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Exploring Student and Program Related Outcomes of the BioFoundry Initiative at Tennessee Tech

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Abstract

Scholarship has highlighted that sustainability principles can often be more emphasized in engineering curriculum to make a larger impression on student learning and have long-term effects with respect to how it is used in industry and design thinking. As part of this work-in-progress, pedagogical efforts related to the Bio-Foundry Initiative are communicated which feature a paired integration of the Engineering for One Planet (EOP) framework with the Renaissance Foundry model (i.e., the Foundry) in an undergraduate chemical engineering course that requires student teams to address societal challenges as learning outcomes. Supported by a VentureWell Faculty grant and an American Society for Engineering Education (ASEE) EOP Mini-Grant, this particular intervention couples sustainability principles from the EOP with the Foundry's innovation-driven learning platform to guide students through the development of a protype of innovative technology. This contribution presents the major pedagogical foundations related to the design and implementation of this work, as well as progress made on three major outcomes of this project including the successful implementation of this work, the development of prototypes of innovative technology, and dissemination of scholarly work.

Keywords

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

Introduction

An interdisciplinary team comprised of chemical engineering (CHE) and education faculty at Tennessee Technological University (TN Tech) proposed the *Bio-Foundry Initiative* that integrates sustainability-focused training with an intentional adoption of natural phenomena, such as biomimicry, into engineering design concepts within the Foundry-guided courses. 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. The Bio-Foundry Initiative was initially funded by a VentureWell Faculty grant that provided support for the first iteration of the initiative that focused on biomimicry elements. This was expanded upon by an American Society for Engineering Education (ASEE) EOP Mini-Grant Program wherein the biomimicry elements were integrated into the nine principles reflected in the EOP framework. Both represent an expansion of the normal course-related efforts that for the last several years have leveraged the successful implementation of the Foundry to guide innovative and interdisciplinary learning environments in chemical engineering [3], [4].

In this contribution, we offer an overview of the pedagogical elements of the Bio-Foundry

Initiative as well as efforts to evaluate the initial outcomes related to the ASEE EOP Mini-Grant Program. Originally, three major outcomes were associated with the ASEE EOP Mini-Grant Program: 1) instruction would be provided in a foundational core course that would resonate throughout students' program of study in chemical engineering; 2) students would produce prototypes of innovative technology that address real-world societal challenges that are environmentally and socially sustainable; and 3) efforts in this course would be shared for the benefit of other educators to integrate the paired EOP and Foundry-guided strategy into engineering education courses. As part of this contribution, we offer preliminary evidence that speaks to all three of these outcomes as well as lessons learned from the implementation of this work. We also provide implications for integrating the EOP framework into engineering education and offer next steps related to the development of the Bio-Foundry Initiative in TN Tech's chemical engineering curriculum.

Background

1) BioFoundry Initiative

When looking at implementing sustainable approaches to engineering applications, one of the most reliable approaches one can select is the imitation of processes found in Nature. Within centuries of evolutionary work, Nature implements friendly and healing processes for the environment in order to minimize negative impacts and conserve energy. The "imitation" of these types of processes has been termed biomimicry and, excitedly the learning and applications of this approach in engineering curricula is ongoing (e.g., [5]). Through additional efforts to advance this area of inquiry, a team of faculty at Tennessee Tech University has proposed using the integration of the EOP framework [1] with the Foundry model [2] to guide students in the learning and implementation of the sustainability principles suggested by the EOP. We have called this effort the Bio-Foundry Initiative.

2) Connections with the EOP Framework

The EOP framework is a very useful taxonomy of nine principles associated with best practices in sustainability [1]. However, the ability to apply such principles might be enhanced through a systematic selection of challenges found within engineering applications that, afterwards, need to be addressed by development of a Prototype of Innovative Technology (PIT). The integration of the EOP framework with the Foundry [2] is a key aspect we are interested in implementing in courses and then assessing the impact on the students. The Foundry provides a systematization based on six elements that are organized in two paradigms, i.e. the Knowledge Acquisition Paradigm and the Knowledge Transfer Paradigm. Within the first paradigm, the Foundry element referred to as "organizational tools" offers an opportunity to add guidance to students in resolving their challenges towards the development of their proposed PITs. The EOP has been selected as part of this organizational tools element so that students can effectively use it to guide the implementation of the nine sustainability principles in a systematic fashion. We describe the work done by students and present a preliminary assessment of the integration in typical courses within the chemical engineering curriculum.

