Innovative Manufacturing Education Experience for First-Year Engineering Students: Using a Seminar Course and Volunteerism to Enhance Manufacturing Skills

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Abstract

Traditional first-year engineering curricula place a premium on education related to math, science, and often an introductory engineering course involving elements of design, analysis, and programming. While the opportunity for first-year students to gain hands-on experience is increasing, these experiences typically focus on design-related activities, while experiences with manufacturing skills and processes are limited. Yet with the "maker movement" in full swing, today's students have a strong desire for engineering experiences where they learn manufacturing skills and build things that complement the design skills they are learning in first-year classes and beyond. This paper explores the details of how a 1-credit seminar course is being used at a large Midwestern university to provide an innovative manufacturing education experience to first-year engineering students. This is accomplished by grounding the course in the manufacturing tools and processes used in the university's Artisan and Fabrication Laboratory (AFL) to facilitate learning about manufacturing through the technology that students have access to and can use. As part of the course, students can volunteer (and most do) to gain hands-on experience with the tools and processes that are discussed in the class through specific activities in the AFL designed to complement what is taught in class. As this class has been taught in both the Fall and Spring semesters since Fall 2013 (7 semesters), assessment data and student feedback is available and is reviewed in this paper. The overall result is a class that is in high demand from the first-year engineering student body and that greatly enhances students' understanding of manufacturing.

Tags: manufacturing, education, engineering, first-year, volunteerism

Introduction

Today's engineering curricula provide adequate design and analysis experience for students, yet provide little or no formal education related to manufacturing tools and processes (Todd, Red, Magleby, & Coe, 2001), despite calls from industry to provide more focus on manufacturing in the engineering curriculum (Mason, 1998). At the same time, many engineering programs in the U.S. now provide students with access to high-tech "maker spaces" to manufacture their designs for student projects (Wilczynski, 2015). This provides an opportunity to introduce manufacturing concepts to engineering students, especially at an early phase during the first-year engineering curricula when students are still exploring engineering and have time to devote to learning new skills that will help them throughout their undergraduate career.

This paper describes the development and implementation of a 1-credit hour seminar course for first-year engineering students at a large Midwestern university designed to give an introduction to manufacturing from an engineering perspective. This is accomplished by utilizing the tools and processes that are part of the university's "maker space," while utilizing volunteerism to enhance students' opportunity to get hands-on experience. The paper will discuss an overview of the course (including the characteristics of the institution, the "maker space," and the students), how the course is designed (including the content, pedagogy, and assessment), assessment data, student feedback, and finally a summary and future work.

Course Overview

The course is titled "ENGR 103: AFL – Intro to Manufacturing," which is a 1-credit seminar course offered at a large Midwestern university in the Fall and Spring semester for First-Year Engineering (FYE) students. The course, offered since Fall 2013, is designed to give students an introduction to manufacturing processes from an engineering perspective by utilizing the tools and processes that are part of the College of Engineering's Artisan and Fabrication Lab (AFL). The course is organized such that students meet with the instructor each week for 50 minutes in a classroom setting. In the classroom setting, instruction and class discussions focus each week on the manufacturing tools and processes of the AFL, including the background knowledge required to utilize those tools and processes. As an optional part of the curriculum, students can volunteer to participate in pre-determined hands-on activities in the AFL designed to provide deliberate and distributed practice for the manufacturing tools and process learned about in class, yet this is not mandatory nor part of their grade. All students participate in a semester-long project where students design a part and then manufacture it using the manufacturing tools and processes in the AFL for which they learned about in class.

Characteristics of the Institution

This course is taught as part of the FYE program, which offers several seminar courses titled "ENGR 103 - Introduction to Engineering in Practice." These ENGR 103 seminar courses focus on different aspects of engineering practice such as nuclear nonproliferation, learning communities, and engineering for the planet, and are typically offered in the Fall semester. Typical course size in an ENGR 103 seminar course varies from 30 to 60 students. The typical class size for ENGR 103: AFL – Intro to Manufacturing varies from approximately 40 to 60 students.

