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WIP: A Comparison and Assessment of Capstone and Cornerstone Students' Perceptions of the Application of ABET Design Criteria

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Abstract

This Work In Progress seeks to discover students' assessments of their ability to employ their problem-solving skills to the engineering design process across their undergraduate degree. This will be accomplished by analyzing students' perceptions of their own abilities to apply design thinking at the outset of their first-year Cornerstone program, and again at the conclusion of their senior Capstone Design courses. The researchers embarked on this WIP upon identifying that the ABET-mapped course objectives and student outcomes for the first-year and senior programs were uniquely paired in focusing on the application of design thinking.

First-year and senior students in a large, private R1 university are required to take design courses that have students apply the engineering design process through an opened-ended design project, specifically, first-year Cornerstones of Engineering and senior Capstone design. Students in these courses will complete a survey of self-assessed knowledge of the course learning outcomes from each design course before and after the courses, which are directly linked to the ABET student outcomes used for accreditation for the engineering program. Data from these learning outcome surveys will inform how courses can improve design thinking and how these learning outcomes can be implemented in mid-degree courses. The following questions will be addressed: (1) On what aspects of the ABET student outcomes do students self-report the most improvement in the first year and senior design courses? (2) What experiences do first-year and senior students share in their respective design courses? (3) Do senior students use the engineering design process learning outcomes from first-year in their Capstone design projects? With more research and data, future results aim to answer (4) How could the curriculum help support more robust engineering design outcomes based on our findings?

Introduction

This research was done at Northeastern University that has a common first year engineering program that covers engineering design and problem-solving in two Cornerstone courses. These first-year Cornerstone courses were developed as part of a curriculum redesign that focused on incorporating engineering design with computational problem solving, data analysis and visualization tools. This research compares the design and teamwork learning outcomes of students who have gone through the whole undergraduate curriculum from the first-year program to the Chemical Engineering (ChE) senior Capstone Design course. This study evaluates student engineering problem solving and design thinking between the two courses using the courses' learning outcomes and the ABET student outcomes as a framework.

Cornerstone Description

Students entering the College of Engineering at Northeastern University have a common curriculum in the first year which includes two general engineering courses, named Cornerstone 1 and Cornerstone 2. Students in Cornerstone will typically keep the same professor and remain with the same cohort of 32 students for the pair of courses. Both Cornerstone courses focus on learning the principles of engineering design and problem solving through a series of hands-on assignments that develop the skills necessary to complete team design-build projects. The Cornerstone courses' design outcomes include developing appropriate problem definition; creating conceptual, preliminary, and detailed designs; developing design communication and implementation; and practicing professional report writing and presentations. Complimenting the design outcomes, the courses also cover outcomes pertaining to engineering technical skills such as programming, graphical design, and microcontroller design. To meet and apply the extensive list of goals set forth by the course syllabus (included in this paper's appendices), students are placed in teams and tasked with applying their weekly lessons to creatively problem solve a solution to a common, yet open final design project for each course. Problems used in Cornerstone courses are deliberately chosen to apply learning and cover topics from all engineering majors.

The topics in each Cornerstone are laid out in a progression so that the courses are not repetitive, but rather build the students' technical skills sets so that they begin to apply their new knowledge in engineering design. In each of the Cornerstones, a new design element, programming tool, graphical design tool, microcontroller design tool, and project are presented to students, with the Cornerstone 2 project requiring the cumulative knowledge from both courses. The major differences between the Cornerstone courses are summarized in Table 1.

Table 1- Differences between Cornerstone 1 and Cornerstone 2 Courses

Cornerstone 1		**Cornerstone 2**
Engineering Design Process	**Design Elements**	Value Sensitive Design
C++	**Programming Tool**	Matlab
AutoCAD	**Graphical Design Tool**	Solidworks
Intro to Arduino Boards + Sensors	**Microcontroller Tool**	Advanced Arduino Elements
Minor Design Project	**Integrated Project**	Final Design Project

Capstone Design Description

Capstone Design is a one semester, senior, project-based design course in which teams of 4-5 students design a novel process that take into consideration public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. The Capstone groups are required to:

1. Develop a business plan to define novelty, scope, and product needs
2. Design a detailed chemical process with process flow diagrams and piping and instrumentation diagrams
3. Collect data through proof-of-concept experiments, simulations, or a prototype to perform data analysis which informs their designs for optimization
4. Ensure their designs meet safety and health requirements
5. Perform economic evaluations of their design production
6. Perform multiple project milestones as a team that includes multiple forms of communication, such as oral, written, and visual, on design progression using the engineering design cycle

ABET Student Outcome Comparison

At the beginning of this work, learning outcomes from the first-year Cornerstone and senior Capstone courses were compared to find which ABET outcomes they shared in common to link the first-year and senior year design experiences. ABET Student Outcomes 2, 4, 5 and 6 were identified in the best linking course outcomes as indicated in Table 2. ABET Student Outcomes was determined as the optimal measurement tool because of its reputation and universal measurability across universities. Research

[1, 2, 3] has shown ABET criteria as having a positive impact on programs and graduates who have the prescribed design skills, ability to work in teams, and communicate effectively [4]. Therefore, our work could find common comparisons in the greater engineering community.

Table 2- Number of matching learning outcomes between Cornerstone and Capstone courses and their corresponding ABET Student Outcomes

Number of matching outcomes	**ABET Student Outcomes** [5]	
-	(1)	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
1	(2)	An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
-	(3)	An ability to communicate effectively with a range of audiences.
1	(4)	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
2	(5)	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
2	(6)	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
-	(7)	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Literature Review

Following the release of the ABET Engineering Criteria 2000 [6], a large increase in literature was released on the assessment of Capstone courses. From this literature, a call for expansion of design experiences throughout the undergraduate curriculum became a theme. [7, 8, 9] More recent research has validated this and shown that as students' progress in design related courses, their experiences with the various phases that projects and products go through serve as a unifying theme to tie together courses that are perceived as unrelated [10] and changes the quality of design thinking with increasing prior experience [11]. Additionally, students with pre-graduation engineering work experience provided notable outcomes in their relationships to ABET criteria surrounding technical knowledge, problem solving, creative thinking, and professional traits [12].

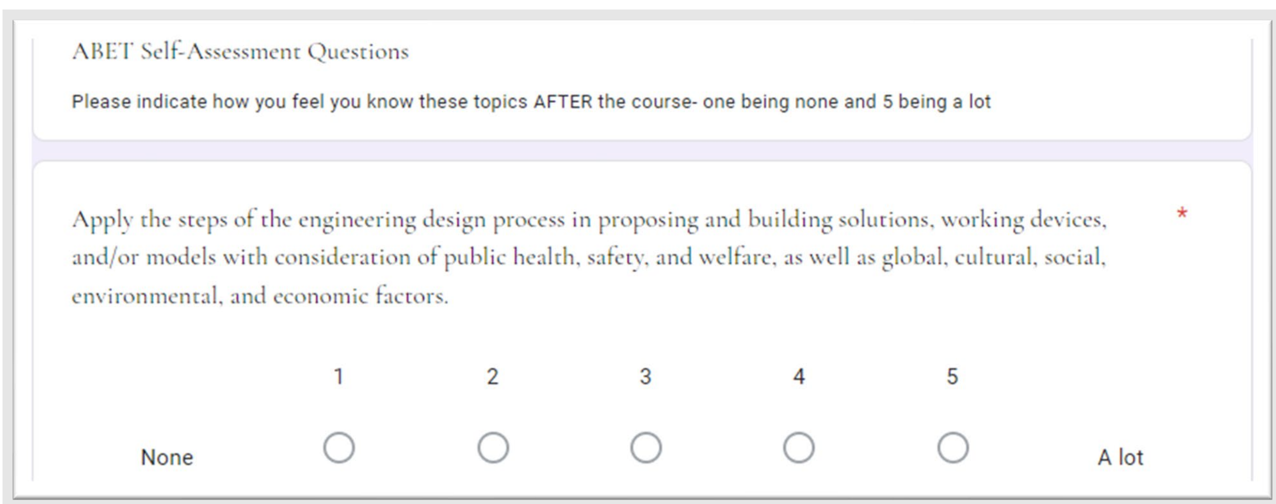
In response to the growing demand for earlier and more robust design experiences, many institutions have strengthened their first-year programs. More recently, steps to blend engineering majors [13] and blend design concepts with technical skills have provided a richer learning environment through an integrated approach to first year engineering [14]. Rebranding the integrated first year as Cornerstone, results show that the Cornerstone approach is successful, and students see a positive improvement in their perspectives on engineering and self-efficacy in their abilities to become an engineer [15]. Even at an international school not participating in ABET, one study showed that switching to a Cornerstone approach helped students overcome difficulties, gain a better understanding of their Cornerstone projects, and their future professional roles as an engineer [16].