Evaluation of Initial Outcomes Related to the ASEE EOP Mini-Grant Program

Originally, three major outcomes were associated with the ASEE EOP Mini-Grant Program: 1) instruction would be provided in a foundational core course that would resonate throughout students' program of study in chemical engineering; 2) students would produce prototypes of innovative technology that address real-world societal challenges that are environmentally and socially sustainable; and 3) efforts in this course would be shared for the benefit of other educators to integrate the EOP and Foundry-guided paired strategy into engineering education courses.

1) Foundational Core Course Integration

As per the ASEE EOP Mini-grant proposal, the paired EOP-Foundry guided approach was integrated as part of the redesign of the CHE 3551 – Transfer Science II (Fluids) lab course. This is built on previous iterations of the Bio-Foundry initiative applied to the same lab course. CHE 3551 is considered a foundational core course in chemical engineering because it provides laboratory skills that are critically important for the practice of a chemical engineering professional. In addition, it is part of the transport phenomena sequence that includes Transfer Science I (Heat Transfer) and Transfer Science III (Mass Transfer) which provides an opportunity for the learning of transport processes at the microscopic-scale level.

Regarding the technical portion of the course, the following core concepts were covered: kinematics of fluid flow, the hydrostatic equation for fluids, the Bernoulli equation for ideal fluids, and the velocity profile for Newtonian fluids as well as piping systems, pumps, and valves. Furthermore, the friction losses associated with fluid flow (i.e., piping, pumps, valves) were taught through real-world problem-solving applications. Students were also trained in the application of the Systematic and Integrated Sequence Approach (SISA) [6] to obtain the velocity profile of a Newtonian fluid. As a Foundry-guided course, students also engage in a systematic introduction to teamwork and team management [2].

As part of the mini-grant implementation, the paired pedagogical approach that combined the EOP Framework and Foundry-guided course design was intended to help students better engage with the specific content related elements of CHE 3551 by engaging in knowledge acquisition and knowledge transfer processes as determined by the Foundry [3], [4]. While other methodologies that use active learning with sustainability principles may only focus on one principle at a time, this new paired approach features a more holistic vision of design thinking that leverages the Foundry as a platform to engage students in all the principles of the EOP [3], [4]. In this regard, the pairing of the Foundry with the EOP framework was intended to help students better understand how sustainability principles can be incorporated into design thinking processes to enhance innovation in prototype development.

2) Student Prototypes of Innovative Technology

The aforementioned pedagogical environment in Transfer Science II – Fluid Mechanics (Fluids) in chemical engineering not only integrated the EOP Framework into the Bio-Foundry Initiative, but it also tasked students with the development of PITs in accordance with the Foundry Model.

As part of this project, student teams were tasked with identifying a challenge related to the central topic of the course that is related to fluid mechanics and work in teams to then apply the different elements of the Foundry with the purpose of developing a PIT. The integration of the Foundry as part of this course is utilized as a bridge between the technical components presented and the practical applications introduced to get students to discover innovative opportunities in areas with social needs or challenges [7].

As part of these efforts, students were purposefully introduced to the EOP core principles and trained to integrate these principles as part of the design thinking process associated with the Foundry model throughout the course. In this way, student teams were tasked with developing a prototype of innovative technology that addressed societal challenges as learning outcomes which integrated CHE 3551 core concepts. Further, intentional activities that asked student-teams to leverage the EOP framework as part of the design processes within Foundry-guided learning experiences were pivotal to enhance this learning environment, and these are being integrated in future iterations of this course as part of this redesign. As part of this pedagogical intervention, students were encouraged to use EOP based sustainability elements as a lens to guide their collaborative efforts.

