Promoting Innovative Learning Strategies: A Collaborative Curricular Re-Design at the Undergraduate Level

Stephanie Jorgensen[1], Andrea Arce-Trigatti[2], J. Robby Sanders[1] and Pedro E. Arce[1]
[1]Department of Chemical Engineering/ [2]Department of Curriculum and Instruction
Tennessee Technological University

Abstract

The theoretical and motivational impetus for a curricular redesign is herein described that incorporates immersion experiences within three core chemical engineering undergraduate courses taken sequentially in the junior and senior years at Tennessee Technological University. The efforts are aligned with the Quality Enhancement Plan (QEP) at this same university which is aimed at improving undergraduate curricula via the promotion of inquiry learning strategies.[1,2] The redesign incorporates a range of immersion experiences envisioned as activities that enhance student learning through the Renaissance Foundry Model (herein, the Foundry)[3] which promotes an iterative learning process that culminates in the construction of a prototype of innovative technology.[3] A scaffolded strategy of implementation is expected to provide insights to the ways in which students engage with innovation-driven learning goals and make connections between past experiences, content knowledge, and their own perspectives to sculpt a challenge statement that will provide the basis for a prototypic-centered solution.

Keywords

Innovative curricula, learning technologies, industry partnerships, professional development

Introduction

This work offers an overview of the theoretical framework and motivation for a curricular redesign within three undergraduate Chemical Engineering (ChE) courses (ChE 3111: Heat Transfer; ChE 3121: Fluid Mechanics; ChE 4661: Biotransport Phenomena) at Tennessee Technological University (TTU). The redesign of these courses utilizes immersion experiences to enhance the innovation-driven learning processes that are central to the curriculum's pedagogical platform – the Renaissance Foundry.[3] The impetus for this redesign is founded on leveraging the incorporation of experiential learning experiences (*i.e.*, immersions) as part of students' active and inquiry-based learning spaces within their core course content to subsequently increase their engagement with the innovation-based processes outlined in the Foundry.[1-4] These immersion elements are being implemented through a variety of enhancement activities in each course and are envisioned to provide an immersive experience to students within the classroom. The efforts are supported via a curriculum grant that was awarded to the authors from the university's Quality Enhancement Plan (QEP) that is focused on creative inquiry, *i.e.*, Enhanced Discovery through Guided Exploration (EDGE). Our purpose in this work is to outline the efforts associated with this curricular redesign and to connect with the theory and literature that provided its foundation. We also provide preliminary observations from the first course of this sequence (ChE 3111: Heat

Transfer) as a primary illustration of the pedagogical implications of this redesign with regards to critical and creative thinking, problem identification, and the connection of complex ideas.

Theoretical Framework

Inquiry-Guided and Active Learning Strategies

This curricular redesign draws heavily from the literature on inquiry-guided and active-based learning strategies. Interest in inquiry-guided learning strategies can be linked to a larger, national call towards problem- and project-based learning approaches at the postsecondary level.[2,4,5] Specifically, within the past two decades there has been a shift from problem-based learning within traditional, lecture, classroom structures to the integration of project- and inquiry-based learning methods within dynamic, flexible spaces in an effort to increase student engagement.[2,6,7] These student-centered learning methods foster a more engaging classroom environment that encourages students to become active contributors to their own learning.[2] Further, scholars posit that the learning that results from such methods better prepares students upon entering the workforce as such environments effectively expose students to the intricacies often present in evermore complex and dynamic professions.[8]

The origins of inquiry-guided learning are traditionally affiliated with scientific inquiry.[9] Specifically, this approach to learning has been linked to the scientific research processes wherein students are exposed to the scientific method and encouraged to make evidence-based explanations derived from a process of posing questions, gathering and analyzing data, and constructing arguments based on these connections.[9-11] Inquiry-guided learning (IGL) models are also based on the premises promoted by student-centered approaches that capitalize on teachers as facilitators of learning - rather than solely transmitters of knowledge - and students as active proponents of their learning processes.[1,12,13]

