Institutional Effectiveness
2023-2024

Program: Chemical Engineering BSCHE
College and Department: College of Engineering, Department of Chemical Engineering
Contact: Dr. Holly Stretz and Dr. Robby Sanders
Mission:

The Department of Chemical Engineering at Tennessee Technological University strives to develop the 21st Century Renaissance Engineer through development and implementation of novel learning environments anchored by the award-winning Renaissance Foundry Model. The foundation of this platform is rooted in the guidelines provided by the National Academy of Engineering's Vision for the Engineer of 2020. Educational protocols within the department are consistent with the mission and vision statements given below:

Mission: The Mission of the Department of Chemical Engineering is to prepare relevant and adaptive chemical engineers in state-of-the-art areas by emphasizing real-world problem solving and critical thinking skills.

Vision: The Vision of the Department of Chemical Engineering is to be a recognized leader in chemical engineering education through excellence in teaching, research, and service.

Attach Curriculum Map (Educational Programs Only):

Mapping of Student Outcomes and Program Educational Objectives

	Program Educational Objectives			
Student Outcomes	**Real World Problems Solver (RWPS)**	**Critical Thinker (CT)**	**Continue Formal Education (CFE)**	**Work at Frontiers in Chemical Engineering (FChE)**
1 Formulate	X	X		X
2 Design	X	X		X
3 Communicate	X			X
4 Ethics	X	X		X
5 Teams	X			X
6 Experiment	X	X		X
7 Knowledge	X	X	X	X

Please find the curriculum map attached.

Attached Files: See Appendix 1

PO1: Be real-world problem solvers

Define Outcome:

The graduates of our program will obtain positions such as plant process engineer, design engineer, group leader, production engineering, sales engineer.

Assessment Methods:

Student learning outcomes 1-7 are mapped to Program Goal 1, so the same assessment methods communicated for the SLO's apply here. In addition, LinkedIn profiles of alumni often contain position titles.

Criteria for Success (Thresholds for Assessment Methods):

1. Student learning outcomes are met.
2. Position titles are aligned with those of real-world problem solvers.

Link to 'Tech Tomorrow' Strategic Plan:

1.A Experiential Learning,4.E Economic Development

Results and Analysis:

Please refer to results shared for student learning outcomes 1-7.

Also regarding positions held by CHE graduates, an exploration of job titles indicates good alignment with real-world problem solving.

Use of Results to Improve Outcomes:

No actions are currently planned.

PO2: Be critical thinkers

Define Outcome:

The graduates of our program will demonstrate that they consistently make informed decisions through a process wherein they utilize critical thinking skills.

Assessment Methods:

Student learning outcomes 1, 2, 4, 6, and 7 are mapped to Program Goal 2, so the same assessment methods communicated for the SLO's apply here. In addition, the California Critical Thinking Skills Test (CCTST) is used as the exit exam at the university.

Criteria for Success (Thresholds for Assessment Methods):

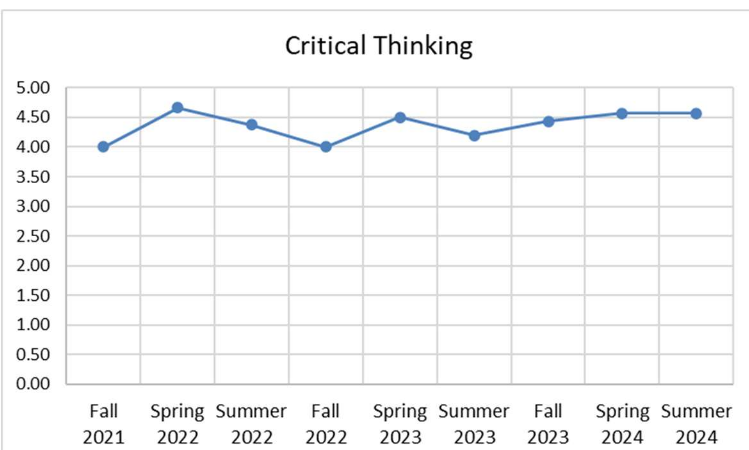
1. Student learning outcomes are met.

Link to 'Tech Tomorrow' Strategic Plan:
3.A Efficiency and Effectiveness

Results and Analysis:
Results (for Critical Thinking)--Program Goal 2 and Student Learning Outcomes 1, 2, and 6: For 2023-2024, 34 students in CHE took the California Critical Thinking Skills Test (CCTST) with a mean score of 78.9. This score is similar to that from the converted scores from the previous two years (2021-2022: 78.7, n = 31 and 2022-2023: 80.7, n=26).

Source: https://www.tntech.edu/iare/assessment/criticalthinking.php

In addition, per results from a "Co-Op Employer Survey" discussed in more detail below, CHE co-ops continue to demonstrate a high level of competency in critical thinking (Note: A score of 4 or 5 indicates that the employer agrees or strongly agrees, respectively, with the following statement, "Student can identify and respond to needs based upon an understanding of situational context and logistical analysis of relevant information.")



Use of Results to Improve Outcomes:
Chemical engineering students continue to perform well on the CCTST exam, and employers seem pleased with the demonstrated critical thinking skills of co-op students. No actions are currently planned in specific response to these outcomes.

PO3: Have continued their formal education

Define Outcome:
Our graduates will demonstrate that they have continued their education beyond the BS through some form of professional development (not necessarily leading to another degree) or will have graduated from a professional school with an MS, PhD, MD, JD or similar degree.

Assessment Methods:
Student learning outcome 7 is mapped to Program Goal 3, so the same assessment methods communicated for this SLO applies here. In addition, completion of the FE and related professional exams provide indications of a commitment to lifelong learning.

Criteria for Success (Thresholds for Assessment Methods):

1. Student learning outcome is met.
2. Students/graduates complete the FE (or related) exam.

Link to 'Tech Tomorrow' Strategic Plan:
1.A Experiential Learning

Results and Analysis:
Results from various professional exams completed by chemical engineers are provided in the attached file. These include the "Fundamentals of Engineering" (FE), the "Principles and Practice of Engineering" (PE), the "Fundamentals of Surveying" (FS), and the "Principles and Practice of Surveying" (PS) exams. Results without specific marking of FE represent the completers of the FE exam. In total 10 of 16 exams taken were passed during the Spring 2020 to Spring 2024 timeframe.

Note: "Enrolled" represents students who took the exam within 12 months of graduating, and "Graduated represents students who took the exam more than 12 months from graduating.

Attached Files: See Appendix 2

Use of Results to Improve Outcomes:
An analysis of the subscores on the various exams needs to be completed.