Over the course of two semesters of implementation, a total of 31 PITs were produced in the CHE 3551 course under this Bio-Foundry EOP redesign. The topics covered in these prototypes included wastewater, drinking water, and water purification, *inter alia.* Table 1 illustrates the major categories of these PITs and examples of these student-team work products.

Table 1. Major Categories and Examples of Prototypes of Innovative Technology in the fluid mechanics course in a Foundry-guided class in two semesters.

Category	**Example**
Bernoulli's equation with frictional loss; pressure & velocity calculation at different pipe widths.	Flow of water through a horizontal pipe: 1. Pressure at the wider section is higher than that at the narrower section. 2. Velocity at the wider section is lower than that at the narrower section.
Bernoulli's equation for storage and flow of a Newtonian fluid in a cylindrical and rectangular device.	Water storage in the tank of different geometries and its flow through different pipes/channels/orifices.
Conveyance of non-Newtonian fluids through pipes & channels.	1. Hydraulic Shock absorber 2. HVAC Refrigerant analysis
Non-Newtonian fluid flow in complex channels.	Blood flow in human artery
Reynolds' Number and Positive & Negative Displacement Pumps.	Flow of different types of engine oils in different vehicles.
Bernoulli's equation and Fluid Flow through porous media.	Storing rainwater and low-cost filtration.
Application of Navier-Stoke equation for determining velocity profile using SISA method.	Velocity profile in Poiseuille's flow in cylindrical & rectangular pipes.

Category	**Example**	**Remarks**
Bernoulli's equation with frictional loss; pressure & velocity calculation at different width of the pipe.	Flow of water through a horizontal pipe: 1. Pressure at the wider section is higher than that at the narrower section. 2. Velocity at the wider section is lower than that at the narrower section	7 PITs (5 Pre EOP semester, 2 post EOP semester)
Bernoulli's equation for storage and flow of Newtonian fluid in a cylindrical and rectangular devices	Water storage in the tank of different geometries and its flow through different pipes/channels/orifices.	6 PITs (4 Pre EOP semester, 2 post EOP semester)
Conveyance of non-Newtonian fluids through pipes & channels	1. Hydraulic Shock absorber, 2. HVAC Refrigerant analysis	3 PITs (2 Pre EOP semester, 1 post EOP semester)
Non-Newtonian fluid flow in complex channel.	Blood flow in human artery	2 PITs (1 Pre EOP semester, 1 post EOP semester)
Reynold's Number and Positive & Negative Displacement Pumps	Flow of different types of engine oils in different vehicles.	4 PITs (2 Pre EOP semester, 2 post EOP semester)
Bernoulli's equation and Fluid Flow through porous media	Storing rainwater and low-cost filtration.	5 PITs (3 Pre EOP semester, 2 post EOP semester)
Application of Navier-Stoke equation for determining velocity profile using SISA method	Velocity profile in Poiseuille's flow in cylindrical & rectangular pipes	4 PITs (3 Pre EOP semester, 1 post EOP semester)

