Implementation of a Novel Second-Year Mechanical Engineering Course to the Curriculum

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Abstract

In 2012, the University System of Ohio member universities, which are overseen by the Ohio Board of Regents, moved from operating on a quarter-based calendar to a semester-based calendar. In conjunction with this change, the Mechanical Engineering curriculum at The Ohio State University was revised, and a new and unique course was added to the required curriculum for students in the major. The course, titled “Introduction to Mechanical Engineering”, encompasses elements of both the spiral curriculum and experiential learning strategies. A prior ASEE paper outlined the structure of the course at the time of pilot development, and the student feedback provided by the pilot program participants. Now in its third year of full-scale implementation, the course has undergone some modification from its original design. Additionally, exploration has begun within the department in order to incorporate additional elements of the mechanical engineering curriculum into the course in a more comprehensive spiral approach.

The key challenges for this course are that it is a required course for all students in the major in a very large department, and that it is a hands-on course in which all students are required to complete every aspect of the machining, assembly, and programming of a compressed air motor individually. The course was designed specifically with this requirement to ensure that every student interact directly with every aspect of the process, in order to prevent the specialization, uneven participation and resulting uneven skill and knowledge gains that can occur in group project settings. One interesting outcome of the course has been the relatively large number of female students who completed the course and then applied and were selected as undergraduate teaching assistants for the course. In a department and discipline where female students remain under-represented overall, they have been participating at high levels in this role. We report here on the evolution of the course from its original pilot program through the first four semesters of full-scale implementation, as well as future plans for the course. Our assessment includes detailed feedback from students and teaching assistants who completed the course in the initial two years.

Introduction

As a land grant institution with Research I status, The Ohio State University (OSU) has a long tradition of engineering education. In 2012, after over three years of preparation, the university switched from a longstanding quarter-based schedule to a semester schedule. The Department of Mechanical Engineering at OSU utilized this transition to review and improve their curriculum in order to better prepare their graduating engineers for entrance to the profession in an increasingly competitive, global economy. Extensive input from alumni of the prior 20 years was utilized with information collected from student exit interviews, surveys, and considerable faculty discussion to direct the curricular revisions. The primary changes to the curriculum included a reduction in number and reorganization of the required courses in the core curriculum, the addition of a required statistics course, the reorganization of the format and timing of the
course labs, and the addition of a sophomore level design and manufacturing oriented course. It is this sophomore level course that is the focus of this article.

The first year engineering curriculum at Ohio State, like that of many engineering programs, includes a fundamentals course that involves the students in a design-build project. In addition to the design-build project, the first year engineering program covers a broad range of engineering concepts and skills, and is intended to give students an overview of engineering practice and methods. The design-build project in the first year program is a group project, as is frequently the case with these types of assignments. Students enter their specific engineering discipline following the completion of their first year engineering program. Students entering the Mechanical Engineering program have a wide range of skills and knowledge regarding machining and electronics, depending on their prior exposure and experience. Given that most mechanical engineers will be working on the design of mechatronic applications and devices throughout their career, it is important that they have an understanding of not only the engineering science governing mechatronic functions, but also how they are designed and manufactured. In addition, both alumni and prospective employers have recently voiced a desire for additional coursework and education in hands-on engineering skills and knowledge. Furthermore, alumni and graduating students at Ohio State, as along with many other voices in the literature, often bemoan the lack of integration between an academically rigorous engineering science curriculum and the application of this subject matter to real world problems and models. This lack of integration and application is often cited as a factor in the problem of engineering student retention, as well as the related issue of poor student engagement in the curriculum. Research has also shown that attitudes of students who persevere in the engineering curriculum are often different than those who leave the curriculum prior to graduation. Prior to the implementation of the sophomore level course that is the subject of this paper, Mechanical Engineering students experienced a gap in this area of integrative engineering design between their first-year program and their senior-year capstone course.

Therefore, it was undertaken to develop a hands-on, design oriented sophomore level course that would not only introduce students to many of the focus areas within mechanical engineering, but to also integrate these topics and the design and physical production of models using real-world systems. A number of other schools have also recently undertaken similar efforts in regard to sophomore level engineering design courses, hands-on education, and an introduction to the discipline of mechanical engineering, including Villanova University, Georgia Tech, Kettering University, Purdue University, Rensselaer Polytechnic Institute, Virginia Polytechnic Institute and State University, The University of Houston, The University of Southern Alabama, Pennsylvania State University, and Rowan University, as well as the University of Utah. An additional challenge for Mechanical Engineering at OSU is the large size of the program, with a typical annual sophomore enrollment of 250 to 300 students. There are also several specific features of the OSU course that were felt to be important, which are also not typically included in the standard design-build course structure. These include the requirements that every student in the class independently complete the full machining and assembly process for a single cylinder of a six-cylinder engine project, as well as an individual, open-ended design-build Arduino based electronics and programming project. Structuring the course around independent project assignments rather than group projects ensures that each student gains the full range of experiences and skills that are taught in the course, with the intent of giving all the students...
exposure to, and an introductory understanding of, a wide range of mechatronic design principles and practices.