Associated with epistemological foundations central to constructivism, inquiry-guided based approaches challenge students to engage in learning processes that are dictated by discovery, investigation, and the formation of connections between ideas.[1,2,11] Within the literature, there exist various inquiry learning strategies that can be implemented and adjusted to fit the context of learning and the content of focus; however, the pith of this strategy lies with various characteristics that describe the approach: innovative driven, activity centered, process focused, and discovery driven.[10] In the sphere of postsecondary education, the notion of inquiry-guided learning practices has been understood as a catalyst to promote various 21st Century Skills[4,14] including critical thinking, problem-solving, lifelong learning, and student self-regulation practices.[2]

Immersion, Pedagogy, and the Foundry

Immersion within pedagogy is conceptualized as an experiential learning process that is aligned with the theoretical basis on which constructive thinking is founded.[1,12] As students experience real-world processes, they are exposed to complex and ill-structured problems that are inherent with their social, historical, and economic context.[11,12] When combined with inquiry-guided approaches to learning, students are charged with navigating such complexity by formulating rational and innovative connections based on their previous experiences and new knowledge of the situation.[1,13] Thus, the argument for immersions combined with inquiry-guided learning is the potential to expose students to various contexts and perspectives while expanding on the knowledge base from which experiential connections can be made.

The enhancement activities highlighted in this redesign therefore leverage the key theoretical elements that propel active- and inquiry-based learning strategies as effective techniques to promote student engagement and learning. Specifically, these enhancement activities require students to engage in inquiry-guided approaches that develop problem identification, problem exploration, and problem solving from a practical and responsive approach while exposing them to the problems they might routinely encounter upon graduation and employment.[3] By interacting with experts in both the classroom and in the field, while engaging in the innovation-driven strategies proposed through the Foundry, students are provided a broader perspective on how the course fundamentals apply in the real-world.[1,2]

Redesigning the ChE Curriculum

Motivation

The rationale of the enhancement activities with the redesign of the ChE curriculum was to expand on the critical and creative thinking foundation provided by the Foundry model already being implemented in the courses selected.[3] Preliminary observations of students enrolled in the ChE curriculum at TTU have revealed that students who return to the classroom after being immersed in industry experiences (i.e., external immersions) through co-op, internship, and other immersion opportunities[15-17] provide leadership in identifying challenges for team projects as part of the Foundry-centered curriculum. [3] In addition to refined problem identification skills, student teams that include at least one member that has returned from a co-op or internship experience are preliminarily observed to also have a more refined solution method to the identified challenge than student teams that lack a member returned from co-op or internship experiences.

Based on these observations, a range of enhancement activities were envisioned to provide immersion-like experiences in the classroom setting to promote innovation via exposure to aspects of industry integrated into the Foundry platform.[15-17] Introduction to real-world application of technical chemical engineering knowledge via the enhancement activities was intended to expose students gradually to different levels of guided inquiry and help them to develop skills necessary to become masters not only at providing a prototypic-centered solution to a given challenge but also to illustrate mastery of problem identification.[3] Meant to utilize immersion as a way to enhance the iterative processes that student teams experience as part of the Foundry for these courses, the authors of this redesign presented a comprehensive, guided, pedagogical scaffolding approach to be executed across the three courses to help students improve the skills developed as a result of the implementation of the Foundry.[3] This scaffolding is reflective of inquiry-guided learning and aligned with the aforementioned TTU QEP and with the student learning objectives in the courses.[1,3,18]

