Developing an Inquiry-guided Laboratory Manual with ABET-centered Student Learning Objectives for Chemical Engineering Transfer Science Courses

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Abstract

The purpose of this contribution is to illustrate the alignment of a novel, undergraduate laboratory redesign with the student outcomes listed under the 2019-2020 ABET criterion 3[1]. The context for this redesign is a chemical engineering transfer science laboratory course, where the main instrument driving the redesign was the creation of an Inquiry-Guided Laboratory Manual (IGLM)[2] that incorporates elements from Renaissance Foundry model (herein the Foundry) and student-centered, inquiry-guided learning to help students reach learning objectives aligned with all elements of ABET criterion 3[3–5]. Embedded in this process, the assessments featured in the IGLM will be described, including reflections, lab assignments, and the development of prototypes of innovation[3]. This will be followed by an in-depth overview of the alignment between the redesign framework, the ABET criterion 3, and the learning objectives outlined in the IGLM. Implications for student learning and a discussion of the pedagogical items related to the redesign of engineering laboratories with the ABET criterion 3 will be offered as part of a case study for a transfer science course in chemical engineering.

Keywords

Student Learning Objectives, ABET Criterion 3, Engineering Laboratories, Inquiry-guided Learning, Innovation-driven Learning

Introduction

Within engineering classrooms, there has been a movement towards active and inquiry-guided learning strategies that aim to foster a holistic style engineer, instead of the traditional laboratory experience[6–8]. The engineering laboratory is an essential part of the engineering curriculum; by helping students make connections between what they are learning and their own experiences, and also by helping students to gain the teaming skills necessary for effective collaboration with a diverse team of thinkers[4,9]. Since the engineering laboratory is widely acknowledged as the primary setting for which engineering students are able to develop and hone their engineering skills, it becomes imperative that they are provided clear, unambiguous educational objectives as part of the lab experience[6]. The purpose of this contribution is to illustrate the alignment of a novel, undergraduate laboratory redesign with the student outcomes listed under the 2019-2020 Accreditation Board for Engineering Technology (ABET) criterion 3[1].

The context for this redesign is a transfer science laboratory course in chemical engineering. The main instrument driving the redesign was the creation of the IGLM[2] that incorporates elements from the Foundry model and student-centered, inquiry-guided learning in an effort to provide students with specific learning objectives for each laboratory experiment, tailored to align with the student outcomes listed by ABET criterion 3[3–5]. The Foundry is an innovation driven learning platform that fosters collaboration amongst students and promotes student-centered learning through the two key learning paradigms of (1) knowledge acquisition and (2) knowledge transfer[3]. The goal of this redesign is to facilitate the corroboration of students' actions and experiences in an engineering laboratory environment with specific learning objectives for each experiment with each module designed to encompass a particular level of inquiry-guided learning[5,10].

As part of this contribution, the redesign is being featured as a case study of a transfer science course to demonstrate how the assessment of students may reflect this effort. To begin, major points in the literature that provide insight into the newest modifications in ABET criteria[1] will be reviewed. Afterwards, the design of educational learning objectives and the pedagogy of the Foundry within engineering educational laboratories will also be highlighted[3]. Details pertaining to this redesign will then be outlined to underscore how the IGLM encompasses both inquiry-guided learning and the Foundry model[3]. This will be followed by a description of the alignment between the redesign framework, ABET criterion 3, and the student learning objectives provided in the IGLM. Implications for student learning and a discussion of the pedagogical elements related to the redesign of engineering laboratories with the ABET criterion 3 will be offered.

Background

The inquiry-guided laboratory manual incorporates both paradigms of the Foundry throughout a series of experiment modules that have been designed to progressively traverse the levels of inquiry-guided learning. Meaning, as each sequential experiment module is encountered, students are ascending to the next level of inquiry-guided learning. These levels, and the assessments incorporated within the experimental modules, are intentionally aligned with the new 2019-20 ABET criterion 3[1]. Further, the purpose of applying inquiry-guided learning to the design of the lab experiments is to facilitate the development of higher-order thinking skills, which are necessary for complex problem solving[5,11] The following subsections provide a foundation for how these components connect to one another and are relevant to understanding the purpose of this redesign.

