Incorporating Engineering Design Content in an Engineering Technology Curriculum

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Abstract

This study presents a series of methodical curriculum development and revision activities in the new Mechanical Engineering Technology program at Missouri State University to incorporate a comprehensive engineering design content. A sequence of five courses in the curriculum are restructured to emphasize different aspects and dimensions of engineering design. Incorporated with Accreditation Board of Engineering and Technology (ABET) accreditation requirements, courses are linked to emphasize different aspects of engineering design throughout the curriculum. Students complete integrative design projects in this sequence of courses and apply the theory in real-world engineering problems. Enterprise skills, including teamwork, professionalism, and recognizing ethical values are also integrated into the curriculum with these course projects. The resulting curriculum is relevant in that it tailors to the needs of regional industry partners and practical in that it provides hands-on education, resulting in employment-ready graduates.

Redesigning a Curriculum

Mechanical Engineering Technology (MET) program at Missouri State University was developed in 2013 to address the industry's needs for employment-ready mechanical engineering technologists in the region and to close the gap between a graduating student and a qualified engineer as much as possible. Delivering a student-centered, interactive, and cooperative learning environment has been the primary purpose of the activities during the curriculum development stage. Course structures have been designed in a way where the instructors supply the core material and give students an opportunity of developing their computational and analytical skills as well as teamwork skills, professionalism, and ethical values. The content materials have been integrated to encourage student to use, develop, and combine their ability and talents to design and improve integrated systems of people, technologies, material, information, and equipment within the context of societal and contemporary issues in their practice.

In addition to the educational demands of industry in the region for employees with strong abilities and skillsets, Accreditation Board of Engineering and Technology (ABET) accreditation requirements have also been considered when developing the program curriculum. ABET requires MET programs to prepare graduates with knowledge, problem solving ability, and hands-on skills to enter careers in the design, installation, manufacturing, testing, evaluation, technical sales, or maintenance of mechanical systems. Therefore, supervised in-class activities, laboratory exercises, and term projects have been created for courses to support lectures and assignments to enable student learning. ABET accreditation standards also emphasize major design experiences based on students' course work. Following ABET Student Learning Objectives (SLO) have been adopted and addressed in courses.

A. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities;
B. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
C. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
D. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
E. an ability to function effectively as a member or leader on a technical team;
F. an ability to identify, analyze, and solve broadly-defined engineering technology problems;
G. an ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature;
H. an understanding of the need for and an ability to engage in self-directed continuing professional development;
I. an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;

J. a knowledge of the impact of engineering technology solutions in a societal and global context;
K. a commitment to quality, timeliness, and continuous improvement.

Comprehensive engineering design content has been incorporated in the curriculum as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants (National Research Council, 2012). Incorporating different aspects of engineering design, a sequence of five courses have been designed that focus on scoping, generating, evaluating, and realizing ideas as explained by Sheppard (Sheppard, 2003). The sequence starts with a freshmen level introductory course named “Introduction to Engineering Design” that introduces fundamental concepts of engineering design including computational methods, the design process, and communication techniques. The sequence continues with a sophomore level second course, “Electrical Circuits” that concentrates on electrical circuits design by providing in-depth knowledge of theory, analysis, and applications of electric circuits. The third course in the sequence is a junior level course named “Mechanical Design and Analysis: that focuses on traditional manufacturing process design and mechanical design to present engineering materials and mechanisms design in the curriculum. The fourth course, “Product Design and Conceptualization”, is also a junior level course that introduces prototyping, designing for different considerations, robust design, design economics, as well as patents and intellectual property. Students complete an integrative design project in each course and apply presented theory into real-world engineering problems. Course deliverables include written reports with detailed design data and analysis, group and individual presentations, and one or more working, physical product prototypes. Projects are also used to introduce enterprise soft skills, including various levels of communication, teamwork, professionalism, and recognizing ethical values. The sequence is finalized by a senior level capstone “Senior Design” course that requires student participation in interdisciplinary teams to bring a product from conceptual design through manufacture. Activities include detail design, material selection, cost estimation, process planning, schedule and production requirements planning, distribution systems design, software planning and implementation, and product fabrication.