PO4: Be working at the frontiers in CHE

Define Outcome:
Graduates from our program will utilize and apply technologies such as bio materials, nano- and micro-systems, multi-scale analysis, informatics, group dynamics, and multi-media.

Assessment Methods:
Student learning outcomes 1-7 are mapped to Program Goal 4, so the same assessment methods communicated for the SLO's apply here.

Criteria for Success (Thresholds for Assessment Methods):

1. Student learning outcomes are met.

Link to 'Tech Tomorrow' Strategic Plan:
4.E Economic Development

Results and Analysis:
Please refer to results shared for student learning outcomes 1-7.

Use of Results to Improve Outcomes:
No actions are currently planned.

SLO1: Formulate and Solve

Define Outcome:
Formulate and Solve - an ability to identify, formulate and solve complex engineering problems by applying principles of engineering, science, and mathematics.

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives
    a. (Likert≤3)
2. Course-Level Assessments : (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.
    a. CHE 4060/4061 Kinetics (≤ 70%)*
    b. CHE 4540 Controls (≤ 70%)
3. Co-Op Employer Assessments : (Semi or annually). The Department uses a survey report directly completed by the students’ supervisor at the co-op site to learn about

important student competences. The questionnaire requires responses related to each of the 1 through 7 student outcomes.

   a. (Likert≤3)

*Note: Effective with the Fall 2022 semester, the CHE 4210 course with lab (4 credits total) was divided into a lecture section (3 credits) and a lab section (1 credit) which are numbered CHE 4060 and CHE 4061, respectively

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
   a. A population of seniors is surveyed once every third year.
      i. Likert ≥3/5
2. Course-Level Assessments
   a. Course-Level Assessments are completed for select courses every term in which they are offered
      i. >60% (>70%)
3. Co-Op Employer Assessments
   a. Co-Op employer assessment data is gathered for every student participating in co-op at the end of their internship. The collective data is evaluated every third year.
      i. Likert ≥3/5

Link to 'Tech Tomorrow' Strategic Plan:
2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:
SLO1: FORMULATE & SOLVE – an ability to identify, formulate and solve complex engienering problems by applying principles of engineering, science and mathematics

Assessment Process		**2021-2022**	**2022-2023**	**2023-2024**
(threshold Student Outcome attainment level)				
Senior Survey (Likert≤3)^		**4.3**	**4.2**	**4.5**
Course-Level Assessments	CHE 4210 or CHE 4060/61 Kinetics (≤ 70%)	**+**	*	**92%**
	CHE 4540 Controls (≤ 70%)	*		
Co-Op Employer Assessments (Likert≤3)		**4.1**	**4.2**	**4.4**

Notes: ^There were 31 or 32 responses for this student outcome each year per the Senior Survey, and only one (in 2024) was below rubric. None of the employer scores of student's co-op performance was below 3.

+Some students scored below minimum rubric of 60% but class exceeded overall 70% threshold. A detailed analysis is available in the Course Level Assessment and Curriculum Improvement Report (CLACIR) that is on-file in the department. Results for CHE 4060/61 for Fall 2023 are based on student performance on two during-the-semester exams and one final exam that are largely focused on problem solving with emphasis in material balances, reactors, rate constants, and stoichiometry.

*Results are not available.

Yellow shading represents a “watch, possibly act” situation while green represents that the value meets threshold.

Use of Results to Improve Outcomes:
Due to faculty departures, the CHE 4060/61 courses/labs have had a different instructor during each of the three academic years reported on herein. A new tenure-track faculty has joined the department starting Fall 2024, and this is expected to provide increased consistency in the content delivered in the course. Also importantly, the department has dedicated significant resources during the 2023-2024 calendar years to formalize and better articulate the lab-related activities, and recognition as well as appreciation for these efforts have been communicated by students.

SLO2: Design for Need, Safety, Global and Social Factors

Define Outcome:
Design for Need, Safety, Global and Social Factors - an ability to apply engineering design to produce solutions that meet specific needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives
    a. (Likert≤3)

2. Course-Level Assessments : (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.
    a. CHE 3550/3551 Trans. Sci. II (≤ 70%)**
    b. CHE 4410 Design I (≤ 70%)
    c. CHE 4420 Design II (≤ 70%)
3. Co-Op Employer Assessments: (Semi or annually). The Department uses a survey report directly completed by the students’ supervisor at the co-op site to learn about important student competences. The questionnaire requires responses related to each of the 1 through 7 student outcomes.
    a. (Likert≤3)

**Note: Effective with the Spring 2022 semester, the CHE 3121 course with lab (4 credits total) was divided into a lecture section (3 credits) and a lab section (1 credit) which are numbered CHE 3550 and CHE 3551, respectively.

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
    a. A population of seniors is surveyed once every third year.
        i. Likert ≥3/5
2. Course-Level Assessments
    a. Course-Level Assessments are completed for select courses every term in which they are offered
        i. >60% (>70%)
3. Co-Op Employer Assessments
    a. Co-Op employer assessment data is gathered for every student participating in co-op at the end of their internship. The collective data is evaluated every third year.
        i. Likert ≥3/5

Link to 'Tech Tomorrow' Strategic Plan:
2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:
SLO2: DESIGN for NEED, SAFETY, GLOBAL & SOCIAL FACTORS – 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

Assessment Process (threshold Student Outcome attainment level)		2021-2022	2022-2023	2023-2024
Senior Survey (Likert≤3)^		**4.2**	**4.1**	**4.4**
Course-Level Assessments	CHE 3550/51 TS II (≤ 70%)	**34%**	**73%**	**97%**
	CHE 4410 Design I (≤ 70%)	**90%**	**85%**	
	CHE 4420 Design II (≤ 70%)	**94%**	**89%**	
Co-Op Employer Assessments (Likert≤3)		**4.2**	**4.3**	**4.4**

Notes: ^There were 31 or 32 responses for this student outcome each year per the Senior Survey, and only one (in 2024) was below rubric. None of the employer scores of student's co-op performance was below 3.

Quantitative results reported here for CHE 3550/51 are based on student performance in the CHE 3551 labs. The attached manuscript details changes in the labs for the Spring 2023 semester that reflect the integration of the "Engineering for One Planet Framework" (EOP Framework[1]) and the use of the Renaissance Foundry Model, requiring student teams "to address societal challenges as learning outcomes." This integration resulted in increases in numerous indicators related to SLO2 and associated with the EOP Framework including design, social responsibility, responsible business and economy, environmental impact assessments, and environmental literacy.