Pilot Course Experience

The course was developed and initially piloted while Ohio State was still operating under the quarter system, in Autumn 2011 and Winter 2012. The results of the first 10-week quarter pilot course, completed by 24 students, were previously reported in References 1 and 18. The original 10-week pilot course was divided into several content focus areas, as outlined following. The first five lectures centered on a preliminary design exercise that taught sketching and prototyping and project management techniques, as well as evaluated student writing abilities. The students then moved into the construction of a two-cylinder compressed air motor, working in groups of four. During this phase of the course they received lecture instruction in machining and fastening methods, as well as engineering drawing and tolerancing. During labs conducted in the machine shop, they put the instruction received in lecture to work performing operations such as milling, turning, boring, reaming, and tapping in the construction of the air motors. The original design was such that the incorporation of electronics was not practical, and so the device was purely mechanical in nature.

The objectives of the ten-week pilot course were:

- Gain an understanding of how the major interest areas in mechanical engineering relate to each other and to the kinds of problems that mechanical engineers are typically asked to solve;
- Have exposure to decomposing, analyzing, and modeling real systems at a basic level;
- Learn to communicate design ideas effectively by means of hand sketches, rough prototypes, dimensioned drawings, the written word, and oral presentations;
- Become proficient in the use of basic machine tools, data acquisition systems, mechanical and electrical measuring devices, Solidworks CAD and CAM software, Matlab, and Excel;
- Develop proficiency working on design teams;
- Become proficient at keeping a design notebook and preparing a poster documenting work in class;
- Be able to design mechanical components and basic systems at a professionally acceptable level of competence, and possess a firm basis for continuing in the field.
The pilot course was evaluated using several different methods and metrics. The previous paper reported on the results obtained via three different methods. First, the results of an assignment regarding student perceptions of Mechanical Engineering at the beginning and then the end of the course were reported. Second, feedback from Focus Group Interviews was reported, as well as (third) the results of the end of course evaluations. The feedback from the students regarding the course indicated that the construction of the air motor – including machining and assembly - was the primary, or even sole, objective of the course. The other elements of the course, including the preliminary design exercise and the associated sketching, writing, and project management techniques were felt to be disconnected and piecemeal additions that did not flow cohesively. In addition, the instructional team felt that the two-cylinder air motor construction was overly complex for the one-quarter or one-semester timeline, and that there was insufficient electronics and programming involvement in the project.

Full-scale Course Implementation

The instructional staff for the pilot course included two professors who conducted the classroom instruction and assisted with the labs, two journeyman tool and die makers who provided lab instruction and supervision, and two Graduate Teaching Assistants who assisted with the lab instruction and supervision. One of the main challenges with the move to the semester course
was the sheer logistics associated with teaching a required course to 100 to 200 students versus
the 24 students involved in the quarter-long pilot course. It was also imperative that students
involved in working with potentially dangerous machine tools, many for the first time in their
lives, have adequate supervision and hands-on training, for the sake of both safety and
proficiency. Therefore, a sizeable number of students who had completed the pilot course were
recruited to act as Undergraduate Teaching Associates (UTAs) for the semester long version.
The UTAs were all selected based on their performance in the course, as reflected both in the
grade they received as well as their competence in the hands-on aspects of the course. One of the
interesting outcomes of these selection criteria was that the resulting percentage of female
students selected as UTAs was significantly higher than the percentage of female students
enrolled in the course. The percentage of female UTAs in the course has consistently been
between 40 and 50 percent, while the percentage of female students enrolled in the course has
been between 12 and 17 percent, with an average female enrollment of 14 percent. Clearly,
female students in the course are highly successful and engaged in the course and find it a
positive enough experience that they are motivated to apply to be a part of the course
instructional team.

