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Board 111: Transformative Approach of Engineering Technology Curricula Based on Sustainability, Systems Thinking, Creativity, and Alignment with Industry Needs

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Transformative Approach of Engineering Technology Curricula based on Sustainability, Systems Thinking, and Creativity

Abstract

The necessity to adapt and reimage the curriculum of engineering technology degree programs is crucial to better prepare students for their future careers in engineering. This necessity arises from the continuous evolution of technological advancements and the increasing importance of sustainability in the engineering field. As technology rapidly advances, engineers, who often begin their careers with an engineering technology background, are at the forefront of applying practical engineering principles and developing sustainable innovations. This paper proposes a multifaceted educational approach that integrates sustainability, systems thinking, and innovative teaching methods into the undergraduate engineering technology curriculum, thereby ensuring that graduates are adept at confronting the sophisticated sustainability challenges of the 21st century. The reform strategy is applied to our four-year Bachelor of Science in Engineering Technology curriculum, and encompasses several key initiatives: embedding sustainability concepts into core engineering courses, crafting learning outcomes that promote systems thinking, utilizing innovative pedagogies based on "Engineering for One Planet," expanding the curriculum with relevant examples, incorporating practical mini-projects, and embedding sustainability frameworks in capstone design projects. The approach also suggests the inclusion of biomimicry principles, the adoption of advanced Life Cycle Assessment (LCA) tools, the integration of energy process assessments, and the utilization of the business model canvas with a sustainability perspective in the curriculum. This holistic educational model aims to not only enrich the learning experience of students in engineering technology programs but also to arm them with the essential competencies and insights needed to tackle complex sustainability issues in their engineering careers. By reimagining the engineering technology curriculum, this paper contributes to fostering a new generation of engineers equipped to drive sustainable innovation in their fields.

Introduction

The Agenda for Sustainable Development, anchored by the United Nations in 2015, outlines a universal call to action to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity by 2030. Central to this agenda are the 17 Sustainable Development Goals (SDGs), which are interlinked and encompass a broad range of social, economic, and environmental objectives. Integrating the Agenda for Sustainable Development into engineering education requires a comprehensive approach that encompasses curriculum reform, innovative pedagogy, and institutional commitment. By doing so, engineering programs can produce graduates who are not only technically proficient but also socially responsible, ready to lead the way in achieving a sustainable future. [1-3]. Important steps in weaving the sustainable development into engineering technology education are curriculum integration, project-based learning, and capstone design projects, supported by research, and institutional commitment.

Curricular Integration forms a foundational element in aligning engineering and engineering technology education with the global trends in sustainable development. This involves a strategic infusion of Sustainable Development Goals into the curriculum and promoting interdisciplinary learning to ensure that graduates are not only proficient in their technical fields but also have a comprehensive understanding of the complexities of sustainable development. That may be achieved by a multiprong approach, such as incorporating sustainable development goals into course content, using customized modules and project-based learning to engage students in addressing real-world challenges related to the goals, and aligning resources and assessment with sustainable development goals related outcomes. [4]

Interdisciplinary and transdisciplinary learning, and collaborative projects will assist students in developing their ability to apply their knowledge in sustainable development contexts. Segalas et al (2012), [5] in their analysis showed that for students to have a both competences of systemic thinking and interdisciplinarity, they need to have in-depth understanding of fundamental science and engineering concepts along with the ability to connect the knowledge with the professional practice. [5], [6]

Engineering technology and systems thinking are intrinsically connected disciplines that, when integrated, can significantly enhance the effectiveness and sustainability of engineering solutions. Systems thinking, a holistic approach to analyzing complex systems by understanding the relationships and interactions within them, is crucial for addressing the multifaceted challenges encountered in engineering technology. Integrating systems thinking into engineering technology equips professionals with the tools to design and implement solutions that are not only technically sound but also socially responsible and environmentally sustainable. As the world faces increasingly complex challenges, the demand for engineers who can think systemically, anticipate the broader impacts of their work, and innovate within complex systems will continue to grow.[7]

To meet the demands of this dynamic field and ensure that graduates are well-prepared for the challenges of the 21st century, it is essential to adopt an educational approach that encompasses the diverse dimensions of sustainability, systems thinking, and innovative teaching methods. This comprehensive strategy not only enriches the education of engineering technology majors but also equips them with the essential skills and knowledge required to address the multifaceted sustainability challenges in their professional pursuits. In the subsequent discussion, we delve into the multifaceted approach aimed at transforming engineering technology education to better align with the needs of both students and the rapidly changing world of technology and sustainability.[8]

Educational Approach for Curriculum Enhancement – The methodology

The educational approach for curriculum enhancement involves various methodologies aimed at improving the content, delivery, and assessment of our engineering technology program, to ensure it does meet the programmatic and workforce needs. Certainly, the educational approach described in the paper involves a multifaceted strategy for enhancing sustainability and creativity considerations in engineering education:

Incorporating Sustainability in Core Courses: The approach recommends integrating sustainability analysis into fundamental engineering and engineering technology courses such as

Mechanics, Dynamics, and Thermo-fluid sciences related courses. This educational strategy aims to lay a strong foundation for understanding and addressing sustainability challenges.