Logistics of the Overall Redesign

To enhance both initiatives, three courses (ChE 3111: Heat Transfer [Fall 2018]; ChE 3121: Fluid Mechanics [Spring 2019]; ChE 4661: Biotransport Phenomena [Spring 2019]), core to the chemical engineering curriculum and taken sequentially in the junior and senior year, were redesigned to merge the common aspects of the QEP and the Foundry through funding provided by the former. All three courses complement one another via content and through the incorporation of the Foundry educational platform.[3] Based on the notion that immersion experiences in industry help students better identify challenges in their field, the redesign incorporates a range of enhancement-like activities to the courses promoting innovation via exposure to aspects of industry that are integrated into the Foundry platform. Through a scaffolding approach, students gradually experience different levels of inquiry-guided pedagogy founded in the Foundry elements to help them develop skills necessary to not only provide a prototypic-centered solution to a given challenge but also a solution to a challenge they identify (Figure 1).[3] This implementation provides insight to the way in which students engage with innovation-driven learning and make connections between past experiences, content knowledge, and their own perspectives to sculpt a challenge statement that will provide the basis for a prototypic-centered solution.

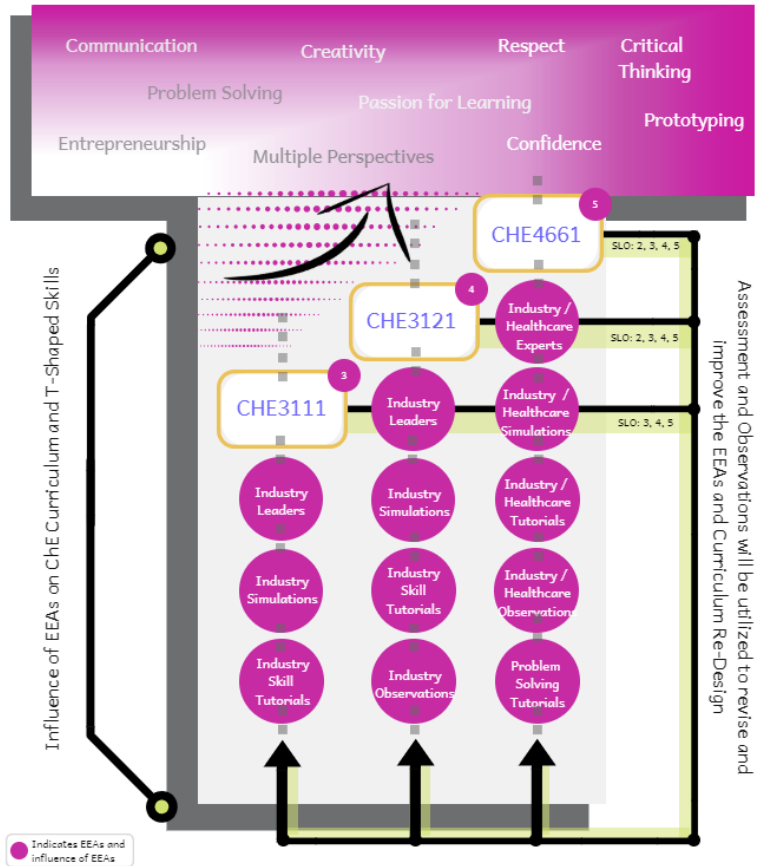

Figure 1 T-Shaped Engineer Model with Integrated ChE Curriculum Re-Design and EDGE Enhancement Activities (EEAs)

Central Factors in the Redesign

Three central factors contributed to the conception of this redesign: the conceptualization of a holistic, T-Shaped Engineer; the innovative, pedagogical framework provided by the Foundry; and the university's current QEP initiatives.

The T-Shaped Engineer

As industry changes with developed technology and often unpredictable client needs, the importance of developing individuals that possess both technical skills and cross-disciplinary interpersonal and transferable skills becomes imperative to the advancement of innovation in a globalized economy.[14,19] The concept of a T-Shaped Engineer has been described as an engineer with deep technical content knowledge and skills that cut across multiple disciplines.[19] Included in these transdisciplinary skills are the ability to communicate and work across disciplines, creativity, innovation, entrepreneurial mindset, and the ability to both find and solve problems, among many others.[14,19] The encompassing of these skills by an individual trained in the technical knowledge of engineering produces a holistic engineer capable of meeting the demands of the 21st century workforce.[4,14]