The AFL, which is utilized by the course, has been in operation since 2008, with the purpose of being a manufacturing lab for students to use for course, research, entrepreneurial, and personal projects. The lab contains several different kinds of manufacturing tools and processes, including Computer Numerical Control (CNC) machines, a water jet machine, saws, drills, and hand tools. The AFL is open to any student (not only engineering students). It has only one full-time staff member as a supervisor, and the rest of the staff are trained student workers who help the students who come in to use the lab. Typically, over 1100 students use the lab in an academic year. Figure 1 below shows a picture of part of the AFL with students using the lab.

Figure 1: The AFL featuring CNC turning and machining centers.

In addition, the AFL and the students who utilize it operate within the culture of the so-called "maker movement," which "tap[s] into an American admiration for self-reliance [that] combine[s] open-source learning, contemporary design, and powerful personal technology like 3-D printers" (Bajarin, 2014). The learning environment of the AFL is essentially students helping students, supervised by a staff member for safety. It utilizes an approach that is similar to the Vygotsky's zone of proximal development model (Vygotsky, 1962), where students are allowed to work with equipment to the point where they are uncomfortable/unfamiliar and need help. This means that a beginner who has never set foot inside a manufacturing lab is as welcome as an expert who can operate equipment with minimal assistance, and each student will get exactly the right amount of help they require to be successful. This is unlike most learning environments students find on campus, and most students tend to engage and thrive in this environment. In addition, as a result of this environment in the AFL and the initial exposure that students get to it in the course, most students tend to participate in the optional volunteer part of the course.

Characteristics of the Students

In the hopes that most students will participate in the volunteer portion of the curriculum, there is a desire to find students who have a very strong interest and motivation to learn about manufacturing processes. To accomplish that task, students are exposed to the AFL during freshman orientation week and asked to fill out an application to enter the class. During student orientation the week before classes start in the Fall semester, the AFL is part of a "scavenger hunt tour" where almost all FYE students visit the AFL during an activity designed to get students familiar with the locations of classrooms and resources on campus. During this "scavenger hunt tour" of the AFL, many FYE students are intrigued with the tools and technology in the AFL, and the staff and student workers in the AFL talk with the FYE students about the ENGR 103 course. In addition, there is an application that must be filled out by students who are interested in taking the course, both for students to show true interest in taking the course, and for the instructor and the AFL staff to get a sense of the manufacturing background of the students who fill out the application. To date, any student that has filled out the application has been allowed to take the course. The application strategy has proved to be successful in finding motivated students, combined with how the hands-on volunteer activities are discussed in class, as the vast majority of students who take the class are very motivated to expand their manufacturing skills, with most participating in the optional volunteer activities in the AFL. For example, in the Fall 2016 semester, 47 of 54 students enrolled in the course are participating in the volunteer activities, which is a typical percentage each semester.

Demographics of the Fall 2016 semester are shown in Table 1 below (estimated by the instructor). This also has been shown to be typical of given semester this course. In addition, 33 of the 54 (61%) students are taking the First-Year Engineering Honors course, as are 8 of the 9 (89%) female students.

Demographics	# / % of students
White Male	31/54 (57%)
White Female	8/54 (15%)
International Male (*)	11/54 (20%)
International Female (*)	1/54 (2%)
Underrepresented Male	3/54 (6%)
Underrepresented Female	0/54 (0%)

Table 1: Fall 2016 Student Demographics (estimated).
(*) note: all Asian students arbitrarily placed in international category

Regarding student skills with manufacturing tools and processes that help students begin utilization of the equipment in the AFL, Table 2 below shows data from the applications of the Fall 2016 students who applied for the course, which shows students came to the course with the following experiences:

Tool/Process	# / % of students with experience
Hand Tools	53/59 (90%)
Drills/Saws	50/59 (85%)
CAD/CAM	36/59 (61%)
CNC	7/59 (12%)

Table 2: Fall 2016 Student Manufacturing Tools and Process Skill Inventory.