Course Learning Outcomes**:** The proposed approach includes developing course learning outcomes for fundamental courses that emphasize function decomposition and a system thinking approach. This involves teaching students to analyze systems from a holistic perspective, breaking them down into components and functions, and scaling back up to the system level.

Innovative Teaching Methods: The educational approach emphasizes the use of innovative teaching methodologies, such as "Engineering for One Planet" and brainstorming techniques. These methods are designed to engage students in the engineering design process, fostering a deeper understanding of the interplay between design parameters.

Expanded Curriculum: The approach involves re-imagining Thermodynamics courses to include examples of systems and systems decomposition, focusing on functional function identification and in-depth study of functions. This is intended to increase student engagement and their comprehension of the relationships between design parameters.

PBL - Mini-Projects: Incorporating mini-projects into higher-level courses is part of the approach, allowing students to study concepts related to energy savings opportunities in industrial processes. This hands-on approach helps students apply their knowledge to real-world sustainability challenges.

Capstone Design Integration: The educational approach integrates various sustainability frameworks into capstone design projects. This includes using Life Cycle Analysis for concept generation, incorporating entrepreneurial mindset (EM) concepts for economic analysis, and applying Engineering for One Planet (EOP) principles for sustainability.

Biomimicry: The approach suggests incorporating principles of biomimicry in fundamental courses and capstone concept generation. This educational strategy leverages nature-inspired design solutions.

LCA Tools: Transitioning from one LCA tool (Granta CESEdu) to another (GaBi) is part of the approach, providing students with exposure to a wider range of tools for sustainability assessment.

Energy Process Assessment: Integrating energy process assessments into courses enhances students' understanding of the energy aspects of sustainability.

Business Model Canvas: The approach recommends incorporating the business model canvas, with a focus on sustainability, into capstone design projects. This emphasizes the importance of economic viability alongside environmental and social sustainability.

This educational approach is designed to equip engineering students with the knowledge, skills, and perspectives needed to address complex sustainability challenges in their projects and future careers. Drexel University’s Engineering Technology program offers an undergraduate BS major in engineering technology. The program current curricula have a common core curriculum for the first 3 years and then is offering 3 concentrations in mechanical engineering technology, electrical engineering technology, robotics and automation engineering technology, filling in the gap between the industry demand and the current educational offerings in the area and nationwide. The program also incorporates 3 cycles of co-operative experiential education. As our curricula evolved, we incorporated several components of sustainability and creativity (Husanu, EESD, 2018) [9], [10].

Our ET Program Educational Objectives (PEOs), as broad statements that describe what graduates are expected to attain within a few years after graduation. Program educational objectives are based on the needs of the program's constituencies.

Drexel University ET program produces graduates who:

1. Apply discipline-specific theory, experiments, real world experience and advanced engineering technology to interpret, analyze and solve current and emerging technical problems.
2. Communicate clearly and persuasively with technical and non-technical people in oral, written, and graphical forms.
3. Function individually and on teams, in contributor and supervisory roles, to design and improve quality systems, components, products and processes in a timely, responsible, and creative manner.
4. Demonstrate behavior consistent with professional ethics and cognizant of social concerns as they relate to the practice of engineering technology.
5. Strive for professional growth and engage in lifelong learning.

The Drexel ET Program Student Outcomes (SOs) are the general student outcomes as described in the ABET-ETAC [11] and these relate to the knowledge, skills, and behaviors that students acquire as they progress through the program. ET students will attain:

1. An ability to apply knowledge, techniques, skills, and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline.
2. An ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline.
3. An ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature.
4. An ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes.
5. An ability to function effectively as a member as well as a leader on technical teams.

Review of Past Curricular Enhancements – Incorporating Sustainability and Creative Thinking

Curriculum Integration: Mechanical Design and Manufacturing Processes

Over the past decade, we have redeveloped core curricula and courses across various concentrations to incorporate sustainable concepts. Our Engineering Technology (ET) curriculum now includes enhanced modules on ***manufacturing processes and mechanical***

design, aiming to provide students with advanced tools for making environmentally conscious design decisions. These modules cover critical topics such as embodied energy, carbon footprint, recycling rates, and toxicity within the context of Product Lifecycle Assessment (LCA), which is essential for informed decision-making regarding mechanical, thermal, and electrical properties affecting design eco-friendliness. Additionally, our manufacturing engineering technology courses now equip students with modern tools like CES EduPack™ and Autodesk software to promote eco-friendly designs. The curriculum integrates concepts from industrial and mechanical engineering technology, emphasizing sustainability, life-cycle assessment, and product-embedded energy. Starting with introductory courses and reinforced through specialized modules in Mechanical Design and Manufacturing Processes, the curriculum culminates in senior design projects that incorporate eco-design principles throughout the ET program.