The Foundry

The Foundry is an interdisciplinary platform that promotes the development of a holistic type of engineering professional encompassing T-shaped skills embodying both content specific training and cross-disciplinary skills (e.g., creative and critical thinking, problem solving, communication, etc.).[3,14,19] It is a product of the efforts of an interdisciplinary team of scholars – the Renaissance Foundry Research Group (RFRG) – that represent the fields of engineering, education, nursing, business, and interdisciplinary studies.[3] The Foundry is also a central piece of the university's overall Quality Enhancement Plan (QEP) directives that spearhead the efforts to advance student-centered active learning platforms across campus.[3,15] Based on innovation-driven approaches to learning, the Foundry leverages two paradigms, knowledge acquisition and knowledge transfer, to engage students in an iterative learning process comprised of six steps that begin with the identification of a challenge related to the course content and finalizes with the development of innovative solutions that address this challenge (i.e., prototypes of innovative technology). The platform is meant to be adaptive and has been implemented at course, program, and administrative levels.

QEP Initiatives

The QEP is a cyclical "five-year university initiative to improve the quality of student learning" by targeting the development of critical/creative thinking and real-world problem-solving skills via active learning strategies.[20] As noted, the Foundry has been a central piece of QEP-related initiatives for this university, in particular as part of a focus on active-based learning. For the current cycle, the focus is a promotion of inquiry-guided learning strategies that enhance problem identification, solution, and analysis skills that integrate critical and creative thinking skills within undergraduate courses, which in the case of the ChE course redesign leverages the theoretical foundations central to the Foundry.[3] Further, the initiative provides funding via the Enhanced Discovery through Guided Exploration (EDGE) Creative Inquiry Curriculum Grant Program[20] to faculty that incorporate creative inquiry projects and assignments into courses they select for redesign. The creative inquiry projects and assignments are then assessed against five student learning objectives as appropriate: 1) Students will effectively use digital information search tools, 2) Students will formulate a creative inquiry question or problem, 3) Students will explore a creative inquiry question or problem, 4) Students will create an original scholarly or creative learning project, and 5) Students will communicate their findings/creations/art/inventions in a discipline-appropriate manner.

The Implementation of the Redesign in ChE 3111: Heat Transfer

Immersion Activities in ChE3111: Heat Transfer

For the first course in this redesign (ChE 3111: Heat Transfer [Fall 2018]) sixty-one students across two sections were introduced to immersion-like activities including, but not limited to: guest speakers representing different aspects of industry (*e.g.,* powerplant, chemical production such as plastics and powders), training tutorials regarding various aspects of industry, problem solving, and entrepreneurial pursuits (*e.g.,* COMSOL®, prototyping, etc.), industry simulations (*e.g.,* virtual reality sessions), and "real-world" immersions such as industry observations (*e.g.,* inquiry guided field trips to various industry settings). Each immersion-like or "real-world" immersion activity is intended to provide a different perspective for students to be able to gain the highest impact over the entirety of the course while still gaining content knowledge via its integration with Foundry platform.[3] For example, in the first iteration of the redesign, three speakers from various industries who spoke to relevant applications of heat transfer were invited to course as a part of the Knowledge Acquisition paradigm.[3] While each of the three speakers spoke of heat exchangers and the various applications of heat exchanger types, students were also exposed to boilers and condensers to heat and cool the steam that powers campus activities, plate-and-frame heat exchangers used in the process of developing specialty plastics, and furnaces used in an annealing process to develop specialty powders for automotive applications which would have otherwise been introduced as ambiguous applications of heat transfer concepts. Instead, students were able to see pictures that the speakers brought as visual aids for discussion, interact with leaders other than their instructor, and guide their learning through questions that targeted their own interests and previous experiences with the topics of the speakers' discussion.

Preliminary Observations from ChE 3111: Heat Transfer

Guest Speakers: Preliminary observations have revealed that student interest in the course topics is largely increased with the presence of the industry speakers as students have expressed appreciation of being able to visualize a real-world application of course topics. Students have noted that "heat transfer is extremely crucial to…industrial processes" and "the material we are learning in class [will] benefit us; understanding heat transfer is [an] important part of life." A majority have indicated that they were able to identify connections between the speakers' topics and the course content, and the discussions with industry leaders provided different perspectives of not only course topics applied in a real-world context, but also student understanding of the professional world.