For the current reporting period, the following description (from a CLACIR addendum) describes the activities and outcomes for the fluids lab (Spring 2024): The first of two viscosity-focused labs included a team-based experiment with a Cannon-Fenske Viscometer and completion of an individual assignment exploring fluid fundamentals and hands-on aspects. Building on this knowledge, the second viscosity lab involved the design, building, and testing of a custom viscometer by student teams. These efforts were followed by the completion of experiments involving two types of Desktop Learning Modules (DLM's)[2] (one focused on flow through a venturi and the other on continuity and hydraulic losses in a smooth pipe). While the experiments with these DLM's were conducted in teams, each student was responsible for turning in their own worksheet. Over the remainder of the semester, the emphasis was on heat exchangers. Completion of experiments with a particular emphasis on Reynolds # and Nusselt # calculations and involving four different types of heat exchanger units including a concentric tube unit operated in both parallel and counter flow configurations as well as a shell and tube, plate, and crossflow exchangers were conducted. Subsequently, a team-based report reflecting the analysis of data sets from each of these units was submitted at the end of the semester. As the work regarding viscometry, flow restrictions and pressure losses, and heat exchangers each involved elements of design, communication, and knowledge acquisition/application, overall student performance in the lab was used as the basis for assessment towards SLO2, SLO3, and SLO7. The average lab score from these activities was 97.8% and 96.0%, respectively, for lab sections 101 and 102, and all students scored well above the 70% minimum threshold. Combined, the overall score was 96.9%.

[1]https://engineeringforoneplanet.org/wp-content/uploads/eop_engineering-for-one-planet_framework.pdf

[2]https://wsu.technologypublisher.com/technology/42035

In the lecture-based portion of the fluids course (CHE 3550), for which there have been two instructors during the three-year reporting period, four of the six sections offered during this timeframe have required students to work in teams to complete a project that requires consideration of design and other factors related to fluid-associated systems (e.g., devices used for measuring fluid flow and other properties, mixing tanks, pumps, pipes and pipe fittings, etc). Each team according completed two presentations (the first communicating progress to date and the second a final presentation) and also submitted a project binder and final report used in assessments. In the other two sections, team-based projects were also completed reflecting the development of a prototype. Per feedback in the CLACIR's (and addenda) for the course/lab as well as from instructor notes, performance on these projects has been excellent.

Outcomes from the design courses for the 2021-2022 and 2022-2023 academic years are detailed in the respective CLACIR's.

Red shading represents a need for “action” while green represents that the value meets threshold.

Attached Files: See Appendix 3

Use of Results to Improve Outcomes:
The significant emphasis on design in the fluids courses/labs in the Spring 2023 and Spring 2024 semesters reflects a strong commitment to ensuring that this SLO is more intentionally targeted.

SLO3: Communicate

Define Outcome:
Communicate - an ability to communicate effectively with a range of audiences

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of

questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives

   a. (Likert≤3)

2. External Review of Senior (Capstone) Design Projects (Annually). External evaluators are invited to assess the quality of Senior Design Projects and to provide feedback on the capstone Design course. The evaluators ask questions of the team members and provide feedback on the technical quality of the projects and oral presentations using an established ABET Criteria-based rubric.
   a. (team average ≤ 70%)
3. Course-Level Assessments : (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.
   a. CHE 3550/3551 Trans. Sci. II (≤ 70%)**
   b. CHE 4060/4061 Kinetics (≤ 70%)*
   c. CHE 4240 Capstone Lab (≤ 70%)
   d. CHE 4410 Design I (≤ 70%)
   e. CHE 4420 Design II(≤ 70%)
   f. CHE 4540 Controls (≤ 70%)
4. Co-Op Employer Assessments: (Semi or annually). The Department uses a survey report directly completed by the students’ supervisor at the co-op site to learn about important student competences. The questionnaire requires responses related to each of the 1 through 7 student outcomes.
   a. (Likert≤3)

**Note: Effective with the Spring 2022 semester, the CHE 3121 course with lab (4 credits total) was divided into a lecture section (3 credits) and a lab section (1 credit) which are numbered CHE 3550 and CHE 3551, respectively. *Note: Effective with the Fall 2022 semester, the CHE 4210 course with lab (4 credits total) was divided into a lecture section (3 credits) and a lab section (1 credit) which are numbered CHE 4060 and CHE 4061, respectively.

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
   a. A population of seniors is surveyed once every third year.
      i. Likert ≥3/5
2. External Review of Senior (Capstone) Design Projects
   a. Design II projects are externally assessed in the Spring of each year.
      i. >60% (>70%)
3. Course-Level Assessments

a. Course-Level Assessments are completed for select courses every term in which they are offered
    i. >60% (>70%)

4. Co-Op Employer Assessments
    a. Co-Op employer assessment data is gathered for every student participating in co-op at the end of their internship. The collective data is evaluated every third year.
        i. Likert ≥3/5

Link to 'Tech Tomorrow' Strategic Plan:
1.A Experiential Learning,2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:
SLO3: COMMUNICATE – an ability to communicate effectively with a range of audiences

Assessment Process (threshold Student Outcome attainment level)		**2021-2022**	**2022-2023**	**2023-2024**
Senior Survey (Likert≤3)		**4.2**	**4.3**	**4.5**
External Assessment of Capstone Labs (team average ≤ 70%)		**+**		**+**
Course-Level Assessments	CHE 3550/51 TS II (≤ 70%)	**50%**	**93%**	**97%**
	CHE 4060/61 Kinetics (≤ 70%)	**+**	*	**94%**
	CHE 4240/4250 Capstone Lab (≤ 70%)	**91%**		**+**
	CHE 4410 Design I (≤ 70%)	**94%**	**90%**	
	CHE 4420 Design II (≤ 70%)	**92%**	**89%**	
	CHE 4540 Controls (≤ 70%)	*		
Co-Op Employer Assessments (Likert≤3)		**4.2**	**4.3**	**4.4**

Notes: ^There were 30-32 responses for this student outcome each year per the Senior Survey, and only two (one in 2022 and another in 2024) were below rubric. None of the employer scores of student's co-op performance was below 3.

As described in the previous results section, a change was made in the CHE 3550 fluids labs for the Spring 2023 semester that reflect the integration of the "Engineering for One Planet Framework" (EOP Framework[1]) and the use of the Renaissance Foundry Model, requiring student teams "to address societal challenges as learning outcomes." This integration resulted in increases in communication and teamwork with the percentage of students performing as excellent on these outcomes increasing from 50% to 93%.