This educational strategy combines essential skills necessary for success in the modern engineering landscape, including the application of fundamental engineering principles with a focus on sustainability, teamwork, and the ability to make decisions based on multiple attributes.[12]

Curriculum Integration: Fundamental and Energy Related Courses

In our fundamental courses such as **thermal-fluid science courses**, which typically rely on lectures, we have incorporated hands-on, experiential activities alongside project-based learning that focuses on sustainable energy solutions in manufacturing settings. Consequently, students are encouraged to delve into the comprehensive understanding of sustainable systems, emphasizing the environmental and societal impacts of engineering systems or technologies.

This approach shifts the focus from isolated subsystems and components to a broader, holistic view of the "big picture".

- Re-imagined Thermodynamics courses to include examples of systems, and systems decomposition: functional function identification and function driven in-depth topics for study: increase student engagement in learning –by-discovery, understanding of correlations between design parameters.
- Generating course learning outcomes for fundamental courses to incorporate function decomposition and systems thinking approach.
  - Starting from the general to particular: system to component to function and back to system (scaling up)
  - Incorporating learning-by-discovery using EOP framework for core learning principles.

Below is an example of a thermal-fluid science course SLOS mapping with program PEOs

Table 1

ABET Student Outcomes		1	2	3	4	5
SLO 1:	Develop engineering skills related to heat transfer, thermodynamics and fluid mechanics courses a. Apply their knowledge of mathematics and science to thermal-fluid engineering systems b. To illustrate the development of the governing equations associated with thermal systems.	**X**				
SLO 2:	Recognize and apply analytical techniques and design principles as applied to thermal - fluid systems, including identifying system requirements and appropriate standards. a. To use heat transfer principles to understand the behavior of thermal systems. b. To investigate the influences of various system parameters and conditions on the resulting steady or transient response of the system. c. To provide the basic tools used in thermal system design as applied to industry	**X**	**X**		**X**	
SLO 3:	Prepare a high-quality engineering reports including presentation of goals, background, results, analysis, and conclusions		**X**	**X**		

In the area of **energy and sustainability**, we developed a set of 3 courses focused on renewable energy, with a focus on energy conversion, clean energies such as wind and solar, providing students an overall view of renewable energy sources. A second, more advanced course related to renewable energy and green energy manufacturing was introduced. This course is focused towards a more complex integration of renewable energy sources, progressing to the examination of the relationships of energy, sustainability, and industrial practices. This includes system integration, modern tools of assessment and evaluation such as thermal imaging, and introduction to industrial energy efficiency area. The educational experience is further enriched through project-based learning, employing "GaBi LCA Simulation" for Green Energy Manufacturing insights, coupled with laboratory exercises related to each lecture topic [13].

A third undergraduate course in energy and sustainability areas addressed to junior and senior students examines sustainable industrial energy systems, culminating with the thorough examination of energy audit process and the energy flow in an industrial setting. These activities not only foster teamwork but also enhance the capacity for undertaking projects of larger breath and meaningful depth, encouraging a deep dive into the analysis of industrial systems for energy audits and efficiency improvements. This comprehensive approach broadens students' understanding and expertise in energy and sustainability in industrial environments.

In the Figure 1 below, we present the how the main sustainable design areas are integrated throughout several areas of curricular developments in the engineering technology curricula at Drexel University., illustrating what aspects of each area are implemented in various courses.

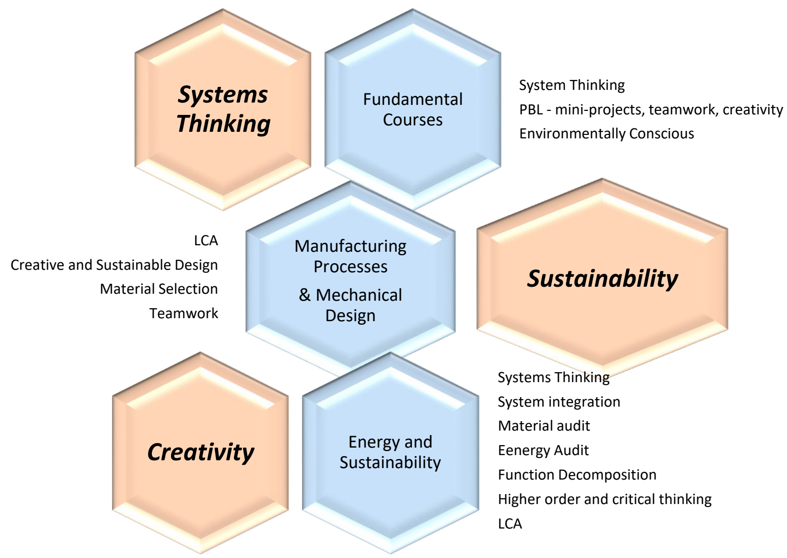

Figure 1: Incorporating Sustainability and Creative Thinking in Engineering Technology Curriculum

Results and Discussions: Analysis and Assessment and Evaluation of the Student Learning Outcomes of the Past Curricular Enhancements

As the curricula transformed, the capstone design evolved with it, trending towards incorporating a more integrative approach and more sustainability related projects.
However, past improvement efforts have been more discipline oriented and driven by industry and educational needs in a particular discipline. The natural continuation of these efforts was a thorough SWOT analysis of our curricula for the program and each concentration. The analysis was focused on several aspects:

1. ET's Program Learning Objectives and/or concentration-specific learning criteria.
2. Student competencies as related to ET program educational outcomes.
3. Programmatic needs of the engineering technology as a major and each concentration
4. Industry needs in terms of skills and competencies.
5. The availability of resources such as faculty expertise, equipment, and finances.
6. ABET-ETAC criteria and requirements [11].