Even with this data that shows most students have a basic level of experience with manufacturing, due to the safety requirements involved with the operation of the equipment, this class is taught as if most students have little to no manufacturing background so that all students start on the same level.

Course Design

This course was designed using a backward design model championed by Hansen in his book *Idea-based learning: A course design process to promote conceptual understanding* (Hansen, 2011). Hansen utilizes prior work in backward design (Tyler, 1949) (Wiggins & McTighe, 2004) to foster a course design process that focuses on student outcomes first, then works backward to use these outcomes to design the content, assessment, and pedagogy. Just as important, Hansen advocates the use of various tools, discussed in detail later, to check for the alignment of the content, assessment, and pedagogy. This ensures that learning outcomes match what students are asked to do, how students are graded and the feedback they receive, and what the students experience in the classroom.

Content: Development of Curricular Priorities

The first step in the backward course design model advocated by Hansen is to "determine what students should get out of the course" (Hansen, 2011, p. 22). This is done by identifying what Hansen calls the Big Ideas, Essentials Questions, Guiding Concepts, and Curricular Priorities for the course. The Big Ideas are something that "connect the dots for the learner by establishing learning priorities…they serve as 'conceptual velcro' – they help the facts stick together and stick in our minds" (Wiggins & McTighe, 2004, p. 66). The Essentials Questions are designed to promote conceptual understanding and "require the learner to make connections and transfer what they have learned in one context to related aspects of another" (Hansen, 2011, p. 76). Guiding Concepts are "the key concepts that need to be addressed in trying to answer" (Hansen, 2011, p. 77) the Essential Questions. The overarching goal for this course is for students to develop the knowledge and skills needed to utilize manufacturing tools and processes and then apply that knowledge and skills. This follows from the Big Ideas, Guiding Concepts, and Essential Questions are listed in Table 3 below.

Category	Explanation
Big Idea	Manufacturing Processes: many different manufacturing processes are needed to make a finished part, and knowing which manufacturing process to use in which order is a complex task that one learns through hands-on application experience.
Essential Questions	What type of manufacturing processes are used in the AFL? How are the manufacturing processes in the AFL used? What knowledge and skills are required to use the manufacturing processes in the AFL? How does one design for manufacturing?
Guiding Concepts	Knowledge & Skills, Tools, Processes, Design: the knowledge and skills of manufacturing tools and processes are needed to design, apply, and manufacture a finished product.

Table 3: Big Ideas, Guiding Concepts, and Essential Questions.

Curricular Priorities are the process of establishing "the selection of what has the best chance for increasing students' conceptual understanding of the modes of thinking in the field" (Hansen, 2011, p. 23). Curricular Priorities are made up of Enduring Understandings items, Important to Know items, and Good to Be Familiar With items. The Enduring Understandings items are the most important of the Curricular Priorities, and are “what students should take away from their studies long after a given course has ended” (Hansen, 2011, p. 37). Important to Know items are the second most important of the Curricular Priorities, and are “important knowledge, skills, and concepts that have connective and transfer power” (Wiggins & McTighe, 2004, p. 72). Good to Be Familiar With items are the least important of the Curricular Priorities, and is “knowledge that students should be familiar with” (Wiggins & McTighe, 2004, p. 72). One tool that is helpful to develop Curricular Priorities is a concept map, which is a graphical way of organizing content. In Figure 3 below, the course content is organized in a content map that shows the Enduring Understandings in green and the Important To Know items in red. As this is a 1-credit hour course, the Good to Be Familiar With items have been removed from the course for simplification to allow students to focus on the Enduring Understandings.