+For the capstone lab (CHE 4240/4250, Spring 2022), good results were produced by all 11 teams based on replies from their external sponsors. Though one team argued that their project could not be quantitatively assessed consistently and though the sponsor was happy with the qualitative result from the team, the course objectives (vary one parameter, repeat results, analyze using statistical tools, present in all rubrics) were not met fully in the end by that one team. For CHE 4060/61, the performance was relatively consistent for all three reports with the 1st quartile exceeding the 70% performance goal, with the exception of the batch reactor lab. For the capstone lab (CHE 4250, Spring 2024), students interacted well with each other and performed well on the team project presentations, but only two projects involved an "external sponsor" limiting opportunities to further showcase communication skills. A detailed analysis is available in each of the respective Course Level Assessment and Curriculum Improvement Report (CLACIR) on-file in the department.

*Results are not available.

Red shading indicates "act." Yellow shading represents a “watch, possibly act” situation while green represents that the value meets threshold.

Use of Results to Improve Outcomes:
The department is actively working to identify external sponsors for capstone teams that will be formed for the Spring 2025 course/lab offering of CHE 4250.

SLO4: Ethics

Define Outcome:
Ethics - an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives
    a. (Likert≤3)
2. Course-Level Assessments : (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the

curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.

    a. CHE 4420 Design II (≤ 70%)
    b. CHE 4540 Controls (≤ 70%)

3. Co-Op Employer Assessments: (Semi or annually). The Department uses a survey report directly completed by the students’ supervisor at the co-op site to learn about important student competences. The questionnaire requires responses related to each of the 1 through 7 student outcomes.
    a. (Likert≤3)

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
    a. A population of seniors is surveyed once every third year.
        i. Likert ≥3/5
2. Course-Level Assessments
    a. Course-Level Assessments are completed for select courses every term in which they are offered
        i. >60% (>70%)
3. Co-Op Employer Assessments
    a. Co-Op employer assessment data is gathered for every student participating in co-op at the end of their internship. The collective data is evaluated every third year.
        i. Likert ≥3/5

Link to 'Tech Tomorrow' Strategic Plan:

2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:

SLO4: ETHICS – an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

Assessment Process (threshold Student Outcome attainment level)		2021-2022	2022-2023	2023-2024
Senior Survey (Likert≤3)^		**4.3**	**4.3**	**4.5**
Course-Level Assessments	CHE 4420 Design II (≤ 70%)	**94%**	**92%**	
	CHE 4540 Controls (≤ 70%)	*		
Co-Op Employer Assessments (Likert≤3)		**4.2**	**4.3**	**4.5**

Notes: There were 31 or 32 responses for this student outcome each year per the Senior Survey, and only one (in 2024) was below rubric. None of the employer scores of student's co-op performance was below 3.

*Results are not available.

Yellow shading represents a “watch, possibly act” situation while green represents that the value meets threshold.

Use of Results to Improve Outcomes:

SLO5: Teams

Define Outcome:

TEAMS - 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.

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives
    a. (Likert≤3)
2. External Review of Senior (Capstone) Design Projects (Annually). External evaluators are invited to assess the quality of Senior Design Projects and to provide feedback on the capstone Design course. The evaluators ask questions of the team members and provide feedback on the technical quality of the projects and oral presentations using an established ABET Criteria-based rubric.
    a. (team average ≤ 70%)

3. Course-Level Assessments: (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.
   a. CHE 4240 Capstone Lab (≤ 70%)
   b. CHE 4420 Design II (≤ 70%)
4. Co-Op Employer Assessments: (Semi or annually). The Department uses a survey report directly completed by the students’ supervisor at the co-op site to learn about important student competences. The questionnaire requires responses related to each of the 1 through 7 student outcomes.
   a. (Likert≤3)

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
   a. A population of seniors is surveyed once every third year.
      i. Likert ≥3/5
2. External Review of Senior (Capstone) Design Projects
   a. Design II projects are externally assessed in the Spring of each year.
      i. >60% (>70%)
3. Course-Level Assessments
   a. Course-Level Assessments are completed for select courses every term in which they are offered
      i. >60% (>70%)
4. Co-Op Employer Assessments
   a. Co-Op employer assessment data is gathered for every student participating in co-op at the end of their internship. The collective data is evaluated every third year.
      i. Likert ≥3/5

Link to 'Tech Tomorrow' Strategic Plan:
1.A Experiential Learning,2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:
SLO5: TEAMS – 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

Assessment Process (threshold Student Outcome attainment level)		2021-2022	2022-2023	2023-2024
Senior Survey (Likert≤3)^		**4.4**	**4.3**	**4.6**
External Assessment of Capstone Labs (team average ≤ 70%)		**#**		**+**
Course-Level Assessments	CHE 4240/4250 Capstone Lab (≤ 70%)	**93%**		**+**
	CHE 4420 Design II (≤ 70%)	**95%**	**93%**	
Co-Op Employer Assessments (Likert≤3)		**4.5**	**4.5**	**4.7**

Notes: ^There were 31 responses for this student outcome each year per the Senior Survey, and only two (one in 2022 and another in 2024) was below rubric. None of the employer scores of student's co-op performance was below 3.

#Team work was mandatory to complete the course requirements, and good results were obtained by all 11 teams based on replies provided by each of their external sponsors (Spring 2022).

+For the capstone lab (CHE 4250, Spring 2024), student performance on the team projects was very good with students demonstrating knowledge (based on project focus) related to prior course content including heat exchanger, gas scrubber, and distillation column operation, lab and chemical safety, and the use of software such as Excel, MATLAB, and COMSOL. Two student teams also demonstrated skill in solid objects modeling, and one team developed experience with gas monitoring. Unfortunately, only two of the projects involved external "sponsors."

Yellow shading represents a "watch, possibly act" situation while green represents that the value meets threshold.

Use of Results to Improve Outcomes:

The department is actively working to identify external sponsors for capstone teams that will be formed for the Spring 2025 course/lab offering of CHE 4250.

SLO6: Experiment, Analyze, and Interpret

Define Outcome:

Experiment, Analyze, and Interpret - an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions.

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives
    a. (Likert≤3)
2. External Review of Senior (Capstone) Design Projects (Annually). External evaluators are invited to assess the quality of Senior Design Projects and to provide feedback on the capstone Design course. The evaluators ask questions of the team members and provide feedback on the technical quality of the projects and oral presentations using an established ABET Criteria-based rubric.
    a. (team average ≤ 70%)
3. Course-Level Assessments: (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.
    a. CHE 4060/4061 Kinetics (≤ 70%)*
    b. CHE 4240 Capstone Lab (≤ 70%)

*Note: Effective with the Fall 2022 semester, the CHE 4210 course with lab (4 credits total) was divided into a lecture section (3 credits) and a lab section (1 credit) which are numbered CHE 4060 and CHE 4061, respectively.