Modules and Training: In the pilot implementation of this redesigned curriculum, a tutorial of COMSOL® software applied to heat transfer topics was developed and deployed for the course. In this edition of implementation, the tutorial consisted of an out-of-class video assignment where students were envisioned to watch and/or follow along with a COMSOL® demonstration of an application related to lab course work. After the video assignment, students were tasked with a challenge in class to apply their recently-acquired knowledge of COMSOL® software to an example that was intended to provide connections between their understandings of heat transfer concepts with their knowledge of the software. Preliminary results of effectiveness of this tutorial were varied, with some students expressing a need for additional feedback to connect the computer software to the application while others found the software useful for visualizing the physical system for which the software was being used.

Implications/Conclusions

The first iteration of implementation of this new curriculum is still underway. However, students are engaged with guest speakers' topics, invigorated by the course redesign, and connected to the course material in ways which were not previously observed by students in the course before the curriculum redesign. Further results will be analyzed in the closing weeks of the pilot semester and in future work.

References

1. Lee VS. *Teaching and learning through inquiry: A guidebook for institutions and instructors.* Stylus Pub Llc; 2004.

2. Lee VS. What is inquiry-guided learning? *New Directions for Teaching and Learning*. 2012;2012(129):5-14. https://onlinelibrary.wiley.com/doi/abs/10.1002/tl.20002. doi: 10.1002/tl.20002.

3. Arce PE, S JR, 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. C*ritical Conversations in Higher Education*. 2015;1(2):176-202. https://www.asee.org/documents/conferences/annual/2016/Zone2_Best_Paper.pdf.

4. Felder R, Brent R. Active learning: An introduction. *ASQ Higher Education Brief*. 2015:1-5.

5. Van Note Chism N, Bickford DJ. Improving the environment for learning: An expanded agenda. *New Directions for Teaching and Learning*. 2002;2002(92):91-98. https://onlinelibrary.wiley.com/doi/abs/10.1002/tl.83. doi: 10.1002/tl.83.

6. Neill S, Etheridge R. Flexible learning spaces: The integration of pedagogy, physical design, and instructional technology. *Marketing Education Review*. 2008;18(1):47-53. http://www.tandfonline.com/doi/abs/10.1080/10528008.2008.11489024. doi: 10.1080/10528008.2008.11489024.

7. Scott-Webber L. *In sync : Environmental behavior research and the design of learning spaces.* United States: ; 2004. http://catalog.hathitrust.org/Record/004966112.

8. Mobarak HM, Wu H, Hossain M. Effective teaching method for engineering education from student's perspective. International Conference on Engineering Education and Research, 2016.

9. Hmelo-Silver, CE, Duncan RG, Chinn CA. Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*. 2007;42(2):99-107. http://www.tandfonline.com/doi/abs/10.1080/00461520701263368. doi: 10.1080/00461520701263368.

10. Furtak EM, Seidel T, Iverson H, Briggs DC. Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research*. 2012;82(3):300-329. https://www.jstor.org/stable/23260047. doi: 10.3102/0034654312457206.

11. Bell T, Urhahne D, Schanze S, & Ploetzner R. Collaborative inquiry learning: Models, tools, and challenges; *International Journal of Science Education*. 2010;32(3):349-377.

12. Prince MJ, Felder RM. Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education*. 2006;95(2):123-138. https://search.proquest.com/docview/217947665. doi: 10.1002/j.2168-9830.2006.tb00884.x.

13. Kuhlthau CC, Maniotes LK. Building guided inquiry teams for 21st-century learners. *School Library Monthly*. 2010;26(5):18. https://search.proquest.com/docview/237137470.

