The machine design problems are packaged as mid-term and final take-home exams, in which students work either in pairs or individually. Percentage of credit is assigned up front in proportion to the amount of time planned for each: 70% industrial project, 30% machine design projects.

The two courses complement each in their use of team leaders. Prior to the senior year mechanical engineering students have a variety of teaming experiences from in-course design projects, beginning with the freshman engineering course, and cooperative learning exercises in the classroom, to laboratory courses, and participation in extra-curricular projects (mini-baja, formula car). One objective of our senior year curriculum is to offer more formalized teaming experiences in which the students utilize knowledge and experience gained in their first three years. When developing the two new capstone design courses we intentionally chose to use different teaming models. The DTFS course utilizes multiple projects with five person teams, in which each student takes a turn as team leader. The DMS course typically has one major term project with the entire class working as a single large team on an industrial project solicited from a local company. There is one team leader with the rest of the team organized into functional groups.

They also complement each other in their use of multidisciplinary teams. Miller and Olds,4 and Lewis et al.,5 discuss the use of multidisciplinary teams in the engineering design experience as one involving students from clearly distinct disciplines. We expand the definition of multidisciplinary teaming to include the following experiences: (1) team members have different experiential backgrounds that create interdependence among team members in achieving the team’s goals; (2) team members are assigned fundamentally different roles or areas of responsibility that create interdependence among the team members in achieving the team’s goals; or (3) members of the team are from different academic disciplines and the expertise developed in that discipline results in interdependence among team members in achieving the team’s goals. Clearly, the focus of our expanded definition is on the interdependence.
experienced between members of a team. This interdependence does not always have to be based solely on disciplinary background.

To create interdependence in the DTFS course the second approach is taken where each student is assigned a specific role and responsibility. Although each student has the same “nominal” mechanical engineering background, each team member is assigned a fundamentally different task. This forces interdependencies among the team members such that, in accomplishing that task each member contributed something different and critical to the team’s success in achieving its objective. In the DMS course the students organize themselves into functional groups, e.g. shaft, bearing, structure, shielding, controls, etc. The group structure is needed to simplify individual tasking and assessment as well as to heighten the sense of accountability among group members.

The courses also complement each other in both project type and length. The DTFS course uses multiple in-house generated projects of two week duration, while the DMS course uses 1 term length industrial project. They are also complementary in their introduction of other non-engineering topics. The DTFS course addresses both engineering economics and contemporary environmental issues while the DMS course addresses design for manufacture issues.

Both courses serve as a culmination of our undergraduate program. Students build on previously learned engineering topics and apply them to design projects. Very little new technical information is “taught” in the DTFS course – instead students are asked to learn what they need on their own and apply the things they learned in earlier courses.

The courses help to prepare them for professional life in a variety of ways. For the first time they have enough accumulated knowledge to credibly attack a “real” engineering design problem. The courses require the students to improve if not perfect their communication skills. Completion of the projects requires good communication both among the team members and to the outside customer. The students make multiple oral presentations and write multiple reports. The interaction with the industrial sponsor in the DMS course also helps to add a more professional aspect to their experience. The multiple teaming exercises help prepare for their professional life by giving experience as team leader and as a team member on a team which must work together to accomplish a goal.

The capstone course sequence reinforces the foundation for continued learning. As part of the design process students must gather information from a variety of sources to help define the problem and then solve it. The instructors lecture on a few new topics but the students are generally expected to learn what they need on their own.

3. Senior Seminar

Senior seminar in mechanical engineering is a required non-credit course for mechanical engineering seniors. The course meets one hour a week for the entire academic year. The course involves five main components: (1) lectures by mechanical engineering faculty aimed at providing the students with important information on topics related to professional practice, (2) presentations by invited outside speakers, (3) administrative information related to senior project,
(4) general information important to seniors, and (5) a forum for the student presentations of
their senior project. The department has had funding to supply lunch for students, faculty and
guest speakers before each seminar.
The faculty lectures cover three main areas: engineering ethics, codes and standards, and
intellectual property. The ethics module includes discussion of the importance of ethical practice
in decision making, relevance to public safety, and presents the Code of Ethics for Professional
Engineers. Ethical decision making is explored through the examination of case studies. The
Center for Ethics Web site (www.onlineethics.org) is used. The students study the Challenger
Disaster case and the Citicorp Tower case. In addition, students view and discuss the fictitious
case study, Gilbane Gold, presented in a video produced by the National Society of Professional
Engineers. Student are then required to write a paper on one of these case studies. We have
experimented with the Ethics Challenge board game developed and used by Lockheed Martin for
ethics training for their employees. Basically, the students work in teams and score points for
selecting the appropriate course of action given various ethical dilemmas. While the students
generally enjoyed the experience, the ethics scenarios included with the game were not
particularly relevant to engineering ethics. Consequently, we decided not to pursue it.

The codes and standards module explores the importance of having engineering standards, the
use of standards in engineering design, the difference between standards and codes, and the
importance to public safety. Several examples are drawn from SAE and ASTM standards and
the ASME Boiler and Pressure Vessel Code. The students also view the Codes and Standards
video produced by ASME. An important point to emphasize is that existing codes and standards
are continually modified and updated and new codes and standards are being developed.
Therefore it is necessary for the practicing engineer to keep current with these developments.

The intellectual property module covers the three basic types of intellectual property: copyright,
patents, and trademarks and goes into depth on copyrights and patents, including the step by step
process required to secure a patent. It also emphasizes the importance of documenting one’s
work.