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
    a. A population of seniors is surveyed once every third year.
        i. Likert ≥3/5
2. External Review of Senior (Capstone) Design Projects
    a. Design II projects are externally assessed in the Spring of each year.
        i. >60% (>70%)
3. Course-Level Assessments
    a. Course-Level Assessments are completed for select courses every term in which they are offered
        i. >60% (>70%)

Link to 'Tech Tomorrow' Strategic Plan:
1.A Experiential Learning,2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:

SLO6: EXPERIMENT, ANALYZE & INTERPRET – an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions

Assessment Process (threshold Student Outcome attainment level)		**2021-2022**	**2022-2023**	**2023-2024**
Senior Survey (Likert≤3)		**4.1**	**4.1**	**4.6**
External Assessment of Capstone Labs (team average ≤ 70%)		**#**		**+**
Course-Level Assessments	CHE 4210 or CHE 4060/61 Kinetics (≤ 70%)	**+**	*	**92%**
	CHE 4240/4250 Capstone Lab (≤ 70%)	**95%**		**+**

Notes: There were 31 responses for this student outcome each year per the Senior Survey, and only two (one in 2022 and another in 2024) was below rubric. None of the employer scores of student's co-op performance was below 3.

#Good results were obtained by all 11 teams based on replies provided by each of their external sponsors.

+For CHE 4060/61 (Fall 2022), the final team lab report (focused on crystal violet decomposition in a batch reactor) was analyzed to evaluate performance for specific components of experimental work. The median score was at or slightly below the target performance, with the exception of "conduct experiment," suggesting students struggled with performing this lab. Results for CHE 4060/61 (Fall 2023) are based on student performance on six guided activities: three team-based lab experiments, two software-centered efforts (using Matlab, COMSOL, and/or Excel), and a team-based activity focused on process safety. All students performed well-above the minimum threshold. A detailed analysis is available in the Course Level Assessment and Curriculum Improvement Reports (CLACIR's) that are on-file in the department. For CHE 4250 (Spring 2024), the strategy for enabling students to collect and analyze data centered on the use of equipment in the unit ops lab, and two detailed data sets were collected using the heat exchanger units. While the analysis proceeded well, problems with the quality of the water supply to the exchanger units created challenges that limited student access and ultimately collecting the data in teams. Due to this, the instructor operated the units and provided the data sets.

*Results are not available.

Yellow shading represents a “watch, possibly act” situation while green represents that the value meets threshold.

Use of Results to Improve Outcomes:
To increase opportunities for students to work with pilot plant-scale process equipment, SOP's should be developed for the liquid-liquid extraction and batch reactor systems available in the unit ops lab.

SLO7: Knowledge Acquisition and Application

Define Outcome:
Knowledge Acquisition - an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Assessment Methods:

1. Senior Survey (Annually). The senior survey provides the opportunity for student feedback (anonymously) on different aspects of the program student outcomes, the CHE curriculum, and the student's experiences while at TTU. In addition, a number of questions are directly related to specific SLOs. In this way, feedback is gathered from the student sector of our constituency on both student outcomes and program educational objectives.
    a. (Likert≤3)
2. Course-Level Assessments : (Every term a course is taught). The Department uses selected courses to learn about student performance at the different levels of the curriculum, refer to the current “Articulation Matrix” table. Course-level assessment is done every term in which the course is taught and an Overview is assembled every third year. Those overviews are used to continuously improve the course and curriculum as a whole and are discussed with the departmental faculty and appropriate actions taken.
    a. CHE 3550/3551 Trans. Sci. II (≤ 70%)**
    b. CHE 4410 Design I (≤ 70%)
3. Co-Op Employer Assessments: (Semi or annually). The Department uses a survey report directly completed by the students’ supervisor at the co-op site to learn about important student competences. The questionnaire requires responses related to each of the 1 through 7 student outcomes.
    a. (Likert≤3)

**Note: Effective with the Spring 2022 semester, the CHE 3121 course with lab (4 credits total) was divided into a lecture section (3 credits) and a lab section (1 credit) which are numbered CHE 3550 and CHE 3551, respectively.

Criteria for Success (Thresholds for Assessment Methods):

1. Senior Survey
    a. A population of seniors is surveyed once every third year.

            i. Likert ≥3/5
2. Course-Level Assessments
    a. Course-Level Assessments are completed for select courses every term in which they are offered
        i. >60% (>70%)
3. Co-Op Employer Assessments
    a. Co-Op employer assessment data is gathered for every student participating in co-op at the end of their internship. The collective data is evaluated every third year.
        i. Likert ≥3/5

Link to 'Tech Tomorrow' Strategic Plan:
2.A Technology Infused Programs,3.A Efficiency and Effectiveness

Results and Analysis:
SLO7: KNOWLEDGE ACQUISTION & APPLICATION – an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Assessment Process (threshold Student Outcome attainment level)		**2021-2022**	**2022-2023**	**2023-2024**
Senior Survey (Likert≤3)^		**4.3**	**4.2**	**4.5**
Course-Level Assessments	CHE 3550/51 TS II (≤ 70%)	**38%**	**76%**	**97%**
	CHE 4410 Design I (≤ 70%)	**90%**	**78%**	
Co-Op Employer Assessments (Likert≤3)		**4.6**	**4.5**	**4.6**

Notes: ^There were 31 responses for this student outcome each year per the Senior Survey, and three (one each year) was below rubric. None of the employer scores of student's co-op performance was below 3.

The changes that were made in the CHE 3551 fluids labs for the Spring 2023 semester as described earlier were associated with an increase in the percentage (from 38% to 76%) of students performing as excellent on critical thinking, materials selection (choice), and systems thinking. Students seemed to benefit from the carefully-coordinated approach in the Spring 2024 semester to better align the lab activities with the lecture content.

Use of Results to Improve Outcomes:
As indicated prior, the department has dedicated significant resources during the 2023-2024 calendar years to formalize and better articulate the lab-related activities, and recognition as well as appreciation for these efforts have been communicated by students.

Summative Evaluation:
There have been challenges associated with changes in the number of faculty in the department over the last two years. As one example and as indicated elsewhere in this report, the CHE 4060/61 courses/labs have had a different instructor during each of the three academic years reported on herein. Fortunately, a new tenure-track faculty and a new instructor have joined the department starting Fall 2024. Further, a new department chair will be in place in January 2025 and another faculty will join the department in the Fall 2025 semester. These additions are expected to aid significantly in balancing workload and in ensuring consistency in content delivered across the curriculum.