With a greater understanding now that more design exposure is better, the Cornerstone to Capstone relationship has been examined to determine what differences in freshman versus senior application of the design process look like [17]. While some results indicate that Cornerstone and Capstone, as project-driven classes, increase the professional and technical design skills of students and can be assessed [18]. This double-edged approach to addressing ABET criteria has created an interesting feedback loop where inequities reported in one can be addressed by the other, but more interestingly have identified a larger absence of skill development in the second- and third-year curriculum [19].

Methods

<u>Pre and Post ABET Self-Assessment Surveys</u>

In Fall 2021, Cornerstones of Engineering had two sections with an enrollment of 61 students. Capstone Design had an enrollment of 16 students. A survey was developed based on the learning outcomes specific to each course, first-year Cornerstone and senior Capstone Design. The ABET survey was administered at the beginning of the course (pre) and then after the course ended (post). The entirety of the course goals and objectives from the syllabus of Cornerstone a can be found in Appendix A and Capstone goals and objectives in Appendix B. For each survey, the students were asked to indicate how well they felt they knew each learning outcome before and after they took the course using a 5-point scale. An example of one question from the Cornerstone post-course survey mapping to the first goal on the syllabus is shown in Figure 1 below. A score of 1 meant students did not feel they knew the objective well and a score of 5 meant students felt they knew the objective well.


ABET Self-Assessment Questions

Please indicate how you feel you know these topics AFTER the course- one being none and 5 being a lot

Apply the steps of the engineering design process in proposing and building solutions, working devices, and/or models with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. *

1 2 3 4 5

None ○ ○ ○ ○ ○ A lot

Figure 1 - Sample Question from ABET Assessment Survey

<u>Senior Exit Survey</u>

A third survey was conducted by the ChE Department for this same group of senior Chemical Engineers taking Capstone Design, as an exit survey to determine how well the students felt they met the ABET course outcomes over the whole curriculum. The survey asked the seniors to grade the Chemical Engineering program in meeting each outcome and asked to provide examples of what in the program helped them achieve each outcome.

Results

Using the ABET criteria as the framework for this research study, the results from the ABET self-assessment survey for both first-year Cornerstone and senior Capstone courses were evaluated for student perception of learning pre and post the courses, which relate to ABET criteria 2, 4, 5, and 6. The data from the results was analyzed using statistical significance under an independent two sample t-test and checked for equal variance assumption using a chi-square test. A 0.05 significance level was used, which validated the results with 95% certainty that results are significant. These statistical significance tests were used to gain a broad understanding of the data, as the small sample sizes may make drawing larger conclusions difficult for this study.

ABET Learning Outcome 2

For the course outcomes mapping to ABET's Learning Outcome 2, survey results (presented in Table 3) indicated that senior Capstone pre scores were initially higher and showed less change for this outcome than first-year Cornerstone students. This increased confidence perhaps highlights their previous experience in performing research. Additionally, the magnitude of differences between first-year and senior students could indicate a larger learning outcome.

Table 3 - ABET Learning Outcome 2 Course Assessment Results: Engineering Design Process Application

ABET Learning Outcome 2	**Senior Capstone Course Outcome**	**First-Year Cornerstone Course Outcome**
An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	Perform research to identify key aspects of a novel process design	Research the scientific principles, technical background required to understand the problem to be solved, and benchmark existing or related products.
PRE	3.54	2.96
POST	4.83	4.36
P-Value <.05 Significant	0.001	0
% Difference	26.7%	32.1%

ABET Learning Outcome 4

For course outcomes matching to the ABET student outcome 4, first-year and senior students showed similar confidence values (shown in Table 4) in both pre and post surveys. This near identical confidence growth may indicate that these concepts are not well-covered in the time between first and senior years. However, when highlighted and practiced through hands-on design, students can gain confidence in ethical and professional responsibilities that may require more upkeep in the curriculum between these courses. Both Capstone and Cornerstone pre and post scores showed statistical significance under a t-test.