The experience and feedback from the initial pilot course was utilized to revise the course prior
to its introduction on the semester schedule. There were several content and format changes
made to the course. As noted earlier, the two-cylinder engine design required extensive
machining and didn’t provide much opportunity for the introduction of electronics, controls, or
programming experience. In addition, the construction of the two-cylinder engine involved a
significant amount of time devoted to various machining processes, which didn’t allow for the
introduction of much open-ended design content. On a positive note, however, the use of an
engine related project did allow for the introduction of a number of inter-related mechanical
engineering concepts: mechanisms and machine design, thermodynamics, heat transfer, fluid
dynamics, system feedback and controls, manufacturing methods, and data acquisition
techniques could all be presented and discussed in connection with the project – thereby
providing a good overview and introduction to a range of mechanical engineering concepts and
practices. It was also determined that the objectives for the course were too ambitious and broad
and should refined to be more concise and cohesive. As such, an engine related project was
maintained as the focus of the course, but the format and content were modified to meet the
following revised course objectives:

• Have an understanding of how the major interest areas in mechanical engineering relate
to each other and to the kinds of problems that mechanical engineers are typically asked
to solve;
• Have exposure to decomposing, analyzing, and modeling real systems at a basic level;
• Be able to communicate design ideas effectively by means of rough prototypes,
dimensioned drawings, and the written word;
• Be proficient in the use of basic machine tools, Arduino microcontroller, data acquisition
systems, mechanical and electrical measuring devices, and sensors and actuators.

In order to meet these revised objectives, the original two-cylinder engine project, which
involved the construction of the entire engine structure, was revised to be a single-cylinder sub-
assembly for a six-cylinder air motor. Each student would now construct the engine block,
piston, and connecting rod for one complete cylinder sub-assembly of an Arduino controlled six-cylinder air motor. A photograph of the new engine design is shown in Figure 2.

Figure 2: 6-Cylinder air motor design used in semester-long course.

The semester long version of the course was also divided into two 7-week sessions. In one session, students attend lecture two times per week introducing them to design, machining, and assembly processes. During this session they attend once weekly labs, two hours in length, during which they learn machining techniques and apply those techniques to the construction of the air motor cylinder sub-assembly. In the other 7-week session, they attend lecture two times per week introducing them to Arduino microcontrollers and their programming, as well as basic electrical circuits and electronics. During this portion of the course they also attend two-hour labs weekly, where they build a variety of electronic circuits using sensors and actuators that are controlled by the Arduino via programs that they write for a wide range of applications. During this electronics and programming portion of the course, they also spend the final three weeks of lab constructing a simple open-ended prototype of their own design. The prototype must include at least one sensor and one actuator, with the constraint that it be something they have not previously used in lab. The course enrollment is split into two approximately equal-in-size sections, and one section begins the semester with the Arduino portion while the other section begins the semester with the machining portion, and they each switch to the other content area.
mid-semester. Each of the sections, machining and Arduino, are taught by different professors who therefore teach each content area twice per semester.

While the primary motivation behind the sophomore level course included providing a good overview and understanding of the mechanical engineering discipline as well as hands-on experience with the creation, assembly, and control of an electro-mechanical device, there were other secondary student objectives that it was hoped the course would address. These included the retention of students within the mechanical engineering curriculum, building the confidence of students who come into the major without any significant hands-on experience in these areas, and developing a greater passion and understanding for the discipline of mechanical engineering with the students. It was also hoped that the development of these insights and hands-on experiences would help improve student motivation and outlook during the demanding and content intensive sophomore and junior years in the mechanical engineering curriculum.

The semester-long, full enrollment version of the course was first offered in Autumn Semester 2012, and it continues to be offered currently. As of this writing, 5 semesters of the full enrollment version of the course have been completed. In each of the semesters the enrollment has fluctuated between approximately 90 and 180 students. As a result, the number of teaching assistants for each of the two sections has ranged from 20 to 30 per semester in the machine shop and 12 to 18 in the Arduino lab. In the machine shop portion of the course, the gender breakdown of UTAs has been approximately equally split between males and females, which is different than the gender breakdown for the course overall, which is has been approximately 86 percent male and 14 percent female on average over the 5 semesters thus far. In the Arduino portion of the course, the split has been less gender balanced, with a range of 70 to 80 percent of the TAs being male and 10 to 20 percent female, however the overall average of female UTAs in the programming and electronics portion has still tended to exceed the overall average enrollment of female students in the course. In addition, over the lifetime of the course the female percentage of UTAs has been steadily, if slowly, increasing. It has gone from approximately 10 percent in the first semester to approximately 30 percent in the current semester, and an additional four female students currently enrolled in the course have expressed interest in becoming UTAs for the coming academic year. These numbers are certainly consistent with a hypothesis that having female role models as course instructional staff has a positive effect on the experience and performance of female students enrolled in the course. Given that the number of women enrolled in computer programming and electronics courses and curricula is still far below those of men, this is an encouraging outcome at the very least.