The 1 through 6 criteria for assessment were geared toward answering the following questions:

- Are we doing as best we can for our students?
- For what industries and occupations are we preparing our students?
- How do specifics courses contribute to meeting the program objectives?
- Where should our resources be directed to achieve the desired outcomes?
- How well prepared are our students for their future? How large of a delta are we creating?

In our quest to better align our engineering technology curricula with sustainable development, programmatic needs, and industry demands, we started by assessing our students' gaps and competencies through several tools: students and faculty surveys, formal and informal assessments of their knowledge in fundamental mathematics, science, and engineering courses at every level (quizzes and targeted exam problems focused on critical fundamental knowledge). The assessment was driven by the analysis of the results of the co-operative experiential education employer surveys over the past recent years (see Figure 2), and the ABET self-review process, analyzing the average scores for the evaluated courses for each performance indicator. Another important driver was the need for recalibration of our program with the societal needs, to respond to the most emerging challenges and demands from industry and society.

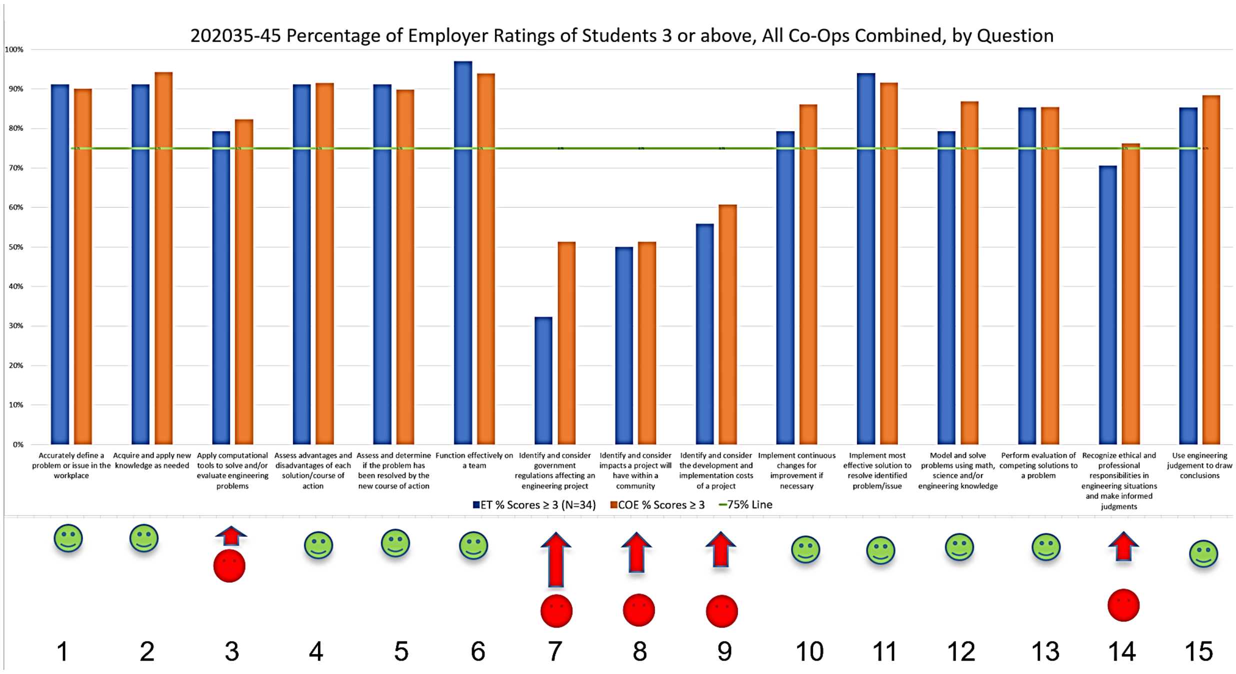

Figure 2 Identification of Skills and Competencies levels: Strengths and Gaps

The assessment of course evaluation vs performance indicators, and of the industry response (employer survey) revealed our program's curricular strengths and weaknesses (see Figure 3). The course assessment is based on our program performance indicators, developed based on the ABET-ETAC criteria for BS in Engineering Technology programs, using a multi-prong evaluation approach: formal and informal students' individual assessments, connected with course SLOs and PI, weighted and averaged for each PI on a percentage score.