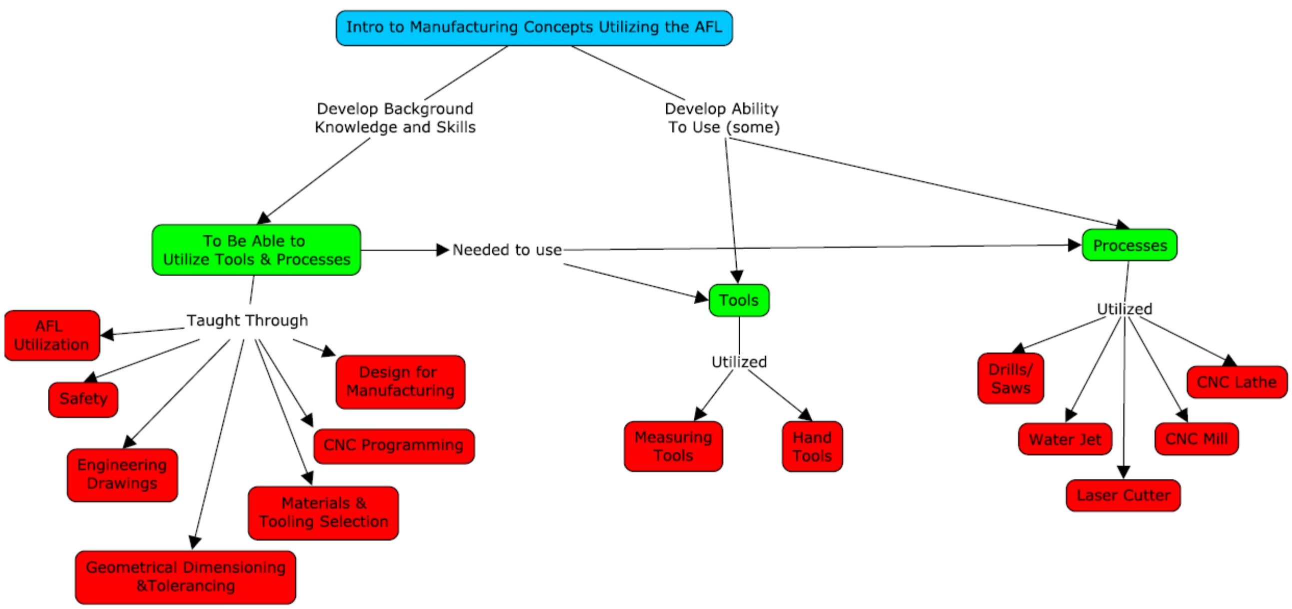


Figure 2: Content Map of the Course Content.

As explained previously, the overarching goal for this course is for students to develop the knowledge and skills needed to utilize manufacturing tools and processes and then apply that knowledge and skills. As such, there are two primary Enduring Understandings (EU) that are focused on meeting this overarching goal.

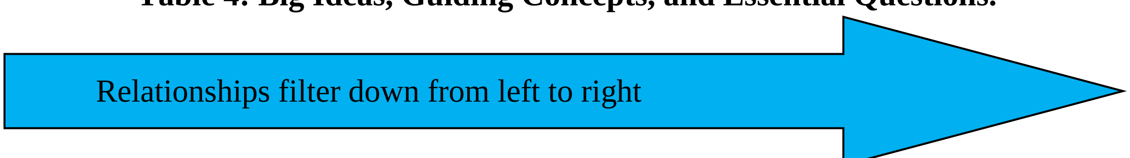
- EU1: To develop the background knowledge and skills needed to be able to effectively utilize the manufacturing tools and processes used in the AFL.
- EU2: To develop the ability to use some of the manufacturing tools and processes utilized in the AFL.