With support from the College of Engineering, the department has dedicated significant effort and time during the 2023-2024 calendar years to formalize and better articulate lab-related activities that have impact in eight courses across the curriculum. Towards this end, lab-specific manuals have been prepared, and these are being continuously updated leveraging what is learned during implementation. Recognition as well as appreciation for these efforts have been communicated by students. Building on this initiative, efforts are likewise underway to develop additional worksheets and SOP's to guide work with some of the larger (pilot plant-scale) pieces of equipment in the unit ops lab including the Edibon Heat Exchanger System, the Hampden Liquid-Liquid Extraction Unit, and the glass distillation column.

The significant emphasis that is now being placed on design in the fluids courses/labs reflects a strong commitment to ensuring that the design-related SLO is more intentionally targeted and that students are able to leverage these concepts in the process design sequence taken the ensuing year. Similarly, in recognition of the important role for chemical reactor design concepts in the process design sequence, efforts were pursued to begin offering the reaction engineering course with lab in the summer and in the Fall semesters. This was the case for the Summer/Fall 2017 through Summer/Fall 2021 semesters which was shown to have a positive impact in facilitating student learning in the process design sequence. While the CHE 4060/61 reaction engineering course/lab has only been offered in the Fall semesters since then, the addition of the new faculty to the department creates the opportunity to reengage on this.

Feedback from students and external sponsors of team-based capstone projects showcases the high impact of engagement of these external sponsors. While such sponsors have only been used sparingly over the last two years, the department is actively working to identify external sponsors for capstone teams that will be formed for the Spring 2025 course/lab offering of CHE 4250.

Assessment Plan Changes:
Rubrics for use in the capstone lab and the process design course will be discussed for consideration as required assessment instruments to use every time that these courses are offered.

List of Appendices:

Appendix 1: Chemical Engineering BSCHE Curriculum Map
Articulation Matrix 2020-2026 (Updated New Course Numbers) (IE)

Articulation Matrix for the period beginning May 2020* for purposes of Course-Level Student Outcomes assessment

Course No.	Description	Required or Elective (R or E)	Mapping to Student Outcomes (SO)						
			1 Formulate & Solve	2 Design for Need, Safety, Global & Societal	3 Communicate	4 Ethics in Global & Societal Context	5 Teams	6 Experiment Analyze & Interpret	7 Knowledge Acquisition
CHE 1010	Intro. to CHE	R			■	■	■		■
CHE 1020	CHE Process., Prod. & Ethics	R			■	■			
CHE 2015	Chem and Biol Eng. Analysis I	R	■		■				■
CHE 2020	Chem and Biol Eng. Analysis II	R	■		■	■			■
CHE 3010	Thermo of Chem. Proc.	R	■	■			■		■
CHE 3050/51	Cond., Rad., Diff. w/Lab	R	■	■				■	
CHE 3735	CHE Operations	R	■						■
CHE 3510/11	CHE Thermodynamics II w/Lab	R	■					■	
CHE 4050/51	Diff. & Mass Transfer w/Lab	R	■		■			■	
CHE 3550/51*	**TS II: Fluid Mechanics w/Lab****	**R**		ABET	ABET				ABET
CHE 4060/61*	**Chemical Reaction Engineering w/Lab****	**R**	ABET		ABET			ABET	
CHE 4250	**ChE Capstone Laboratory**	**R**			ABET		ABET	ABET	
CHE 4410	**Process Design I**	**R**		ABET	ABET				ABET
CHE 4420	**Process Design II**	**R**		ABET	ABET	ABET	ABET		
CHE 4540	**Process Dynamics & Controls**	**R**	ABET		ABET	ABET			

1	Red	(255, 0, 0)
2	Blue	(0, 112, 192)
3	Orange	(255, 192, 0)
4	Purple	(112, 48, 160)
5	Orange, Accent 6	(247, 150, 70)
6	Yellow	(255, 255, 0)
7	Light Green	(146, 208, 80)

ABET – Assessed Student Outcome for ABET continuous improvement purposes, courses shown in **bold**.

*The table has been updated to reflect changes (effective 2022) in course numbers.

**Assessment of lab-related outcomes is documented in the CLACIR.

Appendix 2: PO3 Results
F.E. Exam Results 2020-2024

Professional Exam Results

S2020	# Taken	# Passed	Pass (%)
Enrolled	2	2	100%
ABET Comparator	480	358	75%
Graduated	1	1	100%
ABET Comparator	170	133	78%

F2020	# Taken	# Passed	Pass (%)
Enrolled	1	0	0%
ABET Comparator	452	337	75%
Graduated			
ABET Comparator			

S2021	# Taken	# Passed	Pass (%)
Enrolled	1	1	100%
ABET Comparator	668	494	74%
Graduated	2	2	100%
ABET Comparator	240	161	67%

F2021	# Taken	# Passed	Pass (%)
Enrolled			
ABET Comparator			
Graduated*	1	1	100%
ABET Comparator	1	1	100%
* FS Exam Taken			

S2022	# Taken	# Passed	Pass (%)
Enrolled	1	0	0%
ABET Comparator	600	424	71%
Graduated	2	2	100%
ABET Comparator	269	200	74%

F2022	# Taken	# Passed	Pass (%)
Enrolled			
ABET Comparator			
Graduated	1	1	100%
ABET Comparator	202	133	66%

S2023	# Taken	# Passed	Pass (%)
Enrolled	1	1	100%
ABET Comparator	521	366	70%
Graduated	1	1	100%
ABET Comparator	215	148	69%

F2023	# Taken	# Passed	Pass (%)
Enrolled	1	1	100%
ABET Comparator	321	239	74%
Graduated	5	4	80%
ABET Comparator	278	196	71%
Graduated**	2	0	0
ABET Comparator	174	111	64%
** PE Exam Taken			

S2024	# Taken	# Passed	Pass (%)
Enrolled	3	1	33%
ABET Comparator	654	479	73%
Graduated	3	3	100%
ABET Comparator	273	195	71%
Graduated***	1	1	100%
ABET Comparator	2	2	100%
***PS Exam Taken			

Appendix 3: SLO2 Results
Sustainability Design and Fluids

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Paper ID #40952

The Role of Pairing Sustainability with Innovation Driven Learning: Observation on the Application of the Engineering-for-One-Planet Framework Guided by the Renaissance Foundry Model

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The Role of Pairing Sustainability with Innovation Driven Learning: Observation on the Application of the Engineering-for-One-Planet Framework Guided by the Renaissance Foundry Model

Abstract

This work in progress investigates how the role of an educational intervention that coupled sustainability principles with an innovation-driven learning platform guides students through the development of a protype of innovative technology. Specifically, the intervention includes the purposeful pairing of the Engineering for One Planet (EOP) framework[1] with the Renaissance Foundry model (i.e., the Foundry)[2] in an undergraduate chemical engineering course that requires student teams to address societal challenges as learning outcomes. We argue that pairing the EOP framework with the Foundry results in an increase in students' sustainability efforts in the design of their prototype of innovative technology that addresses identified societal challenges. A preliminary analysis is presented comparing outcomes from two semesters of the CHE 3550, Transfer Science II (Fluids), course, which is a three-credit hour course with an additional one credit of laboratory work (CHE 3551). Preliminary implications related to holistic engineering education efforts and socially relevant learning will be presented and discussed.