Anecdotal feedback from prior students and UTAs in the course revealed that the students found the course meaningful and interesting, as well as helpful with their future progress within the mechanical engineering curriculum and in their professional experiences, including co-op and internships as well as post-graduate employment. In order to capture feedback from a larger portion of the students who had completed the course, a survey of students from all 5 semesters was recently conducted. The survey and its results are discussed following.
Survey

Students were first asked several demographic questions, including during what semester they took the course, whether they had completed their BSME degree and if so when, how many semesters of internship or co-op experience they had completed, and their gender. They were then asked a series of questions to assess their level of knowledge and experience in relevant topics prior to the course, their level of comfort with those topics following their completion of the course, as well as how the experience of the course and the knowledge and skills gained through it affected several aspects of their student and professional experiences. The rating scales utilized in the survey were that of a five level qualitative scale, in the manner of a Likert scale. The specific interpretation of what was meant by each intermediate level of response was left to the individual respondents’ interpretation as it related to their individual work experience and requirements. The responses were open ended in this manner as they were intended to be reflective of the individuals’ self-assessed competence and level of experience. A comment section was also provided for the questions, in order to elicit specific feedback and insights of the survey respondents.

The survey questions and responses, with the exception of the demographic questions regarding when they completed the course and their graduation status, are presented following.

![What level of machining experience did you have prior to enrolling in this course?](image)

Figure 1: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.
Figure 2: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.

Figure 3: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.

Figure 4: Rating scale of 1 to 5, where 1 = Low, 5 = High.
What was your comfort level with electronics and programming at the end of this course?

Figure 5: Rating scale of 1 to 5, where 1 = Low, 5 = High.

Rate the level at which you have utilized the knowledge and/or skills you learned in this course in your other coursework or personal projects:

Figure 6: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.

Rate the level at which you have utilized the knowledge and/or skills you learned in this course in your co-ops/internships:

Figure 7: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.
How helpful were the knowledge and/or skills obtained in this course in assessing or planning career options or interests?

Figure 8: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.

How helpful were the knowledge and/or skills obtained in this course in helping secure internships/co-op positions?

Figure 9: Rating scale of 1 to 5, where 1 = None, 5 = A great deal.

In what manner do you feel that this course affected your desire to remain in the mechanical engineering major?

Figure 10: Rating scale of 1 to 5, where 1 = Negatively, 5 = Positively.
Discussion

The survey responses indicated that students had relatively little experience with machining, electronics, programming or general hands-on engineering activities prior to enrolling in the subject course. With regard to machining, 82% rated their experience level at either a 1 or 2 prior to the course. In electronics and programming experience, the students have somewhat more incoming familiarity, with 51% rating their experience level at a 1 or 2, and 36% rating their experience level at a 3 prior to the course. For hands-on engineering experience, the students’ estimates of their incoming experience level was 46% at the level of 1 or 2, and 49% rating their level as a 3. Following the course, however, 77% of the respondents rated their comfort with machining at either a 4 or 5 out of 5, and 23% rated their comfort at a 3. Similarly, 84% of the students rated their comfort with electronics and programing at either a 4 or 5 following the course, and 21% rated it at a 3.

Students were also asked to assess the usefulness of the knowledge and skills gained in the course in their other coursework, personal projects, and co-op or internship experiences as well
as for assessing and planning career options or interests. In the use of knowledge and skills for other coursework or personal projects, 64% of the respondents gave a rating of 4 or 5 out of 5. Only 41% of the respondents rated their use at 4 or 5 in co-op or internship experiences, however. The rating of the helpfulness of the skills and abilities obtained in the course for assessing or planning career options or interests was similar to the ratings for use in coursework or personal projects, with 69% rating that at 4 or 5.

The most encouraging of the survey responses involved three questions regarding the impact of the course on students desire to remain in the mechanical engineering program, the level of insight it provided into the field, and the affect it had on their self-confidence and sense of capability in their studies and profession. With respect to the impact the course had on their desire to remain in Mechanical Engineering, 76% of the respondents rated the course at a 4 or 5. Regarding the level of insight provided into the field of mechanical engineering and its practice, 79% gave the course a rating of 4 or 5. As to the affect of the course on their self-confidence and sense of capability in engineering, their studies, and professional practice, 69% of the students rated the course at a 4 or 5.

In addition to the numeric rating responses, students were also asked to comment on specifics related to the questions beginning with the question shown in Figure 6. The questionnaire in its entirety is shown in Appendix B, and the questions with their respective responses are shown in Appendix B. The responses to the open ended comment invitations were overwhelmingly positive, although there were some comments indicating a personal preference for one aspect of the course over another, and a few somewhat critical, or even snarky, comments from students whose background in one of the course content areas was already strong at the beginning of the course.