Table 4- ABET Learning Outcome 4 Course Assessment Results: Ethical and Professional Responsibilities

ABET Learning Outcome 4	**Senior Capstone Course Outcome**	**First-Year Cornerstone Course Outcome**
An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	Prepare a preliminary process design to meet defined business, throughput, quality, and safety/environmental specifications, including identifying and specifying key process conditions	Apply the steps of the engineering design process in proposing and building solutions, working devices, and/or models with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
PRE	2.85	2.76
POST	4.67	4.63
P-Value <.05 Significant	0	0
% Difference	39%	40.4%

ABET Learning Outcome 5

ABET Student Outcome 5 had two course outcome similarities for the Cornerstone and Capstone courses. The first is presented in Table 5. As would be expected, senior students indicated more confidence in their team presentation skills coming into the Capstone course than the first-years, most likely from the greater years of experience in multiple courses over their educational experience. However, the first-year students showed greater improvement in their confidence to present in a team, which is to be expected with the practice provided in the Cornerstone course. Both Capstone and Cornerstone pre and post scores showed statistical significance under a t-test.

Table 5- ABET Learning Outcome 5 Course Assessment Results 1: Team Presentations

ABET Learning Outcome 5	**Senior Capstone Course Outcome**	**First-Year Cornerstone Course Outcome**
An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	As a team, utilize oral and written communication skills for technical, managerial, and public audiences.	Create and deliver effective individual and team presentations on engineering projects and topics
PRE	3.92	3.04
POST	4.83	4.46
P-Value <.05 Significant	0.001	0
% Difference	18.8%	32.1%

The second match for ABET Learning Outcome 5 is presented in Table 6. Similar to the previous results, seniors show a higher confidence in project management skills than first year students in both the pre and post surveys, but first year students showed a greater improvement in confidence at the completion of their first engineering design course. Both Capstone and Cornerstone pre and post scores showed statistical significance under a t-test.

Table 6 - ABET Learning Outcome 5 Course Assessment Results 2: Project Management

ABET Learning Outcome 5	**Senior Capstone Course Outcome**	**First-Year Cornerstone Course Outcome**
An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	Practice time and project management to succeed in bringing a project to a successful conclusion on a timely basis.	Apply teamwork, collaboration, creativity, and problem-solving skills to the conception of a particular solution, the creation of iterative prototypes, and the implementation of a final solution or product
PRE	4.15	3.54
POST	4.83	4.64
P-Value <.05 Significant	0.002	0
% Difference	14.1%	23.9%

ABET Learning Outcome 6

Table 7 provides the first part of the results for Cornerstone and Capstone students' confidence in their data and interpretation and analysis skills. Interestingly, seniors initially rated themselves lower to start than first-years but had a greater increase in confidence in the post course survey. There could be several reasons for this, such as small sample size; alternatively, seniors may not connect first-year data analysis in the same way, despite experiencing similar problem solving and data analysis concepts. Both Capstone and Cornerstone pre and post scores showed statistical significance under a t-test.

Table 7- ABET Learning Outcome 6 Course Assessment Results 1: Analyze and Interpret Data

ABET Learning Outcome 6	**Senior Capstone Course Outcome**	**First-Year Cornerstone Course Outcome**
An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	Identify the use and limitations of process simulation in the design process	Properly analyze and interpret computational and experimental results as part of team-based engineering practice;
PRE	2.85	2.93
POST	4.67	4.25
P-Value <.05 Significant	0	0
% Difference	39.0%	31.1%

Table 8 provides the second set of results for the ABET Learning Outcome 6 analysis. Similar to the previous data, seniors showed an unexpected lower pre survey confidence in this skill set compared to the first-year students, but a greater gain in confidence. Because this pattern emerged in both analyses of this learning outcome, there is future work to be done to uncover the true root of this lowered confidence in Capstone students regarding data analysis.

