121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014

Paper ID #9723

A THIRD-YEAR REVIEW OF DESIGN AND PACKAGING FOR SENSOR SYSTEMS

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A THIRD-YEAR REVIEW OF DESIGN AND PACKAGING OF SENSOR SYSTEMS

Faculty from the Electrical Engineering and Design Engineering Technology Departments at Trine University have developed a joint design module for upper-level courses in their respective disciplines. In this module, student teams collaborate in designing and prototyping the electronics and packaging for a hand-held sensor system. The principal objective of the collaboration is for students to incorporate design factors external to their discipline in a program-focused design project. This effort advances the students' abilities to work effectively in multidisciplinary teams during their senior capstone courses. The design module was introduced in the fall 2011 semester, and was repeated in fall 2012 and fall 2013. An assessment, conducted with current and former participants in fall 2013, demonstrates the efficacy of the project.

1. INTRODUCTION.

The engineering education community has embraced the concept of multidisciplinary design over the past two decades [1-3]. This movement reflects a renewed emphasis on design in the engineering curriculum, particularly at the freshman (cornerstone) and senior (capstone) levels [4]. The benefit of training engineers to work in multidisciplinary teams is self-evident when considering the integration of mechanical design, electronics, software, human factors and ergonomics, and materials science that is present in many engineered systems [5]. Universities have adopted a variety of approaches to give their graduates experience and skills working on multidisciplinary teams [6, 7]. Individual courses are frequently used, including both core courses within a discipline [8-11] as well as elective or special-topic courses [12-17]. The nature of capstone courses make them inherently suitable for multidisciplinary projects [18-19]. Students may elect to participate in stand-alone collaborations [20-26], while some universities deliberately structure the capstone experience for multidisciplinary work [27-30]. Institutions have also explored and implemented program-level efforts such as interdisciplinary minors, certificates, and degree programs [31-35].

A less common approach towards multidisciplinary education is the module-level project, defined here as a project having a time span of less than a semester. One example of a module-level project is a robot design-build assignment within a "circuits for non-electrical students" course, where students apply concepts presented earlier in the semester [36]. Another example is a set of mini-projects placed at the beginning of a two-semester capstone course. These experiences provide students with a low-risk introduction to the multidisciplinary design skills they are expected to exercise later in the academic year [37] and in their careers. It should be noted that both examples occur within the context of a single course.

This paper describes a recurring multidisciplinary design project module between the Electrical and Computer Engineering (ECE) and Design Engineering Technology (DET) programs at Trine University. Students from two classes collaborate to design, prototype, and assemble the physical and electrical components of a handheld sensor system. Year-to-year changes in the project are presented, and an assessment of the project's effectiveness towards helping students work and communicate with people outside their discipline is discussed.

2. PROJECT DESCRIPTION.

In the module discussed here, students from ECE 483 (*Instrument Systems*) and ETD 313 (*Design for Manufacturing and Assembly*) are teamed together to design and prototype a handheld analog sensor system. The first occurrence of the module, in the fall 2011 semester, was discussed in an earlier paper [38]. It has since been repeated, with changes, in the fall 2012 and 2013 semesters. In it, electrical engineering students must design a circuit board that will convert an analog measurement of something in the environment into a human-readable form (i.e., a seven-segment LED display). Their designs are first realized as schematic diagrams and verified on a prototyping board. Students then transfer the conceptual design to a printed circuit board (PCB) which is manufactured by an outside supplier. When the boards are returned, the students solder components to the boards and trouble-shoot their designs. These activities support the ECE 483 course objective that students will 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, safety, manufacturability, and sustainability".

Concurrent with the electrical design, technology students design a package to hold the circuit board and batteries. The package must include design features to allow for changing the battery. Designs must be compatible with manufacture by plastic injection molding, although some allowances are given for manufacture by rapid prototyping. After a design review and subsequent revisions, student designs are printed on the University's fused deposition modeling (FDM) machine. Technology students must also estimate the cost to manufacture the tooling associated with their design. These activities directly support the ETD 313 course outcome of demonstrating the ability to simplify design and estimate manufacturing costs in the context of Design for Manufacture and Assembly (DFMA).

In addition to the course outcomes stated above, the module lets students work on an open-ended project with people outside their discipline. Both sides of each design team must negotiate design decisions, such as placement of components including the display and on-off switch or a method for securing the PCB in the package. As the project progresses, changes to the design must be communicated within groups. To encourage teams to establish communication, an identical homework assignment is given to both classes. Students could only complete the assignment by communicating with their counterparts.

While students are given design parameters for designing the sensor system, many design decisions are left to the students. Selection of what will be measured, sensors, methods for signal processing, display, and the form of the package are all student decisions. Not surprisingly, the design space of student solutions is broad. For the electrical circuit, some groups devised simple designs incorporating resistive sensors, voltage comparators, and LED arrays. Other groups implemented analog-to-digital conversion in order to drive seven-segment LCD displays, and one group implemented a microcontroller-based design. Another group went as far as to design their own inductive vibration sensor in collaboration with their teammates in technology. Similarly, the packages have been as simple as two-piece rectangular boxes, or as complex as ergonomic curved forms incorporating features such as standoffs, flexible snaps, and embossed logos.

A representative sound-level sensor project from fall 2013 appears in Figures 1 and 2. The signal from an electret condenser microphone is fed through a series of voltage comparators, which in turn light up an array of LED’s to indicate the intensity of the sound collected by the microphone. From the technology side of the project, the collaboration was successful, as everything fit together as intended. From the electrical side, there is room for improvement as the PCB did not function correctly after soldering. One of the authors related the students’ experience quite succinctly: “it worked on the proto board!”

FIGURE 1. Handheld Sound Intensity Meter, Fall 2013.

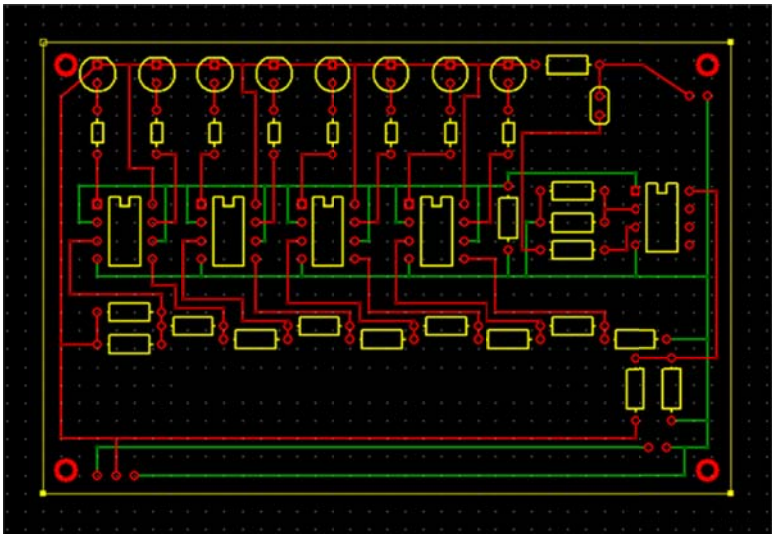

FIGURE 2. Handheld Sound Intensity Meter PCB Trace Layout, Fall 2013.

Figures 3 and 4 depict another sound sensor system. Here, the students used a band-pass filter to measure sound around a specified frequency. The electrical engineering students were successful in transitioning the design from the prototyping board to a soldered PCB. The package is rather elegant, with a curved transition from the grip to the sensor/PCB area. Rather unfortunately, the end of the grip had to be chopped off the prototype since the design length exceeded the build envelope of the FDM machine.

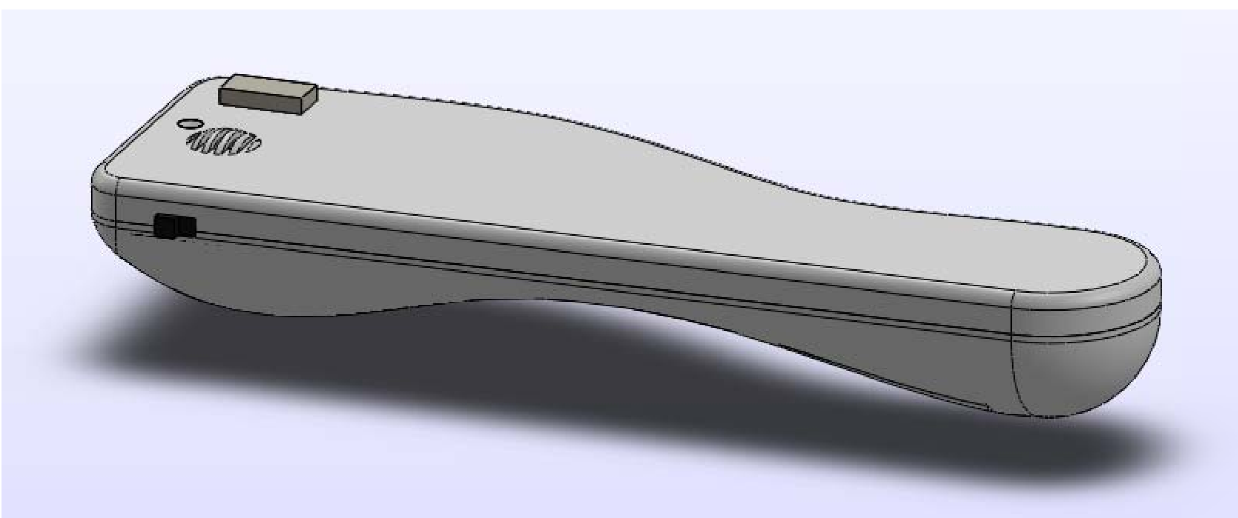

FIGURE 3. CAD Model of Handheld Sound Meter with Band-Pass Filter, Fall 2013.

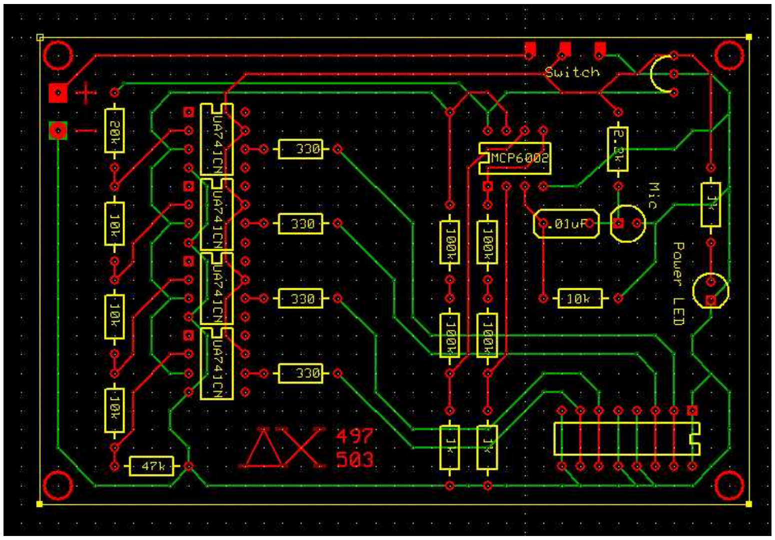

FIGURE 4. Sound Meter with Bandpass Filter PCB Trace Layout, Fall 2013.

Figures 5 and 6 show the components of a temperature sensor system also built in fall 2013. This design involved the use of a single integrated circuit chip that performed the analog-to-digital conversion and served as the driver for the LCD. The use of a forty-pin chip made the design of the PCB more challenging. The students were able to fit the needed traces on the dual-level PCB and performed a calibration so that the temperature was shown in degrees Celsius.

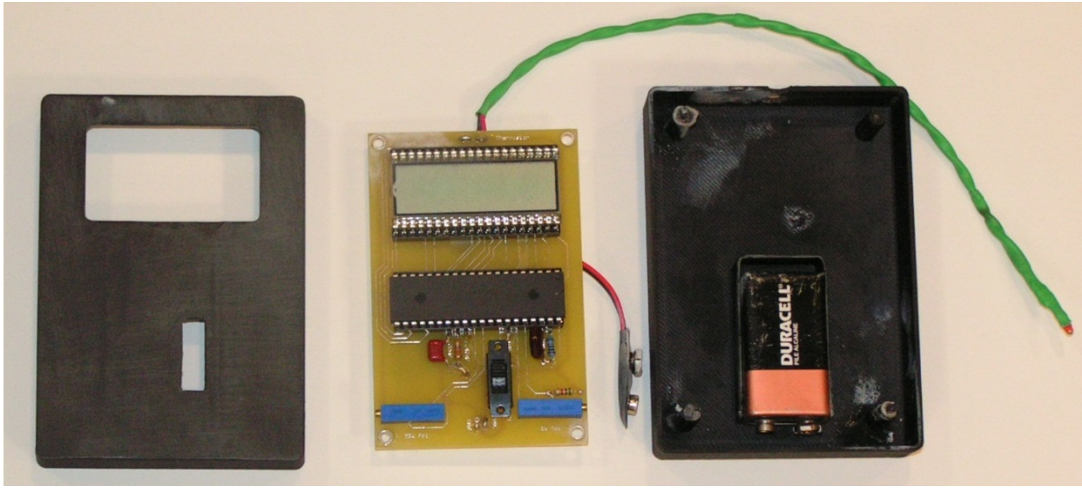

FIGURE 5. Exploded Assembly of the Temperature Sensor, Fall 2013.

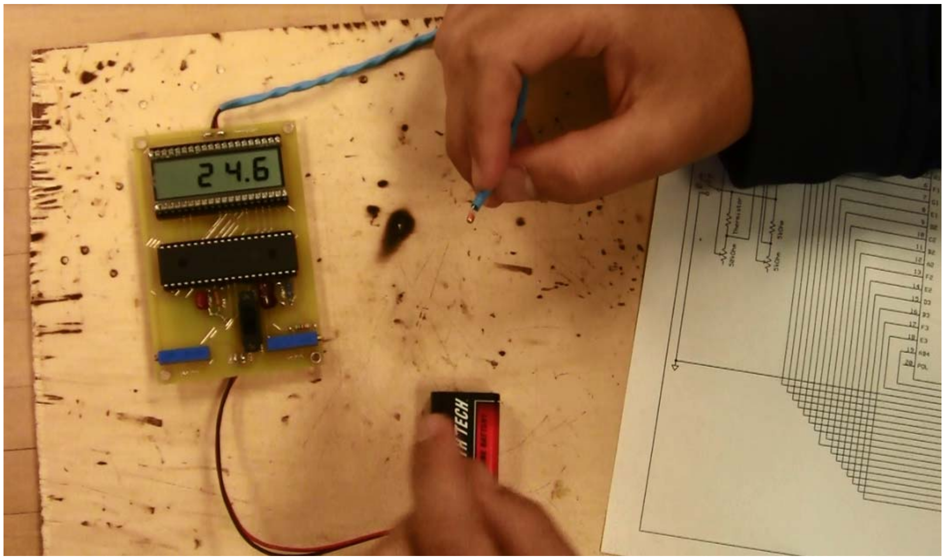

FIGURE 6. Testing the Temperature Sensor, Fall 2013.

3. PROJECT EVOLUTION.

Since the introduction of the module in the fall of 2011, changes have been made to reflect faculty interests and lessons learned from previous occurrences. The most significant changes have been the result of turnover in the faculty assigned to teach ETD 313. In fall 2011, it was one instructor; in 2012, a second instructor took over; and in 2013, this instructor shared the teaching responsibility across three course sections with a third instructor. Each instructor brought his/her own expertise and preferences into the classroom. On the electrical engineering side, the instructor has remained the same, but the project endured a curriculum change that merged two courses into the current course and lab.

Student feedback from fall 2011 indicated that the requirement of interlocking packages stifled creativity, particularly for the technology students, as the exterior form was set early in the project and could not be altered. As a result, this constraint was removed and students were given the charge to design the system as a handheld device. After noting that seven of the eight package designs from 2012 were essentially rectangular boxes, the instructors deliberately encouraged creativity in package design in 2013. Students rose to the challenge, exhibiting a wider variety of package forms such as those seen in Figures 1 and 3. Another change from 2011 to 2012 was a review of DFMA practices in the package design, with student revisions being necessary before FDM printing.

To jumpstart the package design process, a class exercise was introduced in ETD 313 in which students brought in and disassembled hand-held electronic devices. In their design groups, students identified best practices for integrating the PCB with the package, in terms of mounting the PCB, attaching the batteries, and designing/placing switches and controls. At the end of the exercise, groups gave brief presentations to share their findings with the class.

Module administration also changed as needs and weaknesses were identified. The grading rubric for ECE 483 was changed in 2013 because the instructor perceived that the original rubric contained too much detail. This led students to work towards checking items off the list rather than mastering skills through quality work. Also in 2013, students in both programs were required to develop a user's manual so they could further develop their communication skills. Another change was the increased involvement of faculty with students from their counterpart's program. In 2012, the technology professor was invited to the ECE 483 class late in the semester to discuss communication issues that had arisen during the project. In 2013, he discussed DFMA and plastic injection molding with the ECE 483 students at the start of the module.

4. PROJECT ASSESSMENT.

In the fall 2013 semester, the authors introduced an assessment survey to measure the effectiveness of the module. Four student groups were surveyed: current students in ETD 313, current students in ECE 483, and former participants enrolled in the capstone design course for their respective disciplines. Survey participants indicated their agreement to a set of statements according to a five-point Likert scale ("5 = strongly agree", "4 = agree", etc.). The statements assess students' perceptions of how well the project meets course objectives and enhances skills for working in multidisciplinary teams. Survey statements were identical except in their program-specific details. Survey statements and response summaries are found in the Appendix.

The data indicate that module participants perceive it as being successful in helping them work in multidisciplinary teams. Statement #5 on the current-participant survey and statement #4 on the former-participant survey both state, “working on the project helped me work with people outside my discipline”. Their average score for this statement across all four surveys is 4.45, falling between “strongly agree” and “agree”. This score is interesting considering that the replies to statements regarding communication (#6 and #7 on the current-participant surveys) were much lower, averaging 3.72 and 3.66 respectively. Comments from former technology participants support the need to improve communication. According to one, “… the EE’s really didn’t communicate that well with us”.

The lowest survey responses are those in response to the cross-discipline learning (statement #3 on both surveys). This is not surprising since cross-disciplinary learning was not emphasized during the project as much as learning how to collaborate with professionals outside one’s discipline.

One limitation of the data represented here is that it represents a one-time survey from a small population. The sample size inhibits the ability to make meaningful conclusions from statistical analysis. Another limitation is that the responses measure self-reported qualitative data as opposed to quantitative measures of learning.

Despite these limitations, the project has been well-received. Almost all respondents replied “strongly agree” or “agree” to the “I recommend this project be repeated in future semesters” statement, with an average score of 4.47. In end-of-semester evaluations, one electrical engineering student said, “the projects made the class very enjoyable and made the material apply in real world situation [sic]”. From the authors’ viewpoints, the project allows students to work on a complex and unstructured project with a high level of complexity and uncertain outcomes. Through designing a circuit, designing a package, laying out a PCB, soldering circuits, and occasionally failing at these tasks, students discover that real design is not always a sterile, linear process.

5. CONCLUSIONS.

A recurring joint design module between electrical engineering and engineering technology students gives both groups the opportunity to reach program-specific learning outcomes in the larger context of multidisciplinary design. The project is open-ended, allowing students to exercise their creativity towards meeting objectives. Specific details of the project's administration have changed each year, reflecting changes in faculty and lessons learned from previous semesters. A survey of current and recent participants show that, despite difficulties in communication, the project is beneficial towards helping students work well in multidisciplinary groups.

ACKNOWLEGEMENTS

The following students' work is depicted in this paper. Electrical and Computer Engineering: Joey Buchman, Dan Burns, Joshua Czajkowski, Nick Easley, Antonio Huerta, Bill Leismer, Karston Shephard, and Michael Stabler. Design Engineering Technology: Cameron Aldrich, Dan Borgerding, Joshua Easley, Brandon Fewell, Mason Grubbs, Kyle Pierce, Cody Stark, and Zack Walk.

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APPENDIX: TABULATED SURVEY DATA.

TABLE 1. Statements and Responses from Current ETD 313 Students.

STATEMENT	SA	A	N	D	SD	N/A	Average
1. Working on the project has helped me understand fundamental design guidelines for fundamental design guidelines for injection molding	**1**	**13**	**5**		**1**		**3.65**
2. Working on the project has helped me understand factors governing the cost of injection molding tooling.	**3**	**10**	**6**		**1**		**3.70**
3. Working on the project has improved my understanding of circuit board design and manufacture.	**4**	**5**	**7**	**3**		**1**	**3.53**
4. Working on this project has helped me think creatively and critically about product design.	**11**	**7**	**2**				**4.45**
5. Working on this project has helped me work on projects with people outside design engineering.	**9**	**11**					**4.45**
6. I understood what my colleagues in electrical engineering were doing in the circuit board design.	**4**	**9**	**6**	**2**			**3.71**
7. My colleagues in electrical engineering understood what we were doing with the mechanical design.	**1**	**10**	**8**	**1**			**3.55**
8. I would recommend this project be repeated in future semesters.	**7**	**11**	**2**				**4.25**

SA = Strongly Agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly Disagree.

TABLE 2. Statements and Responses from Current ECE 483 Students.

STATEMENT	SA	A	N	D	SD	N/A	Average
1. Working on the project has helped me understand fundamental design guidelines for analog signal instrumentation design.	**8**	**6**	**1**			**1**	**4.47**
2. Working on the project has helped me understand factors governing the cost of analog instruments.	**7**	**6**	**2**				**4.33**
3. Working on the project has improved my understanding of the plastic injection molding process and designing for that process.		**8**	**4**	**3**	**1**		**3.19**
4. Working on this project has helped me think creatively and critically about product design.	**8**	**8**					**4.50**
5. Working on this project has helped me work on projects with people outside electrical engineering.	**7**	**7**	**2**				**4.31**
6. I understood what my colleagues in design engineering were doing in their mechanical design.	**2**	**8**	**4**	**1**		**1**	**3.73**
7. My colleagues in design engineering understood what we were doing with the circuit board design.		**12**	**3**			**1**	**3.80**
8. I would recommend this project be repeated in future semesters.	**14**	**1**	**1**				**4.81**

SA = Strongly Agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly Disagree.

TABLE 3. Statements and Responses from Former ETD 313 Students.

STATEMENT	SA	A	N	D	SD	N/A	Average
1. Working on the ET/EE design project last year has helped me remember fundamental design guidelines for injection molding.	**1**	**4**	**1**				**4.00**
2. Working on the ET/EE design project will help me with mechanical design elements in my senior design project.	**1**	**2**	**2**		**1**		**3.33**
3. Working on the ET/EE design project will help me integrate electrical components in my senior design project.		**2**		**1**	**1**	**2**	**2.75**
4. Working on the ET/EE design project will help me work with people outside design engineering.	**3**	**3**					**4.50**
5. Working on the ET/EE design project will help me communicate design ideas with people outside design engineering.		**4**	**2**				**3.67**
6. The ET/EE design project was a positive learning experience.	**3**	**3**					**4.50**
7. I would recommend this project be repeated in future semesters.	**2**	**3**	**1**				**4.17**

SA = Strongly Agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly Disagree.

TABLE 4. Statements and Responses from Former ECE 483 Students.

STATEMENT	SA	A	N	D	SD	N/A	Average
1. Working on the ET/EE design project last year has helped me remember fundamental design guidelines for analog instrumentation design.	**4**	**2**	**1**				**4.43**
2. Working on the ET/EE design project will help me with electrical design elements in my senior design project.	**5**	**1**	**1**				**4.57**
3. Working on the ET/EE design project will help me integrate mechanical components in my senior design project.	**3**	**2**	**1**	**1**			**4.00**
4. Working on the ET/EE design project will help me work with people outside electrical engineering.	**5**	**2**					**4.71**
5. Working on the ET/EE design project will help me communicate design ideas with people outside electrical engineering.	**5**	**2**					**4.71**
6. The ET/EE design project was a positive learning experience.	**6**		**1**				**4.71**
7. I would recommend this project be repeated in future semesters.	**5**	**1**	**1**				**4.57**

SA = Strongly Agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly Disagree.