Keywords

Sustainability, Engineering for One Planet, Renaissance Foundry Model, Holistic Professional, Foundry-guided learning

Introduction

Recent efforts at the turn of the century have focused on transforming engineering educational programs and foundations (e.g., VentureWell, The Lemelson Foundation, *inter alia*) to incorporate principles of sustainability into the design thinking process of engineering systems, products, and processes.[1, 3, 4] This type of training intentionally integrates sustainability principles that focus on key aspects of environmentally responsible models that efficiently address complex social challenges.[4, 5] In this respect, sustainability efforts focus on maintaining the balance of a particular system, process, or function that does not negatively interrupt natural resources or processes inherent to the environment.[1, 3, 5] Thus, current efforts within our department that are related to sustainability center on enhancing students' understanding of the principles related to these efforts and how they influence innovative design solutions that are both socially and environmentally sustainable.

The work-in-progress presented in this contribution explores the mechanics between incorporating the Engineering for One Planet (EOP) framework and a Foundry-guided course design.[6, 7] Specifically, we look at efforts undertaken in previous iterations of CHE 3551, Transfer Science II (Fluids), a three-credit hour course with one credit of lab work offered at a medium-sized, rural, public, four-year university, that inspired the redesign of the course with respect to sustainability. In each of these iterations, prototypes of innovative technology developed by student teams that address societal challenges are a required outcome.[6,7] Preliminary findings from our previous work identified how students that were exposed to this integrated pedagogical strategy advanced their incorporation of key sustainability principles within the design process of their final prototype of innovative technology.[6,7,8] This study provides a statistical distribution comparison of data collected in efforts to magnify the focus on sustainability in this undergraduate chemical engineering course.

Brief Overview of Integrated Pedagogical Strategies

The Renaissance Foundry Model

Engineering education has been moving towards the integration of fundamentals of sustainability within the curricula; however, despite these efforts, scholarship still indicates that systematic models offering a comprehensive integration of sustainability efforts that result in the development of holistic engineering professionals is still needed.[1,3,6,9] In response to this need, the efforts at our institution have focused on developing a pedagogical framework that effectively integrates the use of teamwork, innovation, prototype development and challenge identification known as the Renaissance Foundry Model (i.e., the Foundry).[2] The theory and pedagogical foundations of the Foundry are beyond the scope of this work and have been described in detail within extant literature.[2,6,7] A brief description of the model is provided here to better understand how it was paired with the EOP as an integrated approach.

The Foundry is an innovative-driven platform that is centered on students collaborating in teams to achieve a learning and design process from identifying a challenge and moving this towards the development of a Prototype of Innovative Technology. This process is based on six key elements that are organized in two main paradigms, i.e., the Knowledge Acquisition Paradigm and the Knowledge Transfer Paradigm.[2] The central pivotal element of the Foundry is the "Resources" that are common to both paradigms. In addition, the Knowledge Acquisition Paradigm features the Learning Cycles, and the Organizational Tools which are both preceded by the Challenge identification. The Knowledge Transfer Paradigm is chiefly built on the Linear Engineering Sequence that is followed by the Prototype of Innovative Technology as the outcome of the platform.[2] One key feature of the Foundry is that it is centered on student teams.

The contextual element of this study, featuring the CHE 3551 course, was designed using the Foundry which provided the guidance necessary for the development of a prototype of innovative technology, centered on the sustainability principles featured in the EOP framework.

EOP Framework

The EOP framework is a comprehensive taxonomy of a systems thinking approach that outlines nine key principles of sustainability and their respective learning outcomes to better enhance students' understanding of sustainability concepts.[1,10] The nine principles of sustainability presented by the EOP include: Systems Thinking, Communication and Teamwork, Environmental Literacy, Responsible Business and Economy, Social Responsibility, Environmental Impact Assessment, Materials Selection, Design, Critical Thinking.[1] Further, we found that these key principles align with key elements of the Foundry (e.g., Critical thinking, Communication, Teamwork, Design, Social Responsibility, Systems thinking) that can be leveraged as part of the integration of both frameworks into the development of an educational environment that assists in the formation of holistic professionals. For example, we noted that the outer sphere of the framework which encompassed the development of skills related to critical thinking, social responsibility, materials choices, design, and communication/teamwork, *inter alia*, were closely aligned to the skills being developed as part of the iterative phases of the Knowledge Acquisition and Knowledge Transfer Paradigms in the Foundry.[2, 6, 7] The central sphere, designated to systems thinking, however provides a focus wherein students' efforts to develop a prototype of innovative technology in these courses can be centralized and enhance their efforts to include sustainability in design.[6, 7]

Integration and Preliminary Analysis

Supported by a mini grant from the American Society for Engineering Education in partnership with the Lemelson Foundation, efforts concerning the integration of the EOP in the redesign of the CHE 3551 course were implemented during the Spring 2023 semester. Specifically, the intervention featured a paired pedagogical approach that combined the EOP Framework and Foundry-guided course design and required student teams to address societal challenges as learning outcomes. In particular, intentional activities that asked student-teams to leverage the EOP framework as a way of integrating approaches to systems thinking, knowledge and understanding, skills, experiences, and behavior as part of the design processes within Foundry-guided learning experiences were pivotal to enhance this learning environment.

This study's research design adopts a primarily quantitative approach that leverages descriptive data collected from an EOP designed rubric from two semesters: one prior to, and one during, the EOP framework integration into a Foundry-guided course. Table 1 illustrates the number of students and total projects represented in this analysis from both semesters in the analysis.