Table 8- ABET Learning Outcome 6 Course Assessment Results 2: Analyze Data through Experimentation

ABET Learning Outcome 6	**Senior Capstone Course Outcome**	**First-Year Cornerstone Course Outcome**
An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	Develop a proof-of-concept, experimental or simulated, of the design process	Evaluate the desired solution(s) by assessing feedback, test results, outcomes, and potential safety hazards relative to the Problem Statement and professional standards and codes of engineering conduct.
PRE	2.69	3.07
POST	4.58	4.46
P-Value <.05 Significant	0	0
% Difference (on 5pt scale)	41.2%	31.2%

Senior Exit Survey

There were three ABET outcomes from the senior exit survey in which they referenced both the first-year Cornerstone and senior Capstone Design courses as being examples of the program meeting those student outcomes. As shown in Table 9, Seniors who took the survey identified four ABET student outcomes (1,3,5,7) that they felt they learned from first-year Cornerstone courses. They identified 5 ABET course outcomes (1,2,3,5,7) that Capstone Design course fulfilled. This is of particular interest, as the seniors mention their first-year Cornerstone courses as being an integral learning opportunity in their education to meet these ABET criteria, indicating an importance on the hands-on design courses and student perceived learning.

Table 9: Senior Exit Survey results mapping to ABET Student Outcomes and number of times courses were referenced

ABET Student Outcome	# Responses (N)	# First-year Cornerstone References	# Senior Capstone References	# ChE Laboratory Course References	# Other ChE Courses Referenced
1	5	2	2	0	2
2	6	0	4	2	1
3	4	1	1	0	0
4	5	1	0	0	1
5	5	0	2	2	0
6	4	0	0	4	0
7	3	1	1	0	0

Analysis

<u>(1) On what aspects of the ABET student outcomes do students self-report the most improvement in the first year and senior design courses?</u>

Based on this work-in-progress research, the largest changes in confidence for both courses were surrounding ABET Learning Outcome 4 concerning ethics and professional responsibilities (Capstone 39% and Cornerstone 40.4%). This indicated that design for specific goals is perceived to be significantly learned in both courses. Given the hands-on nature of these design courses that are relatively unique, we postulate that this similar experience indicates that seniors may not have exercised this skill enough since their first-year and shows room for improvement in the curriculum.

Looking at the seniors in Capstone, ABET Student Outcome 6 (data analysis) showed the greatest positive percent difference of 39% compared to Cornerstone's 31.1%. This outcome was surprising considering data analysis was done in other parts of curriculum. We postulate that a reason for this may be that the process design simulation of a novel process was considered different and a rewarding learning experience for the seniors.

Focusing on the first-year students in Cornerstone, the next largest difference (behind what was shared with Capstone) was ABET Student Outcome 5: Team Presentations, with a change in confidence of 32.1%, which was higher than Capstone at 18.8%. An explanation for this is that seniors may have developed more team leadership skills through their time at the university (through other courses in the curriculum, coop, and by way of other team activities, such as student group participation or involvement in sports) enabling the first-year students to have a more novel experience and providing them with an opportunity for growth.

<u>(2) What experiences do first-year and senior students share in their respective design courses?</u>

What we can glean from this work is that in courses that offer hands-on design projects, improvement in confidence across ABET standards is significant. The most improvement in confidence came in ethical reasoning and professional responsibilities (ABET Student Outcome 4) but confidence in the application of the design process, team skill building, and data analysis all can improve significantly in design courses.

<u>(3) Do senior students use the engineering design process learning outcomes from first-year in their Capstone design projects?</u>

From the senior exit survey data, it can be noted that the students report that they do use the design thinking they learned in first-year Cornerstone in their senior Capstone Design projects. A comment from the senior Exit Survey for examples that helped achieve ABET Student Outcome 1 advised, "Major projects in the program were the best help for achieving this [solving complex engineering problems], especially first year Cornerstone classes as well as the final Capstone projects." Results from the ABET self-assessment survey also indirectly point to seniors' use of their previous design experience from first-year by having higher pre course scores for ABET outcome 2 (engineering design process application) and outcome 5 (teamwork), indicating more confidence in these skills prior to the start of the course. An interesting result from the survey was that the seniors' pre scores for ABET outcome 6 (analyze and interpret data) started slightly lower at 2.85 compared to the first-year students at a 2.93. However, the senior students also had a higher post score of 4.67 or 39% difference which was higher than the first-year 4.25 or 31.1% difference. This could indicate that seniors found a perceived higher learning outcome from simulating their process designs than the first-year students. This may be a result of senior students applying their knowledge from the curriculum alongside other experiences such as coop and research, leading to a more fulfilling design learning experience.