Our students' abilities were stronger in the areas of identifying systems, components, or process requirements, students having demonstrated advanced skills to develop and evaluate alternative designs of engineered systems, components, or processes to minimize adverse environmental and societal impacts. Also, our students' scores were higher for demonstrating ability to define an optimal, realistic, and technical approach that meets design requirements in terms of technical, economic, and societal criteria with realistic deadlines.

For the majority of questions in Figure 2, there is no significant difference between College of Engineering (CoE) overall and Engineering Technology (ET) scores. There was no question in which ET scored than CoE to a degree of statistical difference.

Statistical difference is determined by "P(≤ t) two tail" being less than 0.05. The lower the number the greater the statistical difference between CoE and ET. Thus, the question that has the most severe statistical difference – the lowest P two tail score was "Use of Engineering Judgement to Draw Conclusions".

	T All	T 2of3	T 3of3
Identify and consider government regulations affecting an engineering project	0.023546325		0.012366325
Acquire and apply new knowledge as needed		0.019906863	
Apply computational tools to solve and/or evaluate engineering problems			0.025853565
Model and solve problems using math, science and/or engineering knowledge			0.028671051
Use engineering judgement to draw conclusions			0.004925243

Figure 3 Analysis of the ET gaps by comparison with peer engineering programs.

As per Figure 3, we can draw a summary of key takeaways from the analysis performed.

- Co-op (3rd cycle) had the most issues, with 4 questions scoring lower than the CoE mean, to a degree of statistical significance. The one question that had the most severe statistical difference was identified the one related to using engineering reasoning to draw conclusions.
- For the combined co-ops, ET earned a statistically significantly lower score for the question: "Identify and consider government regulations affecting an engineering project".
- In the 2nd cycle of co-op, ET had a statistically significantly lower score for "Acquire and apply a new knowledge as needed".
- There is no statistically significant difference in either first co-op, whether it is one of three co-op cycles or just one co-op cycle per academic journey. However, the sample size was extremely small, so that result should be expected (2 to 4 students).

In analyzing our students' gaps, we concluded that:

- Students' knowledge of math and physics is inadequate to support understanding and analysis in engineering courses, leading to a lack of sufficient depth of understanding in upper-level courses.
- Students' ability to formulate clear problem statements and to select solutions to meet specifications is lacking enough curricular support.
- Students need more curricular support in developing superior skills with modern computing tools – digital modeling, analysis, programming – to support engineering analysis and design.
- Students' ability to communicate and justify engineering decisions is not enough exercised at different levels of instruction.

During the past three academic years we have been re-evaluating our curricula against the ABET criteria for BS level in ET. We analyzed EET, MET and Manufacturing ET programs ABET existing criteria. We compiled the common competencies of these programs, with a look at the newly proposed program designation "Mechatronics Engineering Technology", with a focus on our program critical competencies and identified gaps above-mentioned.

Moreover, most of the gaps identified in our program concern critical competencies for all programs, hence addressing these gaps are of tremendous importance, considering that ABET accreditation is the minimal threshold.

Common aspects of all Engineering Technology programs:

- Fundamental knowledge (math, physical sciences): differential and integral calculus, applied mechanics, dynamics, thermal-fluid sciences, materials.
- Common competencies in:
  - circuit analysis and design with applications
  - computer programming and/or modern software utilization for design and analysis/simulation; automation programming (or software)
  - measurement and instrumentation tools and techniques (tolerancing, dimensioning, design of instrumentation systems, set-up, calibration of measurement tools)
  - application of industry codes, specifications, and standards (criterion 5)
  - product/process design tools
  - analysis, design, and implementation of systems (*concentration specific*)
  - project management tools.
  - Capstone design and integrated experience (PBL) (criterion 5)

Students who possess these skills and competencies "are capable of holding entry level jobs as engineers, *but without a more extensive grounding in mathematics, science, and design, they may be ill equipped to proceed on to higher levels of engineering practice* (according to National Research Council, Engineering Education and Practice in the United States—Engineering Technology Education)".
It is crucial for engineering and engineering technology education to address students' gaps in fundamental knowledge; therefore, we are in the process of implementing a more integrative approach to our courses offered to freshmen and sophomore students, including mathematics and physics sequences for engineering technology program. We are also looking at enhancing the credits allocation to courses in fundamental sciences. These credits will be used to enhance innovative teaching strategies, based on project-based learning (mini-projects, and visits to relevant companies to engage students in understanding the need for the fundamental knowledge), and expanding the incorporation of system thinking at every step.

Framework for Integrating Sustainable Design and Systems Thinking

The assessment and evaluation efforts described above led to several actions: one of the major curricular reframing should be directed towards the implementation of product/process design knowledge and tools. As described above, the premises for such a leap were already in place. We needed a re-development of the senior design course correlated with the creation of new courses that would introduce and reinforce principles of design, systems thinking and sustainable design notions and concepts throughout the curricula.

Our existing curricula incorporated a freshmen/sophomore (undergraduate) course in Graphical Communication – students will explore aspects of CAD design using AutoCAD/Inventor/Fusion360 and SolidWorks, integrated with GD&T notions. The next design related course in our old curricula was Mechanical Design, which is a four-credit undergraduate course of 400 level, followed by the Senior Design Project course sequence (3 senior courses of 3 credit-hour each).