3) Contributions that Integrate the Paired EOP-Foundry Model into other Courses

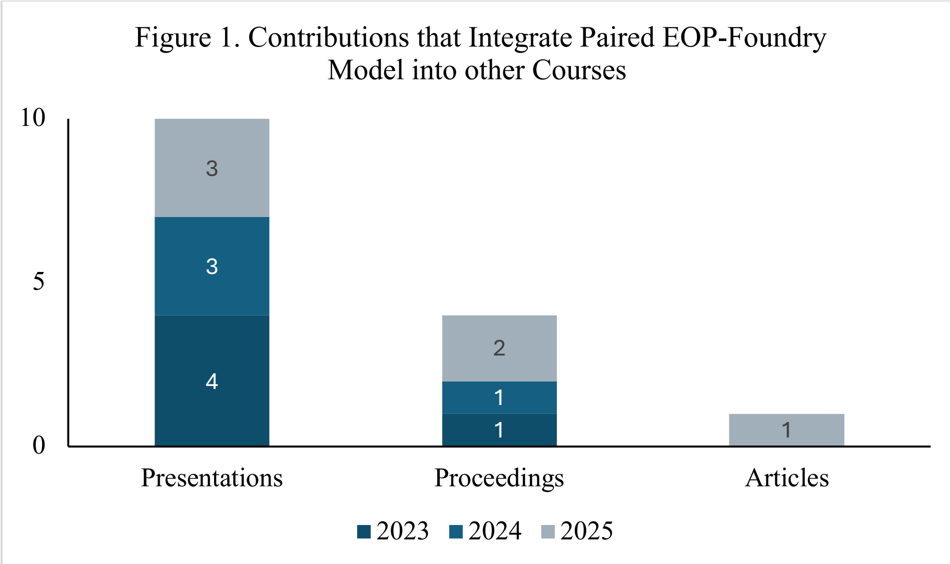

Figure 1 illustrates the types of contributions that have been produced as part of the Bio-Foundry Initiative over the course of three years (2023-2025). The first column indicates that 10 presentations have been shared on the technical and pedagogical aspects of this topic, including at regional and national conferences like the American Society for Engineering Education Southeast Section conferences and the Southeastern STEM Education Research Conference. The second column illustrates that four proceedings have been published that represent efforts related to this work, including in ASEE proceedings and other national and international venues. Finally, through efforts related to the ASEE writing mentorship program, one article featuring the empirical analysis of student learning within these learning environments is currently being produced. Further, the Bio-Foundry Initiative has offered a foundation by which to incorporate the EOP-Foundry paired approach into other courses. For example, within a National Research Traineeship – National Science Foundation (NSF-NRT) program at our university, this paired approach has been integrated into a Food-Energy-Water course that helps students to develop skills related to sustainability and entrepreneurship as they work together to develop relevant prototypes of innovative technology in these areas for local communities [9].

Current Work and Next Steps

In this work-in-progress, we featured the pedagogical elements of the Bio-Foundry Initiative as well as efforts to evaluate the initial outcomes related to the ASEE EOP Mini-Grant Program implementation. We also offered updates on three of the major outcomes from these projects, including the integration of the pedagogical intervention in a foundational chemical engineering course, the results of student-team work in the form of prototypes of innovative technology, and the results of the dissemination of this work over the past few years. With respect to implications, there are always lessons learned from implementing new pedagogical work, including understanding best practices in the ways to integrate the EOP into Foundry-led courses. From our current work, we can see how leveraging the EOP as an organizational tool has helped students to anchor their work in larger scholarship related to sustainability and design within the initial Bio-Foundry Initiative [3], [4]. In future work, we aim to continue to conduct more qualitative and quantitative analysis on student learning and performance outcomes to gauge understanding of sustainability and perceptions about their learning in this type of environment.

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Note: The term "BioFoundry" is proposed by the interdisciplinary team of professionals at Tennessee Technological University by combining two concepts **Bio**mimicry (nature inspired sustainable innovation and learning) and Renaissance **Foundry** Model (an innovation driven pedagogical framework for problem solving). Therefore, the BioFoundry is an initiative that strives to put intentional efforts to integrate sustainability principle into engineering design that is pedagogically guided by the Foundry model. The term "BioFoundry" is not to be confused with "Biofoundry" that is commonly used to describe biosynthetic operations in biochemical or bioprocessing engineering.

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Author Bios

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Dr. Andrea Arce-Trigatti holds a PhD in Education with a Learning Environments and Educational Studies concentration from the University of Tennessee, Knoxville. Her research centers on program evaluation, education policy, and critical thinking and collaborative learning strategies. As a founding member of the award-winning Renaissance Foundry Research Group, she has helped to develop and investigate the pedagogical techniques utilized to enhance critical and creative thinking at interdisciplinary interfaces.

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Dr. Sanders is an Associate Professor at Tennessee Technological University in the Department of Chemical Engineering. He obtained his Bachelor of Science degree in Mechanical Engineering from TTU in 1995, and he obtained his Master of Science and PhD degrees in Biomedical Engineering from Vanderbilt University in 1998 and 2001, respectively. His research interests include innovation-driven learning at the interface of disciplines and biomedical research focused on diseases of the lungs, soft gel materials (e.g., related to wound healing and separations), and bioprocess engineering. He is a founding member of the Renaissance Foundry Research Group.