The course has several Important to Know items, each associated with the corresponding Enduring Understanding in the table below. It is important to note that most of the Important to Know items have a single class period dedicated to the topic (see course schedule in the syllabus). The relationships between the Big Ideas, Essential Questions, Guiding Concepts, and

Curricular Priorities are best understood when these items are all together in a single table, as shown in Table 4 below:

Big Idea	Essential Questions	Guiding Concepts	Curricular Priorities	
			Enduring Understanding	Important To Know
Manufacturing Processes: many different manufacturing processes are needed to make a finished part, and knowing which manufacturing process to use in which order is a complex task that one learns through hands-on application experience.	What type of manufacturing processes are used in the AFL? How are the manufacturing processes in the AFL used? What knowledge and skills are required to use the manufacturing processes in the AFL? How does one design for manufacturing?	Knowledge & Skills, Tools, Processes, Design	EU1: To develop the background knowledge and skills needed to be able to effectively utilize the manufacturing tools and processes used in the AFL. EU2: To develop the ability to use some of the manufacturing tools and processes utilized in the AFL.	AFL Utilization, Safety, Engineering Drawings, Geometrical Dimensioning & Tolerancing, Materials & Tooling Selection, CNC Programming, Design for Manufacturing. Tools: Measuring Tools, Hand Tools Processes: Drills/Saws, Water Jet, Laser Cutter, CNC Mill, CNC Lathe.

Table 4: Big Ideas, Guiding Concepts, and Essential Questions.



In the table format, it can be seen how the relationships filter down from left to right, starting with the Big Idea, filtering down to the Curricular Priorities. In other words, the Big Idea of Manufacturing Processes leads to the Essential Questions and Guiding Concepts centered around knowledge, skills, tools, processes, and design. This leads to the overarching course goal, or the Enduring Understanding, to develop knowledge and skills, and to develop the ability to use some of the manufacturing processes. These Enduring Understandings in the course will be met by focusing on the Important to Know items.

Content: How Students Learn the Content

After establishing the course content through the Curricular Priorities, it is important to determine how students best learn this content so that effective assessments and classroom activities can be designed. The Enduring Understandings for this course targets a particular type of learning focused on procedural knowledge, defined as “knowledge that consists of the rules and procedures for solving problems” (Hiebert & Lefevre, 1986). In the case of the manufacturing processes related to the Enduring Understandings, the “rules and procedures” part is the background knowledge and skills needed to be able to effectively utilize the manufacturing tools and processes used in the AFL (EU1). The “solving problems” part is the ability to use some of the manufacturing tools and processes utilized in the AFL (EU2). This type of learning and knowledge acquisition lines up perfectly with the Enduring Understandings of the course. How students best learn procedural knowledge will be addressed in below.

Procedural knowledge has been shown to be based on the prior knowledge of the learner and tacit to the learner (Cauley, 1986). The combination of these two items makes it difficult to teach the most difficult concept in the course to students: the concept of knowing which manufacturing processes to teach and in which order. For example, it is relatively straightforward to teach a student how to drill a hole, how to cut using a saw, or how to use a grinder, as all are individual tasks, and any task can be taught using rules and procedures (i.e. procedural knowledge). Yet giving students a raw piece of material and a drawing, and then having them know which processes to use and which order to use each process is a complex task. The type of task, to manufacture a part that requires multiple operations to complete, has been shown to be a complex systems issue to understand (Deshmukh, Talavage, & Barash, 1998). Even though the students develop the procedural knowledge of how to use the individual processes, and much class time is spent on the topics of designing and assembling for manufacturing, the knowledge of knowing which process to use when remains a difficult concept for student to grasp because it is unique to the design of the part, therefore difficult to teach. This is accommodated in the course by helping students (providing a more knowledgeable other) in the AFL to help choose the correct manufacturing processes and order of those processes so that students can focus on learning the individual process to a level beyond their initial skill set.