Table 1: Overview of Data from Semester 1 and Semester 2

	Semester 1 (pre-EOP)	Semester 2 (post-EOP)
Total Projects	20	11
Students	60	33

This comparison focuses on general distribution data from this rubric to understand differences in the way students incorporated the EOP principles as part of their prototype of innovative technology. The rubric that was utilized reflected students' performance at five levels representative of Poor to Excellent, with each integrating more elements of the Learning Outcomes associated with the EOP Principles as they reach the highest level (i.e., Excellent). Figure 1 illustrates the differences in student scores for Semester 1 and Semester 2 for the nine EOP sustainability topics as based on a performance of Excellent on the rubric. Overwhelmingly, students in Semester 2 (Post-EOP) integrated the EOP Principles in their prototypes of innovative technology at higher rates at the level of Excellent in comparison to students in Semester 1 (Pre-EOP). Based on the preliminary general distribution analysis, there is evidence that the integration of the EOP framework as a structured approach to sustainable design generally helped student-teams develop prototypes that addressed societal challenges as part of their formation as holistically trained professionals.

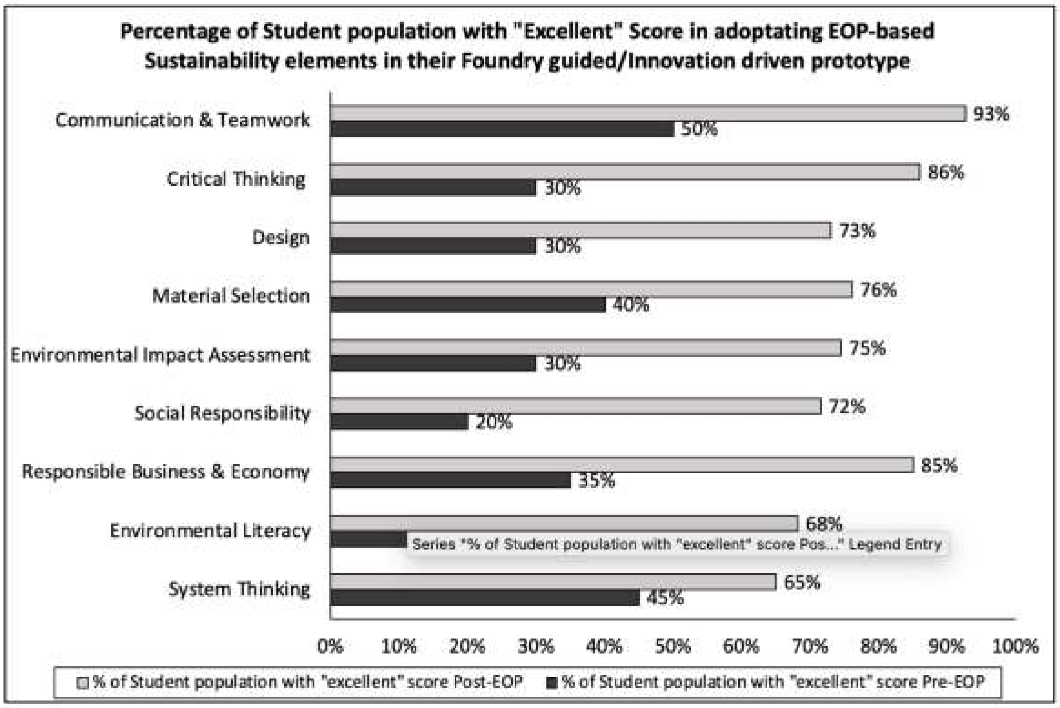

Figure 1: Pre and Post Comparison of Percentage of Students with "Excellent" Score on EOP Principles.[10]

Current Work and Next Steps

As this is a work-in-progress, there are several takeaways that can be investigated further. Concerning research, inferential analysis is needed to ascertain if the differences in performance are statistically significant. Further, after appropriate ethical considerations are obtained, we intend to investigate student perceptions of the role of the EOP framework on sustainability and biomimicry design as part of the implementation efforts. This research will also be integral to the work of current doctoral students interested in engineering education and will expand upon student learning efforts pertaining to the Foundry.

References

1. The Lemelson Foundation. The Engineering for One Planet Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022). *National Science Foundation*. Retrieved from https://engineeringforoneplanet.org/wp-content/uploads/2022_EOP_Framework_110922.pdf
2. Arce, P. E., Sanders, J. R., Arce-Trigatti, A., Loggins, L., Biernacki, J., Geist, M., Pascal, J., & Wiant, K. The renaissance foundry: A powerful learning and thinking system to develop the 21st century engineer. *Critical Conversations in Higher Education,* 1(2), 2015, 176-202.

3. Murphy, R. Introduction to the Chemical Processes: Principles, Analysis, Synthesis. New York, NY: McGraw Hill. (2007).
4. Cleveland, D., & Ireland, L. R. Project Management: Strategic Design and Implementation. New York, NY: McGraw Hill. (2009).
5. Murphy, C., Allen, D., Allenby, B., Crittenden, J., Davisosn, C., Hendrickson, C., & Mtheus, H. Sustainability in Engineering Education and Research at U.S Universities. Environmental Science & Technology, 5558-5564, 2009, 43(15).
6. Matthew, V., Lipkin-Moore, S., Arce, P. E., Arce-Trigatti, A., Lavoine, N., Lucia, L., Selvi, E., Eggermont, M., Tiryakioglu, M., Hall, J., Edelen, R., & Plumblee, J. *A Roadmap for the Design and Implementation of Communities of Practice for Faculty Development*. Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. 2022, https://peer.asee.org/40564
7. Wagle, D., Arce-Trigatti, A., Arce, P. E., and Sanders, J. R. "Engineering for One Planet (EOP) Centered Courses Guided by the Renaissance Foundry Model of Learning". Paper presented at ASEE-SE Annual Meeting, George Mason University, Fairfax, VA, March 12–14, 2023.
8. Wagle, D., Arce-Trigatti, A., Arce, P. E., and Sanders, J. R. "Implementation of the EOP model guided by the Renaissance Foundry Model" 17th Annual Southeastern STEM Education Research Conference, Tennessee Technological University, Cookeville, TN, January 13–14, 2023: Oral Presentation
9. Landis, A. E., Dancz, C. L. A., Parrish, K., & Bilec, M. M. (2021) 'What works? Sustainability grand challenges in engineering curricula via experiential learning', EESD2021: Proceedings of the 10th Engineering Education for Sustainable Development Conference, 'Building Flourishing Communities', University College Cork, Ireland, 2021, 14-16 June.
10. Wagle, D., Arce, P., Arce-Trigatti, A., & Sanders, J. R. (2024). Pairing Sustainability with Innovation: Measuring Student Performance in a Foundry-Guided Intervention. Oral Presentation at the 18th Annual Southeastern STEM Education Research Conference, Middle Tennessee State University, January 12-13, 2024.

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