To bridge the gap between freshmen and junior to senior year, we developed two courses related to engineering and product design. One course is addressed to sophomores to pre-junior level students and the other one to pre-juniors to junior level undergraduate students. Both courses will lead students to a better understanding of design principles, allowing them to close the gaps in the areas of clear problem statements formulation, solutions selection to meet design specifications, engineering analysis and design, and communication and justification of engineering decisions. These courses are developed to mesh seamlessly with the Senior Design courses, giving the students the necessary competencies to thrive in their engineering career.

The Figure 4 below is a schematic mapping of the sequence of courses that majorly and intentionally incorporated design components infused with systems thinking, creative design, Life-cycle Assessment, sustainable material selection, manufacturing processes and design components, assessment of energy and carbon footprint, and clean technologies. All of these courses we inspired by foundational frameworks of Engineering-for-One-Planet for engineering education. [15], [16], [17]

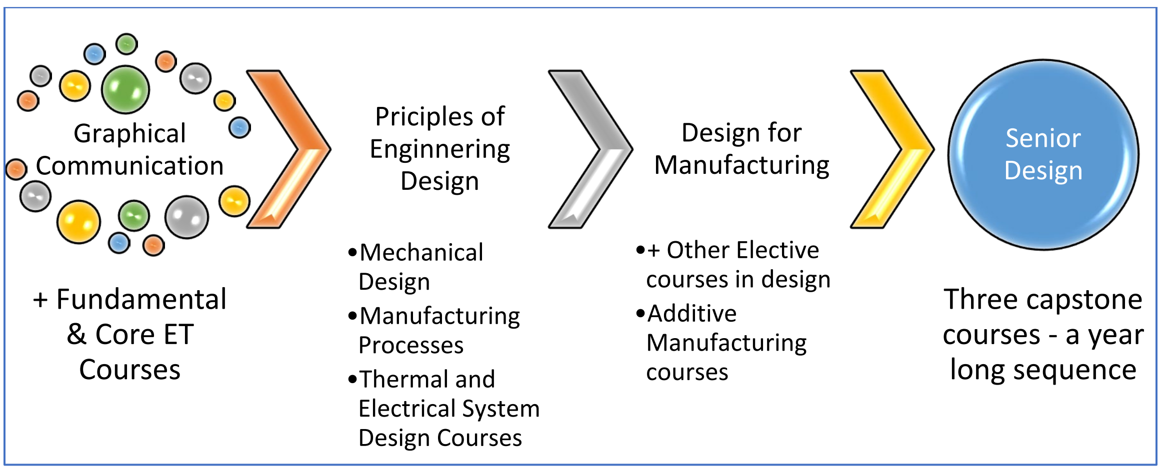

Figure 4: Mapping of Design Related Courses in Engineering Technology Curriculum

MET 300 Principles of Engineering Design – core curriculum 4 credit hour course and pre-requisite for capstone senior design courses sequence.

Course description & Goals: This course is designed to introduce students to the concepts of engineering design. Students will develop a thorough understanding of the design process through collaborative thinking. This course will allow students to apply iterative design process in creating a new product while integrating the marketing, design, and manufacturing functions of the firm. Students will explore design challenges and employ the product design and development process to design a product to meet the challenge.

Course outcomes (Student Learning Outcomes):

Communicate effectively:

1. Learn how to communicate technical manufacturing requirements and product specifications through the use of CAD drawings and specification documents.
2. Co-ordinate multiple, interdisciplinary tasks to achieve a common objective.

3. Identify, address, and communicate obstacles and present pertinent solution(s) for successful design of a product.

Identify, define, and solve problems:

4. Discover – Problem presentation by client, team formation, detailed problem understanding, investigation of prior art, definition of functional requirements and explore and generate possible design solutions.
5. Apply various CAD/CAE simulation tools (Structural and Flow simulations, Topology optimization using Finite Element Analysis methods) for design feasibility and success.
6. Understand the limitations and trade-offs of various engineering materials and manufacturing methods.

The delivery of the topics studied is scaffolded, gradually introducing students to the process of engineering design and product development, then guiding to learn about how to capture information needed to define problem to be solved as well as need and opportunities identification. Then students will explore methods to capture customer needs and determine the stakeholders. Students will learn using experiential activities how to find out Product Design Specifications (both initial to final target specifications). Using a wealth of simulation tools, students will brainstorm to generate concepts, use decisional practices to select solutions and benchmarking to determine the final solution. They will explore concept mapping notions. Next topics will explore design aspects, from embodiment design, detail design to robust design. They will use modern tools such as CAD modelling and CAE simulations in developing several design alternatives to be used in concept selection process, Virtual Simulation CAD modeling and CAE simulations. During this process, they will use several techniques for materials selection, detail design and final solution decisions, incorporating both systems thinking and, biomimicry and sustainable design.