Another aspect of the senior seminar involves bringing in outside speakers to give seminars. The
seminars are specifically targeted to undergraduate students. We generally bring in 4-5 outside
speakers per term. The speakers have included practicing engineers, faculty colleagues from
other schools talking about their research or graduate opportunities, and alumni talking about
their experiences since leaving Union. Talks have ranged from career experiences to research
seminars including speakers on “Fuzzy Logic Applied to CFD”, “Mechanical Reliability of
Solder Joints”, “The Art and Science of Pyrotechnics”, “Distributed Power Generation” and
“PIV Techniques”. The challenge in presenting some of the research talks has been to keep them
at a level which undergraduate students can comprehend. In some cases we offer a joint seminar
with another department on campus or with the local ASME section, bringing in a distinguished
ASME Speaker. If possible we try to get speakers to present on one of the topics mentioned
above related to the profession. For example, we had a patent attorney speak about the patent
application procedure. We have also had former Morton Thiokol engineer Roger Boisjoly give a
major campus lecture on engineering ethics and the Challenger accident.
Early in the academic year the first couple of seminars are devoted to providing students with important information needed on the senior project discussed above. Issues such as expectations, resource availability, and safety guidelines are discussed.

The seminar is used to provide seniors with general information such as how to apply for the FE Exam, notification of job opportunities listed by the career development center, notice of post-graduate fellowships opportunities.

Finally the seminar time is used as a forum for the seniors to give presentations on their senior project. Currently they give an oral progress report at the end of the first term of work and a final report at the end of the second term. All of the student presentations are videotaped to help them improve their presentation skills and to document the achievement of the student outcome on communication skills for ABET. The senior project presentations are used to select students to represent Union at the annual ASME Regional Speaking Competition. Local engineers are invited to the talks and help evaluate them.

The seminar also serves as a culmination of our undergraduate program. Presentations are made at or above the level of a senior mechanical engineering major. The seminar prepares them for professional life by exposing them to contemporary issues in mechanical engineering. They learn about a range of mechanical engineering research projects, about career opportunities, about engineering challenges. It gives them a sense of the engineering profession that they are about to enter and it provides an excellent forum for increasing student faculty intellectual interactions.

4. Technical/Free Electives

It is important to have adequate flexibility in a curriculum to allow students to take electives to complement the required part of the curriculum. Electives in the program can add to the students’ depth and/or breadth of knowledge and enable them to pursue a secondary interest. The mechanical engineering curriculum currently has four free electives and three engineering electives. Many of these are taken in the senior year. The engineering electives can add depth by reinforcing the major or breadth by taking engineering courses outside of mechanical engineering. Since the program is relatively small we cannot offer a large variety of mechanical engineering electives. Consequently, some students elect to take graduate mechanical engineering courses to help prepare them for graduate school. Some take non-engineering coursework to pursue other interests such as preparation for post-graduate professional study in a field other than engineering or to pursue a minor. The non-engineering elective courses add breadth to the curriculum, complementing the General Education Curriculum. Since Union has a strong program in liberal arts, engineering students are encouraged to pursue minors in these disciplines. Of the first set of students to graduate under the new curriculum 27% of the students completed minors (they were in the fields of Classics, Mathematics and Environmental Science).

Conclusion

In 1994, a survey of capstone engineering courses in North America was performed which showed that for 32% of respondents, students work on individual projects, while 83% reported students working in department teams, and 21% reported that students work on interdepartmental
teams. We have designed the senior year experience to give our students all of these experiences. All students have an individual capstone project experience, all students have a team capstone project experiences and a significant number (25%) have an interdepartmental capstone project experience through the IVDS projects.

The experiences described in this paper were designed to help achieve three main educational objectives: (1) culmination of the undergraduate program by providing a significant capstone design experience including application in that process of the analysis tools learned in the first three years, (2) preparation of the students for professional life by exploration of issues and topics related to professional practice, and (3) helping to ensure that students are on a path of lifelong learning by stimulating their intellectual curiosity and building confidence in their ability to learn new things on their own.

One assessment tool used to help evaluate how well these objectives are met is the senior exit survey. The most recent version of this survey administered last spring to the class of 2000. This class was the first to go through the new curriculum and the senior program described above. The survey had several questions designed to provide insight on the level of achievement of these objectives. For example, 86% felt they are able to design a system, component or process to meet a desired need; 100% responded that they were able to function and participate effectively as one member of a multidisciplinary team of engineers working on a project; 92% felt that they are able to be an effective leader of a multidisciplinary team of engineers; 100% commented that their senior project was a valuable experience; 100% felt they were well-prepared to enter the workplace or graduate school; 57% agreed, 43% agreed somewhat, and none disagreed with the statement: “I have sufficient understanding of professional ethics to guide the decisions I will make in situations I will encounter in engineering practice;” 100% feel they are able to communicate in writing and make effective oral presentations in front of a variety of audiences; 100% feel they are comfortable expressing their views and questioning others in a group discussion situation; 71% of the respondents planned to remain or become a member of ASME; 100% recognize the need to continuously update their professional skills; 100% anticipate continuing their education and pursuing additional or advanced degrees in either an engineering or non-engineering field, 86% anticipate taking professional development courses in the future to stay current in their field or to learn new skills; 43% agreed, 50% agreed somewhat, and 7% were neutral about the comment: “I am comfortable using information technology to search and gather relevant information from a variety of sources for use in the solution of engineering problems.”

These results provide indication that the objectives are being met. However, since students were not specifically asked to attribute the acquisition of these abilities to a curricular component, we can only strongly infer, at this point, that it is due to the senior experiences described here. Perhaps we can glean additional information to help evaluate this when this group is surveyed as alumni in two or three years from now. Nevertheless, we believe that we have developed a well-balanced senior program to complement the rest of the undergraduate ME program and to help our students to become well-prepared to practice their profession in the 21st century.
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Bibliography


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