(4) How could the curriculum help support more robust engineering design outcomes based on our findings?

Results from the senior exit survey indicating examples from first-year Cornerstone, senior Capstone design and ChE laboratory courses lead to memorable learning experiences. Interestingly, these are real-world, hands-on, project-based design courses, leading to the conclusion that these types of learning experiences are the most memorable and perceived to be the most valuable to the students. Further research on this topic will be conducted to see why this may be occurring, and how other courses in the curriculum could be redesigned to add these positive learning elements to enhance student learning. In addition, there are a few places that have been identified where there is room for improvement in the curriculum between the first-year Cornerstone and senior Capstone design classes to achieve better student learning perceptions of the ABET outcomes. Initial findings indicate a dip in confidence concerning ABET student Outcome 4 (ethics and professional responsibilities) with an as-yet unidentified cause; future work will need to address this. Similarly, the confusing lower initial confidence reported by seniors in ABET student Outcome 6 (data analysis) requires a deeper look as to what is (or is not) happening in the curriculum leading up to Capstone.

Conclusion

From this work, it is recognized that senior students are cognizant of the learning they gain from the hands-on, project-based courses such as lab, Cornerstone, and Capstone. These experiential learning pedagogies need to be fostered and further research can help identify what aspects of these courses enhance student learning and can be implemented into other courses in the curriculum.

This work in progress is the first iteration of the survey and it is recognized that more data should be collected to fully address the questions being asked here. However, this initial work of comparing learning outcomes from senior Capstone and first-year Cornerstone courses using ABET student Outcomes has uncovered a few interesting gaps where seniors may be losing confidence in the curriculum that spans between the two courses. Further work with data collected from all departments might help to solidify these patterns and help departments evaluate where they can strengthen the courses that lie between these two design courses that bookend an engineering degree.

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Appendix A. - Cornerstone Goals and Objectives from Course Syllabus:

Goal #1. Discover through the iterative engineering design process authentic hands-on design projects

- Learn and apply the steps of the engineering design process in proposing and building solutions, working devices, and/or models with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. *Cornerstone 1 & Cornerstone 2*
- Research the scientific principles, technical background required to understand the problem to be solved, and benchmark existing or related products. *Cornerstone 1 & Cornerstone 2*
- Apply value-sensitive design principles to determine clients' and users' needs and then identify predetermined specifications, functions, objectives, and constraints of any potential solution by writing a Problem Statement. *Cornerstone 1 & Cornerstone 2*
- Generate several alternative solutions that could potentially satisfy the Problem Statement by using various ideation techniques. *Cornerstone 1 & Cornerstone 2*
- Decide which solution(s) to pursue by comparing alternative solutions and their probability of success using specifications, function, objectives & constraints from the Problem Statement. *Cornerstone 1 & Cornerstone 2*
- Implement the desired solution(s) by building and testing models and/or prototypes utilizing basic hand tools, rapid prototyping, and other technologies, as appropriate. *Cornerstone 1 & Cornerstone 2*
- Evaluate the desired solution(s) by assessing feedback, test results, outcomes, and potential safety hazards relative to the Problem Statement and professional standards and codes of engineering conduct. *Cornerstone 1 & Cornerstone 2*

Goal #2. Integrate value-sensitive design, ethical principles, and professional responsibilities into engineering design.

- Incorporate value-sensitive design principles into engineering design. *Cornerstone 1 & Cornerstone 2*
- Apply ethical theories to account for competing values and to make rational and informed decisions that consider the impact of engineering solutions in global, economic, environmental, and societal contexts. *Cornerstone 2 only*
- Employ ethical & professional codes and obligations that emphasize health, safety, welfare and conduct with respect to clients, the public, the law, and the profession; *Cornerstone 2 only*

Goal #3. Develop problem-solving skills in algorithmic thinking through computer programming.