There were many interesting and encouraging comments from students that spoke directly to the motivations and objectives for the course. Several of those have been selected and are first presented and then discussed following.

“Gear train and force analysis centric ME curriculum desperately needed real world applications. Hands on experience with machine design and electronics integration directly helped lead to current position as electromechanical engineer at (Company Name Omitted for Confidentiality Purposes)”.

“The course begins to set students up for what they will face in the real world. The heavy analytical course work is great for shaping engineers to think in a quantitative way but (this course) teaches you how to think about the whole design process. Understanding how we talk to machinists and having a little insight into how things are made sets students to a new level in terms of designing. The electronics portion of the class teaches you how to think methodically but also understand the basic principles of mechatronic systems”.

“Machining section was good for getting familiar with machinery. Arduino section was more interesting, and showed me that I’d like to involve electronics and programming into my career”.

“It helped me realize that manufacturing is quite interesting. I had no interest in the area earlier”.

“..."
“I had little/no controls and machining experience prior to (this class). I never had much opportunity to be very hands on, so when I went to internships before taking the course I felt lost with anything that related to machining processes or simple controls. During internships after (the course), I realized how much the class helped me. I knew basic machining terms when ordering prototypes from the local machine shop. I understood the hard work that goes into making a part. I also worked on a machine that solenoid valves, which was great because I knew how they worked after taking (the course). I cannot express enough how much (the course) helped me during my internships, and I wish more of that was introduced to freshman, at least at a very basic level to familiarize early engineers with what they may see on the job”.

“It made me realize I wanted to be a maker and be an engineer who does very hands on building aspects. It also taught me about the diverse career prospects for engineers, and showed me that I did not have to leave school and become a number cruncher”.

With regard to its impact on their decision to remain in the major, some of the students reported that they were already sold on the program and that it didn’t affect their decision significantly. However, as indicated by the distribution of the numeric rating responses, it did positively affect a large percentage of the respondents. Some of the more interesting and insightful responses included the following:

“The course definitely made me certain that I had picked the right major!”

“Breaking up the monotony of technical courses with a hands-on project that correlates more closely to “real-world” engineering was not only fun, but improved my ability to conquer future internship and academic challenges.”

“Knowing that ME students have to know a little bit about everything is amazing. We had to understand how to communicate to other personnel, interpret/create computer codes and electronics, and use our hands to make things. No other major is this well rounded.”

“This course showed me that ME is not exclusively theory. There is a tangible way to apply the theoretical knowledge amassed thus far to physical objects. Almost all of the other courses are purely theoretical and don’t seem to cleanly translate to real world applications.”

“I really enjoyed the hands on aspect of it. We normally sit in class all day, and learn about a bunch of concepts but never get to actually do anything hands on with it/or see these concepts first hand. I liked that the course gave us the opportunity to physically see and do what we were learning in class.”

**Conclusion**

The reception and feedback on this novel course has been overwhelmingly positive from the students, and as reported in the prior paper, alumni and industry reception to the course has been positive as well. Many visiting alumni, industry representatives, and potential students and parents have commented on the unique and engaging nature of the course. Parents of many of
our students have also reported that their children were extremely engaged in the course, and quite proud of their completed engine block as well as their newly developed knowledge and skills. While there are certainly some students who come to the Mechanical Engineering curriculum with some of the skills and knowledge presented in this course, very few of the nearly 700 students who have completed the course had all of the skills and knowledge presented in the course, and they tended to be non-traditional students with fairly extensive work experience. For the majority of our entering students, the curriculum of the course seems to be meeting or exceeding the goals and expectations.

The results presented here are the first detailed evaluation of the course in regards to meeting some of the important, yet sometimes difficult, needs and objectives that have been indicated in the literature to be important in the retention of students within engineering disciplines. In addition, this course provides students a good overview of the mechanical engineering major and profession. Furthermore, it builds students confidence in their engineering abilities and understanding, and provides an engaging bridge between the demanding, but necessary, theoretical content of mechanical engineering, and the physical application of this theory to real world devices. By including an open-ended prototyping opportunity, it also allows students to express their creativity and to apply engineering concepts in an area of their own interest, which also helps keep students engaged and interested in the profession of engineering in any of the many specific content areas they may eventually choose for themselves. The success of this course at OSU has further motivated the faculty to work toward designing a similar course or experience within the junior year curriculum, traditionally one of the most rigorous and frequently overwhelming periods for mechanical engineering students. Stay tuned for more developments!

References:


