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A Sophomore level Introduction to Engineering Design Course

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ABSTRACT. Iowa State University has a sophomore level course that is known as ABE 218. The objectives of this course include learning a structured approach to engineering design, preparing the students for internships, learning the basics of project management, and connecting the theoretical engineering paper designs to physical reality. This informal paper discusses how the course is structured, identifies the lab projects that are part of the course, and discusses some of the results and challenges associated with ABE 218.

Keywords. Curriculum, engineering design process, internships, introduction to engineering design, project management, sophomore, undergraduate.

ABE 218 and the Iowa State University ABE curriculum

ISU has two sophomore level ABE courses. These courses are the first engineering courses that focus on the ABE discipline. The students have had a basic CAD course and an engineering problem solving course in the ABE department as freshman**.** (Iowa State University, n.d.)

ABE 216: Fundamentals of Agricultural and Biosystems Engineering

Prereq: ABE 160 or permission of the instructor

Application of mathematics and engineering sciences to mass and energy balances in agricultural and biological systems. Emphasis is on solving engineering problems in the areas of heat and mass transfer, air and water vapor systems; animal production systems, grain systems; food systems, hydrologic systems, and bioprocessing. (Iowa State University, n.d.)

ABE 218: Project Management & Design in Agricultural and Biosystems Engineering

Prereq: ABE 216

Project management - critical path, Gantt charts, resource allocations, basic project budgeting, and project management software. Engineering design approaches. Open-ended design projects to demonstrate the preceding principles through application of technical concepts taught in prerequisite coursework. (Iowa State University, n.d.)

The ABE 218 course reinforces engineering principles learned in ABE 216 such as sensible heat, latent heat, heat flow through structures, and mass and energy balances. The ABE 218 course has three hands-on lab projects that create physical prototypes using the engineering design process. The projects will be described in greater detail later in this paper.

ABE 218 Objectives

The ABE 218 course was designed by considering the ABET Student Outcomes. (ABET, n.d.) The specific course objectives are as follows:

Students become better prepared for internships.

Understand workplace expectations
Understand appropriate workplace behavior

Transfer on-paper engineering design concepts to physical reality.

Compare theoretical calculations to measured actual results.
Relate individual sensor measurements into a prediction of the actual process.
Understand sensor uncertainty and propagation of error.

Learn and apply the engineering design process (EDP).

Learn several models of an Engineering Design Process.
Apply a nine-step EDP to Project 2 and Project 3.

Understand the basics of project management

Apply project management techniques to physical projects
Demonstrate basics of engineering documentation

Learn and reinforce engineering knowledge, with a focus on ABE application.

Sensible and latent heat
Global water resources
Global energy resources
Basics of microcontroller programming and application

Understand and use department facility and resources.

The role of Teaching Lab Coordinators
Lab space such as the project lab
Lab equipment such as the water jet

ABE 218 Course Structure

The course has a one-hour lecture plus a two-hour lab each week. Multiple lab sections are scheduled to accommodate the number of students enrolled in the course. The first lectures are heavily connected with learning the EDP process which is applied in the Lab Projects 2 & 3. Mid-semester the students are split into separate groups for two lectures that are specific to the Project 3 that they will be doing. The balance of the semester features content that is not associated with the lab projects.

Lectures

Introduction to Course/ Expectations
Engineering Design Process (3 lectures)
Uncertainty Analysis and Propagation of Error
Microcontroller Discussion plus Assignment
Project 3 Background and Theory, Biological Project Specific (2 lectures) (Biological Project students only)
Project 3 Background and Theory, Mechanical Project Specific (2 lectures) (Mechanical Project students only)
PE Licensure and Ethics
Current Engineering Topics
Appropriate Workplace Behavior
Global Water Issues
Global Energy Issues
Travel Abroad, Grad School, and Career Paths
Course Review

Lab

Project 1
2 weeks
Design and build a mobile.

Project 2
6 weeks
Create a psychrometric box that will predict the amount of sensible and latent heat being added to the system.

Project 3 (Mechanical)
6 weeks
Create an Arduino controlled mechanism that will accomplish a set of tasks.

Project 3 (Biological)
6 weeks
Create a scale bioreactor that will remove nitrate from the system's volume of water.

Grading

The grading for the course is as follows:

2 week open-ended Project 1	10%
6 week open-ended Project 2	30%
6 week open-ended Project 3	30%
Micro-controller assignment	5%
Quizzes (mostly weeks in lecture)	10%
Final	15%

Detailed description of Project 1

Project 1 is to design and build a mobile. The student will submit dxf files for each of the parts to the Teaching Lab Coordinator. The TLC will then nest the design with other parts, and cut the parts out of 3mm thick aluminum. The student will assemble the mobile. If they feel it works correctly, they will present the assembled mobile to the TLC for evaluation.

Constraints: The lever arm for the longer side of the balance must exceed twice the length of the short lever arm. The length of the short lever arm plus the length of the long lever arm must exceed 300mm. The mass of the armature must not exceed 30% of the total mass of the mobile. The pivot location of the armature shall consist of a 6.6mm square cut, with two of the vertices aligned to the vertical plane. When evaluated, the error shall be the angular distance that the balance deviates from a vertical plane.

Evaluation: Aesthetics shall count towards 20 pts. (We are asking for some non-trivial CAD work.) Documentation shall count up to 80 points. (Contact information, working in ink, pages signed, Table of Contents, appropriate notebook.) A deviation from the vertical shall result in a score as follows:

0 – 5 degrees	100 pts
6 – 10 degrees	95 pts
11-15 degrees	90 pts
16-20 degrees	85 pts
>20 degrees	80 pts

The students are allowed to iterate on the design as needed to fix any errors. Typical problems that we find are math errors, problems with scaling, incorrect assignment of material in the CAD program, or not understanding that unsupported pieces of aluminum will fall out of the decorative elements (e.g. the center of the letter ‘O’). The review of the documentation is primarily to make sure that the student understands the expectations of documentation, and that they are ready to do a complete job of documentation on Projects 2 and 3.

The 2 weeks associated with Project one gives the instructor several lectures to deliver the first phases of the Engineering Design Process. Project 1 refreshes the student’s CAD skills and teaches them how to create the files required to work with the water jet.

Detailed description of Project 2

Project 2 is to create a prototype structure and apply instrumentation to it. The instrumentation will produce a display that indicates how much sensible heat and latent heat is being added to the structure. A propagation of error analysis will be conducted on the sensors to determine the uncertainty of the instrumentation system.

Constraints: The structure must be greater than 23”x23”x23”. The structure may not exceed 4’x4’x4’. Materials must be obtained from the specified local source by the TLC. Budget for materials is $30. Instrumentation and ventilation fan will be supplied. Instrumentation will be read via VBA based on an Excel template that is provided. All work and calculations must be documented.

Evaluation: A heat source will be added to the system. The system will predict how much heat has been added. When adjusted for system uncertainty, the error between the actual value and the predicted value determines how many performance points will be scored. Individual notebooks will be scored based on documentation of the EDP, calculations, VBA code documentation, correctness of engineering notebook fundamentals (table of contents, working in ink, legibility, signed and dated), technical assessment of the project, and graphical display of the results. A Peer Assessment will be factored into the individuals final project score.

Detailed description of Project 3 (Mechanical)

Project 3 Mechanical is to create an Arduino controlled mechanism that accomplishes one of three challenges. These challenges require the construction of the physical parts, the application of appropriate sensors, and the appropriate Arduino code required to read the sensors and control the device. Available sensors include color sensors, light sensors, IR Beam detectors, and hall-effect sensors. Available components include servo motors, stepper motors, DC motors with gear boxes, motor driver interface boards, stepper motor driver boards, Arduinos, battery packs, piezo tone generators, and serial cables to allow use of the Serial Monitor.

Tasks: 1. Create a line following robot. The robot must detect whenever it sees an IR signal. It must stop at the end of the course and beep three times. 2. Create a beam traverse robot. The robot must traverse a 20’ length of iron pipe. In the center of the pipe it must detect the bright overhead light and drop 2 Lego people into the target zone. When it finds the magnet at the end of the pipe, it must stop and beep its horn. 3. Create a color sorting device. The device must load 10 colored ping pong balls of two different colors in random order. The device will sort the balls by color.

Evaluation: The basic evaluation is functionality of the system. The time that it takes to accomplish the task is a secondary impact on the functionality scoring. The documentation scoring is very similar to Project 2, with emphasis placed on the process of creating program, and documenting the Arduino code. We are looking for good engineering notebook fundamentals and following the engineering design process.

Detailed description of Project 3 (Biological)

Project 3 Biological is to create a scale bioreactor that will remove nitrate from a rural water supply. A system will be designed using containers for the water, carbon sources, plumbing, and small pumps. The system will need to meet the conditions required for microbial denitrification, which includes appropriate hydraulic retention time and anaerobic conditions. The system will be spiked at 30 mg/L of nitrate solution and allowed to run for 24 h.

Evaluation: The basic evaluation is functionality of the system. Calculations include the mass removal rate as well as the concentration reduction. Reaction kinetics are also calculated using temporal samples collected prior to the final test. The amount of nitrate removed is evaluated by drawing water samples at specific times after starting the reactor. The documentation scoring is very similar to Project 2, with emphasis placed on the process of creating the system. We are looking for good engineering notebook fundamentals and following the engineering design process.