In the Table 2 below we describe the connection between student learning outcomes of the course and program PEOs.

Table 2: MET 300 SLOs mapping to Program Educational Objectives

ABET Student Outcomes[1]		**1**	**2**	**3**	**4**	**5**
SLO 1:	Learn how to communicate technical manufacturing requirements and product specifications through use of CAD drawings and specification documents.	**x**				
SLO 2:	Co-ordinate multiple, interdisciplinary tasks to achieve a common objective.					**x**
SLO 3:	Identify, address, and communicate obstacles and present pertinent solution(s) for successful design of a product.	**x**	**x**			

SLO 4:	Discover – Problem presentation by client, team formation, detailed problem understanding, investigation of prior art, definition of functional requirements and explore and generate possible design solutions.	**x**	**x**			**x**
SLO 5:	Apply various CAD/CAE simulation tools (Structural and Flow simulations, Topology optimization using Finite Element Analysis methods) for design feasibility and success.	**x**				
SLO 6:	Understand the limitations and trade-offs of various engineering materials and manufacturing methods.	**x**				

Student course activities included a system mapping of the product of their choice, leading to identifying potential problems to be solved and stakeholders. The next step was to conduct an analysis of the embodied energy, LCA and manufacturing process energy and materials assessment. Students used both GaBi and CESEdu packages for materials and manufacturing processes selection. At least 30% of the course time was allocated to students' practice of the sustainable design practices, including the Business Model Canvas for the economic analysis, in addition to being included in the topics lectured. For in-class activities, the instructors used Google Jamboard for real-time teamwork and inter-team collaboration. Students were tasked to generate a system map of a product and then to identify each potential problem to be solved, opportunity or need for either improvement or re-design. Then students organized their ideas based on set criteria, including energy and carbon footprint, sustainable materials, sustainable manufacturing processes, recyclability, etc. Another step was to be able to identify customer voice and to convert the identified needs into measurable/quantifiable design parameters.

MET 322 Design for Manufacturing and Assembly – technical elective 3 credit course.

Course description & Goals: One of the final steps in creating a marketable product is the manufacturing of the components. Throughout the design process, engineers must fully understand the variety of processes in which parts can be produced and assembled. Selecting a manufacturing method and ensuring the parts are capable of production is a difficult but critical part of the product design process. This course will allow students to apply the theory of design for manufacturing (DFM) and design for assembly (DFA) to the overall design process. Topics include practical techniques for selection of materials and processes, design considerations for production, manual assembly, and automated assembly, and Boothroyd and Dewhurst methods. Students review case studies and analyze production assemblies.

Course objectives:

1. Gain a firm understanding of the most commonly used manufacturing methods
2. Be able to create engineering drawings that can be quoted by machine shops
3. Understand the limitations and trade-offs of various manufacturing methods
4. Know how to cost-reduce designs by selecting the most appropriate method, and

Student Learning Outcomes:

1. Learn how to communicate technical manufacturing requirements and product specifications through the use of CAD drawings and specification documents.
2. Evaluate the practical design for assembly.
3. Discuss and apply design checklist for DFMA.
4. Identify customer needs and develop a product concept with effective prototyping strategies.
5. Utilize the Quality Function Deployment method to include the "voice of the customer" in the product design process.
6. Describe the meaning and importance of concurrent engineering.
7. Use the Boothroyd and Dewhurst methodology to calculate design efficiency.
8. Apply DFMA analysis to manual and automatic assembly applications.
9. Work on individual and team projects and must identify and address obstacles to successfully designing and fabricating a prototype/product.

The topics covered are revisiting concepts related to product design process, creative concept generation and evaluation, and concurrent engineering. The system thinking is well infused in teaching product configuration and “design for function” concepts, leading again to defining the product and design specifications. The following topics are covered in the subsequent weeks:

- Design for High-Speed Automatic Assembly and Robot Assembly,
- Design Evaluation - Assessing Design Assembly, DFMA Guidelines For Product Design,
- Product Evaluation - Assessing Design for Disassembly and Maintenance;
- Product Architecture - The Impact on Manufacturing- Machining, Injection Molding, Casting, Sheet Metal Forming, PM;
- Industrial Design and Human Factors, Engineering Patents and Intellectual Property;
- Sustainable Product Design through Reliability, Digital Manufacturing and Virtual Product Prototyping

As can be easily seen, the EOP framework is thoroughly implemented in the development and instruction of this course.

Integration of Sustainable Design, System Thinking and Creativity

The integration of sustainable design, systems thinking, and creativity in the MET 300 Principles of Engineering Design and MET 322 Design for Manufacturing and Assembly courses is a testament to a forward-thinking curriculum designed to prepare engineering students for the complexities of modern product development. The detailed curriculum information underscores a holistic approach to engineering education, emphasizing not just the technical aspects of design and manufacturing but also the broader impacts of engineering solutions.[14]

MET 300 Principles of Engineering Design

Sustainable Design:

The course incorporates sustainable design practices, including life cycle assessment (LCA), materials and manufacturing process energy assessment, and sustainable materials selection. Students dedicate significant time to sustainable design practices, utilizing tools like GaBi and

CES EduPack for materials and processes selection, reflecting a deep integration of sustainability into the design process.