- Use algorithmic thinking to plan computer programs that can solve engineering problems; Cornerstone 1 & Cornerstone 2
- Employ the fundamental programming concepts of variables, arrays, functions, loops, and conditional branching. *Cornerstone 1 & Cornerstone 2*
- Create code structures that are reusable and easily interpreted, debug non-working code, and verify existing solutions; *Cornerstone 1 & Cornerstone 2*
- Code programs in MATLAB and C++ to solve problems from a variety of disciplines; *Cornerstone 2 only*

- Use computational techniques in spreadsheet and other software to derive answers to complex numerical problems and to analyze and graphically display data; *Cornerstone 1 & Cornerstone 2*
- Build and debug microcontroller-based breadboard circuits; *Cornerstone 1 & Cornerstone 2*

Goal #4. Develop individual and team communication skills through written, oral, and visual modalities

- Communicate design and engineering information graphically using modern drawing and sketching software tools and the principles of orthographic projection; *Cornerstone 1 & Cornerstone 2*
- Create and deliver effective individual and team presentations on engineering projects and topics; *Cornerstone 1 & Cornerstone 2*
- Clearly document and effectively report engineering projects in interim and final reports that include applicable technical drawings, graphs, and descriptions of:
    - the scientific principles and technical background required to understand the problem being solved, *Cornerstone 1 & Cornerstone 2*
    - the designs and algorithms employed in the solution, including both the advantages and limitations imposed by them, *Cornerstone 1 & Cornerstone 2*
    - the intellectual property related to the proposed design with evaluation of their pertinence to the solution, *Cornerstone 2 only*
    - computer programs employed in the solution, including neatly presented pseudocode and commented raw code, *Cornerstone 1 & Cornerstone 2*
    - the work completed in each step of the process. *Cornerstone 1 & Cornerstone 2*

Goal #5. Function effectively on a team to engage in collaborative and inclusive engineering practice.

- Apply teamwork, collaboration, creativity, and problem-solving skills to the conception of a particular solution, the creation of iterative prototypes, and the implementation of a final solution or product; *Cornerstone 1 & Cornerstone 2*
- Properly analyze and interpret computational and experimental results as part of team-based engineering practice; *Cornerstone 1 & Cornerstone 2*
- Utilize inclusive practices to review and reflect upon team-based engineering work; *Cornerstone 1 & Cornerstone 2*

Appendix B: Chemical Engineering Capstone Design Course Outcomes

ABET Student Outcomes (SO's 1 – 7) which map from the COURSE OUTCOMES listed below are shown in parentheses.

At the completion of this course each student shall be able to:

- Perform research to identify key aspects of a novel process design. (2,6,7)
- Conduct project economic evaluations using capital and operating costs estimations for major items of equipment and select alternatives using economic decision methods. (1,2,4)
- Conduct an assessment of intellectual property issues related to a design process. (2,4)
- Develop, read, and interpret flowsheets, process flow diagrams (PFDs), and piping and instrumentation diagrams (P&IDs). (1,2)
- Identify the use and limitations of process simulation in the design process. (1,2)
- Prepare a preliminary process design to meet defined business, throughput, quality, and safety/environmental specifications, including identifying and specifying key process conditions. (1,2,4)
- Initiate detailed design of major equipment items associated with fluid flow, separations, reactions, and/or heat transfer. (1,2,4,6)
- Design a process which holds paramount the safety, health and welfare of fellow employees, the public, and the environment. (2,4)
- Characterize the hazards associated with chemicals and other agents used in the design process, including toxic, flammable, and reactive hazards. (2,4)
- Identify and develop procedures to control and mitigate hazards to prevent accidents, including acute and chronic chemical releases and exposures, and including over-pressure protection of equipment. (2,4)
- Identify the major regulations that impact the safety of chemical plants. (2,4)
- Perform a HAZOP or FMEA safety analysis of a design process. (2,4,7)
- Develop a proof-of-concept, experimental or simulated, of the design process. (2,4,6)
- As a team, utilize oral and written communication skills for technical, managerial, and public audiences. (3,5)
- Practice time and project management to succeed in bringing a project to a successful conclusion on a timely basis. (5)