What works?

Hands-on projects

Many students thrive on the ability to design and build these prototypes. It is a very different class than a theory based text book and homework type class.

Random group forming

The formation of teams is done by random assignment. This creates an opportunity for students in the department to get to know each other. We do not allow teams to self-select, thus avoiding the opportunity for a close group of students to specialize in project work. (One student becomes good at programming, another at CAD, another at working the math. After multiple team projects in multiple courses, they have each learned only a third of the material, but they are good at it!) We also mix the groups such that individuals are not left-out during the group formation process.

Video tutorials for CAD

Videos were created for each of the major CAD projects that are used in the Department (SolidWorks, Creo, and Inventor). These videos showed how to create a part, assign material, measure the mass of the part, calculate the center of gravity, and finally output a quality dxf. This has nearly eliminated the amount of time required to work with an individual student to accomplish the CAD work. The quality of the dxfs has also improved such that less time is spent fixing the dxf file or returning files to be corrected. Future work includes creating video tutorials for the basics of the Arduino programming.

Teaching Lab Coordinators

The process of receiving dxf files from each student or group is a significant amount of organizational as well as technical work. Project 1 involved receiving dxf files and cutting over 200 unique parts on the water jet. This would not be possible without the support of our Teaching Lab Coordinators and our student lab technicians.

What did not work?

8am Monday Morning Lecture

The initial schedule placed the lecture on Monday morning at 8am. Students focused on the project aspect and very quickly ignored lecture content. Attendance dropped significantly. The challenge came that we ended up teaching the material again during the lab time. As the number of students grew, this was not sustainable. The students that did not attend lecture did not receive much of the material that was included on the final. This created an element of dissatisfaction when students did poorly on the final. The Monday lecture also did not meet during the Monday holiday. This took one of the lecture slots away from us.

The lecture was moved to a slot on Tuesday at 10am. All of the labs were moved to either Tuesday, Wednesday, or Thursday. This gave us a lecture before the lab each week. It also gave us an extra lecture. The later time made it easier for the students (and the faculty) to get to class. We incorporated a quiz most weeks. This reinforced the need to attend lecture, and prepared students to review the materials which eventually ended up on the final.

2 projects

The initial course design had only the Project 2 and Project 3. The students would rush into the project without considering or documenting early Engineering Design Process steps. Adding the new Project 1 gave us a couple weeks to lecture on the early steps of the EDP, and to deliver our expectations for the documentation. The quick look at notebooks on project 1 gave us a one-on-one discussion about the fundamentals of documentation, and made sure the students were started in a correct manner.

3D Printing

The turnaround time and throughput associated with 3D printers makes their use marginal. They will not work for Project 1 due to the partial infill. (The mass of the CAD model is not easily correlated to the physical part.) Several students attempted to build their Project 3 chassis using a 3D printed part. Build times of 28 hours or more were common, plus first pass yield of successful designs was low and required many reprints. As enrollment numbers increased, using a 3d printer was not viable. We will allow limited use- for example to create a pulley or special component mount.

Challenges

Student Number Growth

A hands-on course is very directly impacted by increases in student numbers. A system was developed to manage the large number of dxf files headed to the water jet, and manage the cut materials back to the students. The Teaching Lab Coordinator role is a significant asset for having the labs prepared and organized, ordering material, and managing the receipt of dxf files, running the water jet, and delivering the cut parts back to the students. One-on-One time to resolve issues with CAD, dxfs, or programming challenges became a challenge, which we addressed by creating video tutorials. The physical space requirements for the projects increases with the number of groups.

Results

Feedback from Employers

The companies that we interact with and the members of the external advisory committee indicate that our students are better prepared and more productive at internships.

Feedback from Junior and Senior level courses

Faculty have indicated that the quality of student projects has improved. Some of this may be due to student's better understanding how to access the tools that are available to them within our department. The work with sensors and programming allow them to be better prepared for later courses which teach measurement and control systems in greater detail.

Feedback from Students

The students indicate that many of them enjoy the hands-on projects. Students which have not built a network within their cohort have said that it is good to work with students that they may not know well. The ABE lab section times are frequently on the tour route, and visitors comment how engaged and enthused our students are in that class.

Conclusion

The ABE 218 course at Iowa State University is a sophomore level course that provides a hands-on experience that reinforces engineering theory. The course allows students to use the department resources to create physical parts that connect reality to the theoretical. The students are better prepared to work at summer internships. Overall feedback on the course indicates that it is a valuable part of the total ABE curriculum at Iowa State University.

Acknowledgments

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