Systems Thinking:
Systems thinking is integrated through activities like system mapping, where students identify potential problems, needs, or opportunities for improvement or redesign. This approach encourages students to view products and their design challenges within the broader context of their environment, user interactions, and lifecycle.

Creativity:
Creativity is fostered through experiential activities that encourage brainstorming and concept generation. The course emphasizes capturing customer needs, defining product design specifications, and using simulation tools to explore design alternatives, promoting innovative thinking and creative problem-solving.

MET 322 Design for Manufacturing and Assembly

Sustainable Design:
This course extends the commitment to sustainable design by teaching students to apply principles of design for manufacturing and assembly (DFM and DFA) with a focus on sustainability. Topics such as sustainable product design through reliability and digital manufacturing encourage students to consider the environmental impact of their designs and the manufacturing process.

Systems Thinking:
Systems thinking is woven into the curriculum through the emphasis on understanding the entire product lifecycle, from concept generation to manufacturing and assembly. By teaching students to consider product architecture, manufacturing methods, and the impact of design on disassembly and maintenance, the course promotes a holistic view of product design.

Creativity:
Creativity is further developed in MET 322 through the exploration of product design processes, including creative concept generation, evaluation, and the application of concurrent engineering. Students engage in design evaluation, applying DFMA guidelines and assessing designs for disassembly and maintenance, stimulating innovative approaches to design and manufacturing challenges.

Integration in Senior Design Capstone Project Courses

The curricula of MET 300 and MET 322 are strategically designed to scaffold students' learning experiences, preparing them for the senior design capstone projects. Through the integration of sustainable design, systems thinking, and creativity, these courses equip students with the necessary skills and perspectives to tackle complex engineering challenges. Students learn to approach design problems with a sustainable mindset, considering the environmental, economic, and social impacts of their solutions. The emphasis on systems thinking ensures that students can see the interconnectedness of various aspects of product design and development, enabling them to develop solutions that are not only innovative but also holistic and feasible within real-world constraints.

Design courses provide a comprehensive view of how these courses integrate sustainable design, systems thinking, and creativity to meet the objectives of senior design capstone project courses. The detailed curriculum and activities outlined for both courses underscore a pedagogical approach that prepares students for the multifaceted challenges they will face in their capstone projects. Here's an integration of the revised information with the objectives of senior design capstone project courses:

Objective Alignment with Senior Design sequence

1. Identify the Sources of an Engineering or Technical Problem
   - **MET 300**: Through system mapping and identification of potential problems, students learn to pinpoint problem sources, a skill critical for capstone projects.
   - **MET 322**: The course's focus on the entire design process reinforces students' ability to identify sources of technical challenges, especially in manufacturing and assembly.
2. Apply Appropriate Design Techniques to Clearly State an Engineering Problem Statement
   - **MET 300 & MET 322**: Both courses teach students to formulate clear problem statements, leveraging the design process, customer needs identification, and system thinking.
3. Generate and Evaluate Alternative Solutions to an Engineering Problem
   - **MET 300**: The emphasis on brainstorming, concept generation, and using simulation tools for design feasibility prepares students to explore and select optimal solutions in capstone projects.
   - **MET 322**: The course enhances this ability by teaching students to apply DFMA principles and evaluate designs for manufacturability and assembly.
4. Apply Project Management Techniques and Function as a Team Member
   - The collaborative activities and use of Google Jamboard for teamwork in MET 300 foster project management and teamwork skills, essential for capstone projects.
5. Incorporate Engineering Standards and Realistic Constraints
   - **MET 322**: Detailed exploration of manufacturing methods, DFMA guidelines, and engineering patents integrates practical constraints and standards into design thinking.
6. Develop an Understanding of Economic, Environmental, and Social Impacts
   - **MET 300**: With significant focus on sustainable design practices, including LCA and energy/materials assessment, students are equipped to consider broader impacts in their projects.
   - **MET 322**: The course's coverage of sustainable product design further deepens this understanding.
7. Make Engineering Decisions Using Quantitative Techniques
   - **MET 300**: The application of simulation tools and the assessment of design specifications using quantitative data prepare students for data-driven decision-making in capstone projects.
8. Demonstrate Technical Communication Skills
   - Both courses emphasize the importance of communicating technical information effectively through CAD drawings, specification documents, and collaborative tools, aligning with the communication objectives of capstone projects.

Conclusions

This comprehensive educational foundation ensures that by the time students reach their senior design capstone projects, they are well-prepared to apply these principles effectively. They can identify and solve complex problems, generate, and evaluate alternative solutions, communicate their ideas effectively, and understand the broader implications of their engineering decisions. The integration of these three critical areas—sustainable design, systems thinking, and creativity—thus not only enhances the students' learning experience but also aligns with the broader goals of engineering education to develop responsible, innovative, and thoughtful leaders in the engineering field.

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