14. Grasso D, Burkins M. Beyond technology: The holistic advantage. In: *Holistic engineering education.* 1st ed. New York, NY: Springer New York; 2010:1-10. 10.1007/978-1-4419-1393-7_1.

15. Sanders R, Geist M. Development and implementation of an interdisciplinary course at the interface of chemical engineering and nursing. 2016 Proceedings of the American Society of Engineering Education-Southeast Section Meeting. Tuscaloosa, AL. 2016.

16. Geist M, Sanders R, Harris K, Arce-Trigatti A, & Hitchcock-Cass C. Clinical immersion: An approach for fostering cross-disciplinary communication and innovation in nursing and engineering students. *Nurse Educator*. Published ahead of print, May 24, 2018.

17. Arce PE, Sanders JR, Arce-Trigatti A, et al. The renaissance foundry: A powerful learning and thinking system to develop the 21st century engineer. C*ritical Conversations in Higher Education*. 2015;1(2):176-202. https://www.asee.org/documents/conferences/annual/2016/Zone2_Best_Paper.pdf.

18. Bransford J, Brown A, and Cocking R. *How people learn: Brain, mind, experience, and school.* Waashington, D.C.: National Academy Press; 1999.

19. Inge O. T-shaped engineers for interdisciplinary innovation: An attractive perspective for young people as well as a must for innovative organisations. 37th Annual Conference – Attracting Students in Engineering, 2009.

20. Quality Enhancement Plan. 2016-2021. Available at: https://www.tntech.edu/sacscoc/qep

Stephanie N. Jorgensen

Stephanie N. Jorgensen holds a Ph. D. in Engineering with a Chemical Engineering concentration from Tennessee Technological University (TTU). She is currently on the Faculty in the TTU Department of Chemical Engineering. Her research interests focus on engineering education as well as the development and validation of mathematical and physical models for better understanding of species transport through healing wounds and predicting the effects of facilitated wound closure techniques (*e.g.*, suturing, etc.) on resultant scarring. She is currently a contributing research member of the Renaissance Foundry Research Group.

Andrea Arce-Trigatti

Andrea Arce-Trigatti holds a Ph.D. in Education with a Learning Environments and Educational Studies concentration from the University of Tennessee, Knoxville. She is currently on the Faculty in the Department of Curriculum and Instruction at Tennessee Technological University. Her research centers on cultural studies in education, issues in multicultural education, and collaborative learning strategies. As a founding member of the Renaissance Foundry Research Group, she has helped to develop and investigate the pedagogical techniques utilized to enhance critical and creative thinking at interdisciplinary interfaces.

J. Robby Sanders

J. Robby Sanders is the holder of M.S. and Ph.D. degrees in biomedical engineering from Vanderbilt University and a B.S. degree in mechanical engineering from Tennessee Technological University. He is currently on the Faculty in the TTU Department of Chemical Engineering. His research interests are in engineering education at disciplinary interfaces as well as technological research in the general areas of transport phenomena (including enzyme-based reactions) with applications in clinical diagnostics, soft gel materials, and wound healing. He is a founding member of the Renaissance Foundry Research Group and received the Thomas C. Evans Instructional Paper Award from the ASEE-Southeast Section in 2014 and the companion ASEE Zone II Best Paper Award in 2015.

Pedro E. Arce

Pedro E. Arce is the holder of M.Sc. and Ph.D. degrees in chemical engineering from Purdue University and a Diploma in Chemical Engineering from the Universidad Nacional del Litoral, Santa Fe, Argentina. He is Professor and Chairperson in the TTU Department of Chemical Engineering and a University Distinguished Faculty Fellow. His research interests are in the areas of engineering education including high performance learning environments and technological-based projects in the areas of advanced oxidation of organic contaminants, soil cleaning and remediation, nano-structured hydrogels, and a variety of catalytic systems. Dr. Arce is a founding member of the Renaissance Foundry Research Group that received the Thomas C. Evans Instructional Paper Award from the ASEE-Southeast Section in 2014 and the companion ASEE Zone II Best Paper Award in 2015.