Modifications for 2019-20 ABET Criterion 3

In 2009, the Criteria Committee for ABET received several requests from member societies to add elements to the existing ABET Criterion 3 regarding Student Outcomes (a)-(k)[1]. In response, a task force was formed to review such requests and make suggestions to the full Criteria Committee. After an extensive literature review and three rounds of gathering feedback by the task force, the existing (a)-(k) outcomes were grouped into six topic areas. Following the proposal of the new six topic areas to the Criteria Committee, further discussion resulted in the addition of a seventh topic area. Together, the following seven topic areas have been adopted by

ABET to outline Criterion 3 for student outcomes (1)-(7)[12]: (1) Engineering problem solving; (2) Engineering design; (3) Measurement, testing, and quality assurance; (4) Communication skills; (5) Professional responsibility; (6) Professional growth; (7) Teamwork and project management.

Educational Learning Objectives in Engineering Laboratories

In the early 2000's, a consortium of engineering education professionals gathered at a colloquy in San Diego at the behest of ABET to discuss a pressing issue regarding the lack of defined learning objectives for instructional laboratories[13]. The need for such objectives was identified as remote, distance learning programs in engineering, which were growing in both popularity and number, began to seek accreditation from ABET. As a result, the colloquy was able to provide a list of thirteen objectives that outlined the fundamental engineering skill sets that educational laboratories should be developing in students[4,9,14,15]. The thirteen fundamental learning objectives for educational laboratories in engineering were presented: (1) Instrumentation; (2) Models; (3) Experiment; (4) Data analysis; (5) Design; (6) Learn from failure; (7) Creativity; (8) Psychomotor; (9) Safety; (10) Communication; (11) Teamwork; (12) Ethics in the laboratory; (13) Sensory awareness. Pedagogical strategies needed to achieve these objectives within Undergraduate Level courses inherently require a shift towards active learning techniques that help students become independent, life-long learners, that are self-guided and inherently curious[6].

Pedagogy of the Foundry in Engineering Education

The Foundry is a pedagogical platform that provides a framework for transitioning between the paradigms of knowledge acquisition and knowledge transfer in an iterative process that navigates students across six interdependent elements of innovation-driven learning. The overall objective of the Foundry is to facilitate the design of a prototype of innovative technology in response to a student-identified, learning challenge concerning a complex, societal-relevant issue or problem[3]. As mentioned, the Foundry is an innovation driven learning platform that fosters collaboration amongst students and promotes student-centered learning through the two key learning paradigms of (1) knowledge acquisition and (2) knowledge transfer[3]. These two paradigms work iteratively to help students navigate the six elements that comprise the Foundry model; these are presented in the Foundry engine image presented in Figure 1.

Further, undergraduate, engineering courses that have utilized the Foundry to redesign traditional methods of engaging students with the content of the course have demonstrated the acquisition of skills aligned with the educational learning objectives for engineering laboratories, described above[4,16,17]. For example, through the development of critical and creative thinking skills fostered via the use of this platform, students are addressing objectives related to design, creativity, and learning from failure[4,16,17]. Through the iterative design process inherent in the model, students are obtaining skills associated with modeling, data analysis, and design[4,16,17]. In addition, the collaborative nature of the platform engenders skills associated with communication, teamwork, and ethics, that are further reinforced by the inquiry-learning and active learning practices embedded in the Foundry redesign of the course being featured herein[4,16,17].