The Introduction to Engineering Design course is the introductory course where the students are introduced to engineering design. The course emphasizes the iterative decision making in the engineering design and development process and introduces fundamental steps of product design including developing mission statement, identifying and analyzing customer needs, establishing product specifications as well as generating and evaluating product concepts. The course also includes an engineering graphics component where students learn the basic principles, techniques, and practices for developing drawings in a computer-aided drafting environment. Students in this class are also working on a semester-long course project in teams of four to complete a conceptual design of a product. The goal of the project is to learn and apply principles and methods of the design process to improve teamwork skills and to appreciate the inherent multidisciplinary nature of engineering design. Introduction to Engineering Design course objectives and ABET SLO's addressed by each objective are as follows:

1. Comprehend the structure of the engineering design process, and develop and evaluate a conceptual product using this process (ABET SLO F, SLO H).
2. Understand drafting standards and the conventions of 2D engineering drawings, and communicate the development of a conceptual product (ABET SLO D, SLO G).
3. Comprehend the syntax of engineering design tools to analyze engineering technology problems (ABET SLO D, SLO F, SLO G).
4. Function effectively on a team (ABET SLO E, SLO K)

The Electrical Circuits course focuses on electrical components and automation in a product or component design. Feasibility, cost analysis, and usability of electrical components and automation are introduced to students to make decisions on what to automate when designing a product. The course content also includes analysis of different off-the-shelf electrical systems to investigate sensor/actuator combinations, matching voltages, amperages etc. Students also experience what is available for purchase and how to perform a make-or-buy analysis for electrical components and automation. The course is supported by laboratory hours where students build components and conduct experiments individually and in project groups. Electrical Circuits course objectives and their ABET SLO's include:

1. Demonstrate an understanding of Ohm's, Kirchhoff's, and Power Laws (ABET SLO B, SLO C, SLO G).

2. Design basic series, parallel, and combination circuits (ABET SLO B, SLO D).
3. Use simulation software to predict response of complex circuits to various inputs (ABET SLO A. SLO G).
4. Design circuit noise filters and power distribution systems (ABET SLO B, SLO D).
5. Find steady-state, DC, and transient solutions for AC/DC circuits composed of resistors, capacitors, inductors, op amps, and other electrical components (ABET SLO A, SLO D).

The Mechanical Design and Analysis course introduces simultaneous engineering concept where both product design and in-service performance as well as product fabrication and assembly are considered during the design phase of project inceptions. Students perform a semester long integrative design project which synthesizes these concepts. Mechanical Design and Analysis course objectives and ABET SLO's addressed by each

1. Perform rational material selection, including the evaluation of material performance indices and the use of material selection charts (ABET SLO A, SLO D, SLO F).
2. Perform rational manufacturing process selection (ABET SLO B, SLO D, SLO F).
3. Perform tolerance assignment activities using both traditional and statistically-based tolerancing methods (ABET SLO B, SLO D, SLO F).
4. Synthesize the above skills in order to perform design for manufacture tasks (ABET SLO A, SLO B, SLO D).

The Product Design and Conceptualization course introduces detailed engineering design considerations in an entrepreneurial environment including product architecture, design for environment, design for manufacturing, quality aspects in engineering design, design economics and cost estimation, industrial design as well as patents and intellectual property issues. The course also has a prototyping component where students employ different prototyping tools and technologies, and develop a physical prototype of a product. This component is coupled with a course project where each project team designs and analyzes a product based on aforementioned considerations. Product Design and Conceptualization and their ABET SLO's include:

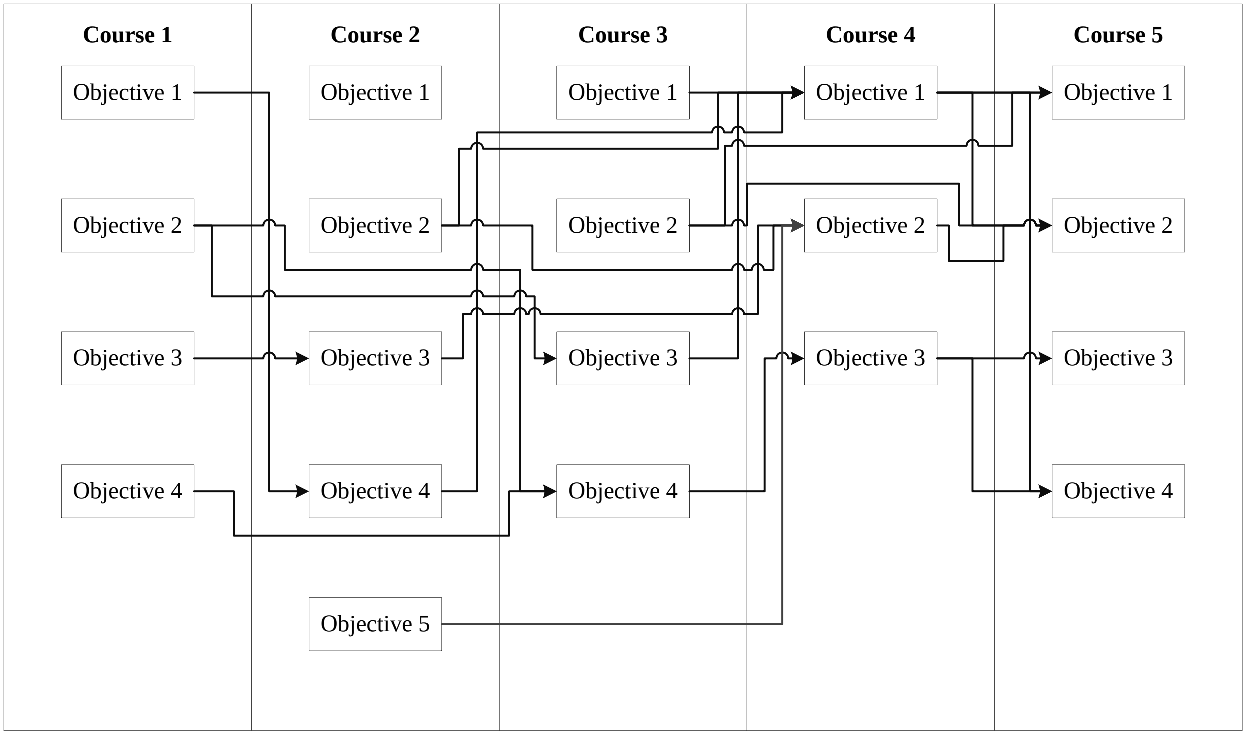
1. Comprehend the structure of the product design and development process. Build, evaluate, and test a physical product using this process (ABET SLO C, SLO D, SLO K).

2. Communicate a design and its analysis (written, oral, and graphical forms) (ABET SLO G, SLO K)
3. Function effectively on a team (ABET SLO E, SLO I)

The Senior Design course draws upon all prior courses by exposing the student to an integrated, capstone design experience. The course is a critical component of the curriculum and provides the student with a comprehensive opportunity to utilize the skills and abilities obtained through the MET program core material as well as the incorporated engineering design content. In addition, this course represents a major design experience and allows students to demonstrate that they have the ability to work in teams to design, develop, implement and improve integrated products and systems. Senior Design course is not a lecture-based course; instead, each team have designated (weekly) meeting times with the course instructor where they review their project accomplishments, next steps, and any potential roadblocks. There are a number of milestones throughout the semester for preliminary and final reports as well as formal and informal presentations. Since this course is used to perform a summative ABET SLO assessment for the program, course objectives are not individually mapped to SLOs. Senior Design course objectives include:

1. Integrate product/process/tooling design skills acquired through previous coursework to design and fabricate a prototype of a complex product involving some automation component.
2. Synthesize analytical market, production system, cost estimation evaluation and design skills acquired through previous coursework to perform commercialization activities associated with the product of item 1, above.
3. Conduct effective meetings, organize and participate in effective teams, and develop and deliver effective reports and presentations.
4. Appreciate the necessity for the continual upgrade of engineering and technical knowledge.

The engineering design content in the courses are linked to each other using course objectives determined by the program's faculty. Below are the generalized objectives of the courses in engineering design sequence.



A Sample Project

In this section, a sample Senior Design course project is presented with some level of detail. The project has been executed by a group of MET students as a culminating engineering design project where they have utilized engineering design tools, methods, and concepts. The project has been assigned to a team with the following problem statement.