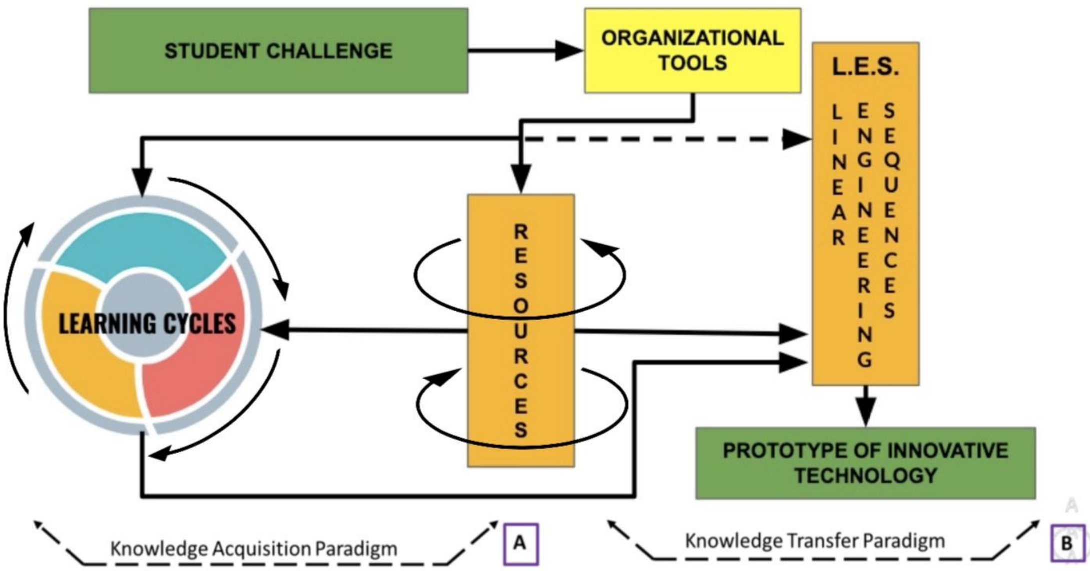

Figure 1. The Renaissance Foundry Model[16]

Inquiry-Guided Learning

Inquiry-guided learning is a form of active learning that incorporates a student-centered approach that facilitates learning through discovery[10]. According to Lee[10], a scaffolded-approach is typically paired with inquiry-guided learning that allows the, "instructors [to] support students' inquiry in any number of ways and [to] gradually withdraw support as students' knowledge base and abilities to inquire develop" (p. 152). Typically there are four levels of inquiry-guided learning that are used in a scaffolding approach: (1) Limited; (2) Structured; (3) Guided; (4) Open[2,10]. When this scaffolding approach is paired with the Foundry model, it allows for students to develop innovation-driven learning skills in a manner that progresses with their own engagement and experience with the content of the course[16]. For the purpose of the IGLM's experiment modules, the structured, guided, and open levels of inquiry-guided learning will be a major component in the redesign of this course.

Context

Course Logistics for Transfer Science I Lab

The main instrument driving the redesign in the chemical engineering transfer science laboratory course featured herein was the creation of the IGLM[2]. This manual incorporates elements from the Foundry model and student-centered, inquiry-guided learning in an effort to provide students with specific learning objectives for each laboratory experiment, tailored to align with the student outcomes listed by ABET criterion 3[3–5]. The transfer science laboratory course is paired with a corresponding lecture course that introduces students to the principles and concepts involved in the transport phenomena being investigated. Transfer Science I is a four credit hour course, dedicated to introducing students to the conservation principles associated with thermal energy in engineering applications.

The transfer science course for this study is listed as a junior-level course in the chemical engineering department's program of study and is the first of three total transfer science courses required to graduate from the program. Per semester, 60 students are enrolled in the course, approximately, split between two or three sections. For the laboratory portion of the course, students will meet for two hours each week, outside of the scheduled lecture course time. The laboratory portion requires students to complete experiments that are aimed at providing hands-on experiences in order to help students acquire fundamental engineering skills through the connection of transfer science principles with real world applications.

Laboratory Redesign with IGLM Experiment Module Framework

As part of the laboratory redesign, the components of the IGLM experiment modules are based on the elements of the Foundry model, coupled with the scaffolding of inquiry-guided learning (structured, guided, and open)[2,10]. The experiment module framework has been designed to allow students to begin at the structured-inquiry level, which is similar to traditional laboratory practices that are heavily instructor-directed. As the students complete each sequential experiment module, the level of inquiry is gradually increased, allowing the laboratory instructor to methodically transition into becoming a collaborative resource for students, which is more similar to a facilitator of learning, as featured in the Foundry model[3]. The IGLM experiment module framework is featured in Table 1. The components of the IGLM are listed in the far-left column and their progression through the inquiry-guided learning levels of structured, guided, and open are featured in the columns to the right of this initial column. The components of the IGLM highlighted in the far-left column only feature those that are related to these levels (i.e., that are changing with the level of inquiry) and are relevant to the Transfer Science I laboratory.

Table 1. Framework of IGLM experiment modules.

Exp Module Elements	Experiment 1	Experiment 2	Experiment 3	Prototype
Experiment Objective	Clear statement regarding the overall objective with descriptive procedural elements and expectations.	Clear statement regarding the overall objective without descriptive procedural elements provided.	Overview of the transfer science principles involved with expectation for students to identify, select, and explore a relevant concept through experimentation.	Prototype of Innovative Technology using Renaissance Foundry Model
Inquiry Learning level	Structured	Guided	Open	
Conceptual Model	Detailed Model with descriptive comments	Descriptive Model	Generic Model	
Experimental Setup & Procedure	Procedure provided with instructions for materials and instrumentation.	Materials and Instrumentation provided but no procedural steps.	Student-directed inquiry, instructor as resource.	
Post-Lab Report: Discussion & Results, Individual Reflection	Structured with Comparative Analysis	Describes methodology, discussion of results, comparative analysis	Defines objective, describes methodology, discussion of results, comparative analysis	

Alignment of the IGLM Learning Objectives with 2019-20 ABET Criterion 3

As a component in each IGLM experiment module, specific student learning objectives have been provided for the experiments at every level of inquiry in order to provide students with defined educational objectives, which were previously not provided. The design of the learning objectives for each experiment were structured to compliment the student outcomes identified by the 2019-20 ABET criterion 3. Each of the learning objectives for an experiment is aligned with a specific student outcome in the 2019-20 ABET criteria in a manner that is consistent with the focus of the experiment module in which it is contained, as shown in the table located in Appendix A.

In the table located in Appendix A, we feature the alignment of the IGLM learning objectives with the 2019-20 ABET Criterion 3. This table helps to facilitate the understanding of how the IGLM lab redesign (which incorporates the inquiry-guided learning levels as well as the Foundry elements) addresses the specific items highlighted in the ABET Criterion 3. For example, the first line illustrates that one component of ABET Criterion 3 emphasizes that students must possess, "An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics". The second column in the table captures the action items featured in this ABET component, which in this example includes: identify, formulate, and solve complex engineering problems; and applying principles of engineering. These action items are meant to be for the students as they complete the IGLM's experiment modules. In the last column, the IGLM learning objectives intentionally align and incorporate these action items into the Transfer Science I laboratory experience.

What is highlighted by this table is that through the intentional development of a laboratory guide like the IGLM, not only can active learning elements be incorporated into the students' learning experiences, but these elements, as featured by the Foundry[3] platform, can help undergraduate, engineering students develop skills that are aligned with the ABET Criterion 3[1]. Such a redesign necessitates intentionality on the part of the facilitators of learning, as each module is intended to help students build on skills acquired in previous experimental modules. This provides assessment measures that are formative in nature and help identify student outcomes as they relate to ABET accreditation. In terms of evaluation, this type of redesign also facilitates departmental and course level review of how instruction is aligned with the 2019-20 ABET Criterion 3[1].

Implications for Student Learning and Curriculum Redesign

As part of the laboratory redesign, this is the first semester that the ABET-aligned learning objectives have been presented in a transfer science laboratory. To ensure that the ABET criterion are being implemented, the IGLM is working as an anchor in the laboratory space. Through the alignment of the IGLM to ABET and its scaffolding approach to inquiry-guided learning, the manual possesses the ability to work as a catalyst for how the Foundry is bridging the gap between lecture courses and laboratory spaces. The novelty of the redesign is a pioneering effort to ensure that active learning in innovation-driven pedagogy is implemented in a laboratory space, which strengthens student experiences at the undergraduate level.