> *Typical roundness testers available to industry today are often capable of measuring much tighter tolerances than are necessarily required by the products which are measured by these devices. Also, these roundness testers are very expensive (~$30,000) for a machine that is capable of measuring workparts up to 15.75 inches. However, approximately 85% of all manufactured cylindrical workparts are under 2.00 inch diameter.*
>
> *As the team of engineers, you will identify a need in the market for a lower cost "Form Measurement Device for Circular Geometries" (FMD-CG) which will be*

capable of measuring five Geometric Dimensioning and Tolerancing controls, including total runout, circular runout, circularity (roundness), concentricity, and cylindricity. Then, you will design and fabricate a prototype FMD-CG within the required specifications.

A set of comprehensive analyses have to be conducted for the product and its production system that include market share analysis, material and process selection, production system and site requirements. A facility layout study has also to be conducted that should account for all necessary machinery and production operations to produce the designed product. Additionally, a capacity plan has to be developed and personnel requirements have to be identified for the production. A selling price for the product has to be identified to yield an attractive potential profit under a high demand scenario.

In the first stage of the project, students have developed a project mission statement and a product function statement, which are introduced in the Introduction to Engineering Design course. These statements mainly include product description, primary and secondary markets, major project assumptions and constraints, stakeholders, project life, and current state of the market. Students have conducted an extensive market analysis to develop a background on the product and its current use in industry. The team has focused on the product demand and market opportunities. They have conducted an extensive customer needs assessment and market forecast analysis utilizing mathematical and statistical tools and methods. This content is introduced both in Introduction to Engineering Design and Product Design and Conceptualization courses.

In the conceptual design stage, students have conducted a functional decomposition analysis for the product and developed product specifications. A major consideration has been given in the product requirements to measure abovementioned five controls. Functional requirements for electronic systems, hardware requirements, and software requirements have been determined considering economic feasibility of FMD-CG. Since the product had to contain electrical and mechanical components as well as software controller, students have utilized tools and techniques that have been introduced in Electrical Circuits and Mechanical Design and Analysis courses for functional decomposition analysis and product specification.

Multiple concepts have been designed with different capabilities. Cost estimation tools have been used to calculate a detailed cost for each concept. In addition, material selection, process selection, make vs. buy decisions, tooling and a detailed inspection plan have been developed for concepts. These tools and methods have been introduced in Mechanical Design and Analysis and Product Design and Conceptualization courses in the curriculum. Developed concepts have been evaluated based on these criteria and the most promising concept has been selected for further consideration. The team then has designed and fabricated a detailed prototype of the selected concept in a laboratory environment.

The next stage included production design and site selection for FMD-CG. Manufacturing and assembly techniques and requirements as well as needed equipment have been considered in developing a production system. A detailed analysis of available manufacturing machines, assembly, and inspection equipment has been conducted for production operations. Similar to the prototype design stage, material selection, process selection, make vs. buy decisions, tooling and a detailed inspection plan have been developed for the production system. In addition, facility requirements have been identified for a facility layout study. A capacity planning analysis had been done based on the required production levels.

Site selection for the production facility and profit analysis were the last stages in the project. The team has considered ten cities in eight states for the production facility based on the available Department of Labor statistics. In addition, a general cost estimation has been done for potential sites. Considering the results of the analysis, expected product life, estimated market share and annual inflation rate, a price for the product has been determined to yield a certain net profit for the operations.

Conclusion

This paper reports a series of course content and curriculum development activities in the Mechanical Engineering Technology (MET) program at Missouri State University to incorporate a comprehensive engineering design content. Courses in this series not only introduce different aspects of engineering design, but also assess and evaluate student learning in individual or team projects. Projects are also utilized to provide opportunities for students to improve their enterprise skills. Courses and their engineering design content are linked to each other using course objectives developed under ABET Student Learning Objectives. In addition to individual and team projects in courses, students participate a culminating capstone project in the Senior Design course where they utilize engineering design tools, methods, and concepts. Future enhancement will include incorporating the design of a product for one of the nationwide student competitions into the courses. For example, Baja SAE® student competition incudes designing and building a single-seat, all-terrain, off-road vehicle that should survive on rough terrains. This engineering design project activities can be merged in the courses so that the student would design and fabricate different components of the vehicle in different courses in the MET curriculum.

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