From this initial implementation, the following implications for redesigning laboratory courses in chemical engineering programs of study can be derived:

1. Such a redesign assists the curriculum to be in compliance with the ABET Criterion in an effective and systematic manner;
2. This redesign also allows the further integration of student-centered and innovation-driven learning skills in courses that are fundamental to the overall program of study for chemical engineering at the undergraduate level;
3. This redesign also strongly integrates the role of the engineering laboratory in student learning by providing experiences that correlate to educational content learned as part of the lecture portion of the course;
4. This redesign brings highlights to the crucial role that the laboratory setting plays in relation to other learning theories that illustrate the need for the effective use of Space in terms of student experience (e.g., the Technological, Space, Pedagogical, Content Knowledge [TSPACK] model)[18].

Consequently, this initial implementation holds departmental and curricular implications that are not only valuable for enhancing student learning, but also for effectively aligning instruction with the 2019-20 ABET accreditation criteria.

Conclusions and Future Work

The purpose of this contribution was to illustrate the alignment of a novel, undergraduate laboratory redesign with the student outcomes listed under the 2019-20 ABET criterion 3[3–5]. What was featured in this work was the creation of a novel IGLM that integrates inquiry-guided learning levels with the major elements of the Foundry model to help students develop skills associated with innovation-driven learning. One thing that we have learned is that the IGLM arguably works as an organizational tool within a Foundry designed course that helps students understand the fundamentals as applied to laboratory environments. Further, the integration of the ABET criterion and learning objectives has provided a more comprehensive understanding of how student learning can progress within this type of interactive environment. In future work, a concurrent study will report the findings from an investigation on the implementation of the IGLM within a heat transfer laboratory course, which provides specific examples of the ABET-aligned student learning objectives tailored to the context of the laboratory course.

In future work, students' experiences will be evaluated through quantitative and qualitative measures in regards to the effectiveness of each of these inquiry levels as featured in the IGLM. In addition, the application of such organizational tools, like the IGLM, to other undergraduate engineering contexts will help to further the understanding of how this type of tool is transferable in other educational settings. For example, as part of the larger sequence related to the Transfer Science courses, the IGLM will be integrated into the laboratory experiences of students within these courses, which will merit further investigation. Such research will help to better understand how and to what degree student learning is aligned with the 2019-2020 ABET Criterion standards.

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Appendix A - Alignment of ABET Criterion 3 and IGLM's Learning Objectives

	ABET Criterion	Action Items	IGLM Learning Objectives - "Students will…"
1	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Identify, formulate, and solve complex engineering problems Applying principles of engineering	Formulate and solve engineering problems related to the thermal properties of solid materials and practice identifying unknown materials by experimentally determining their thermal conductivity.
2	An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Apply engineering design to produce solutions that meet specified needs	Apply engineering design to produce solutions that meet specific needs regarding heat transfer principles and the law of thermal heat conduction.
3	An ability to communicate effectively with a range of audiences.	Communicate effectively	Communicate their efficacy of heat transfer with a range of audiences in an effective manner by the use of pre-lab and post-lab engagement activities.
4	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in a global, economic, environmental, and societal contexts.	Recognize ethical and professional responsibilities in engineering situations Make informed judgments	Recognize ethical and professional responsibilities relating to heat transfer and will consider the potential impact of engineering solutions in global, economic, environmental, and societal contexts regarding the thermal properties of materials.
5	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	Function effectively on a team Create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives defined in this laboratory manual.
6	An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	Develop and conduct appropriate experimentation Analyze and interpret data Use engineering judgment to draw conclusions	Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions through their mastery of laboratory instruments and contextual knowledge of heat transfer regarding the thermal conductivity of materials with respect to temperature gradients.
7	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	Acquire and apply new knowledge as needed	Acquire and apply new knowledge within the engineering laboratory, using appropriate learning strategies that have been developed and taught in both the lecture and laboratory settings.