One of the biggest misconceptions regarding manufacturing and manufacturing process is that manufacturing is a “dirty” process, and a lower-class industry, making a lot of people uninterested in investigating manufacturing as an option for a career or for learning opportunities (SME, 2016). Yet with the “maker movement,” many of today’s millennial generation students are much more interested in manufacturing than even a few years ago (Bajarin, 2014). The AFL is an engineering version of “maker’s space,” and as makers need to “make something” (we call it manufacturing as engineers), the AFL capitalizes on the fact that many of these students want to be “makers.” These students have shown a strong desire to get hands-on experience with manufacturing skills, as evidenced by the number of students that fill out the application for this course and by the number of students that volunteer for the hands-on activity part on the course, both of which has been shown in this document. This misconception also ties into Perkin’s principle of “make the game worth playing” (Perkins, 2009), discussed in detail later in this document, that focuses on motivating the students to learn. This course uses three approaches to motivating students, also explained later in the document in the Pedagogy section.

Procedural knowledge is best developed through practice (Star, 2005). This makes sense as procedural knowledge is focused on rules and procedures for students to follow. Ericsson, Krampe, & Tesch-Römer, (Ericsson, Krampe, & Tesch-Römer, 1993) take the concept of practice a step beyond and argue for deliberate practice. They indicate that “insights and knowledge are steadily accumulating and the criteria for eminent as well as expert performance undergo continuous change" (Ericsson et al., p. 366), and that deliberate, intentional practice is required to develop true expertise. While the students in this course are not going to become experts (Ericsson indicates that over 10,000 hours of deliberate practice is required for that) (Ericsson et al., 1993), the focus on the hands-on volunteer activities and the manufacturing project are intended to provide as much deliberate practice to students as possible in this 1-credit hour course.

The theory of difficulty for this course is simple: the knowledge and skills required in this course are procedural in nature, is based on their prior knowledge, and requires deliberate practice to develop. Research has shown that it takes over 10,000 hours of deliberate practice to become an expert (Ericsson et al., 1993), therefore it is difficult for students to advance their knowledge and skills significantly in a 1-credit hour course. As an example, if one assumes a student participates in the hands-on volunteer activities in the AFL and completes the manufacturing project, the student will have spent about 40 hours volunteering in the AFL and around 10 hours working on their project, for a total of 50 hours of deliberate practice over the course of the semester, which is a long way from the 10,000 hours required to become an expert. But since the course has been in operation since 2013, we have had several (approximately 35) students stay on in the AFL to become Teaching Assistants and continue their work on deliberate practice and become relative experts in the AFL.

Assessment: Development of Learning Objectives

The second step in the backward course design model advocated by Hansen is to "determine how to assess whether students have achieved the learning outcomes" (Hansen, 2011, p. 22). This is done by first identifying the Learning Objectives (LO) for the course, which in this case flow from the overarching goal of the course and the Enduring Understandings. The Learning Objectives for this course are as follows:

By the end of this course, students will be able to:

- LO1: identify appropriate procedures associated with the knowledge and skills needed to utilize manufacturing tools and processes (*).
- LO2: demonstrate the ability access the AFL.
- LO3: demonstrate the ability to work within the AFL's safety culture.
- LO4: generate a design of a part that can be manufactured (*).
- LO5: use manufacturing processes to manufacture a part (*).
  (*) most important

To see how the Learning Objectives align to Curricular Priorities, Table 5 below shows how each Learning Objectives aligns with either an Enduring Understanding item or an Important to Know item.

	Learning Objectives				
Curricular Priorities	**LO1**	**LO2**	**LO3**	**LO4**	**LO5**
Enduring Understanding	X				X
Important to Know		X	X	X	

Table 5: Alignment of Learning Objectives with Curricular Priorities.

The Revised Bloom's Taxonomy, originally developed by Bloom and later modified by Anderson & Krathwohl (Anderson & Krathwohl, 2001), is used to categorize learning objectives based on cognitive and knowledge dimensions. Table 6 below shows how each Learning Objectives fits into this taxonomy.

Cognitive / Knowledge	**Level 1: Remember**	**Level 2: Understand**	**Level 3: Apply**	**Level 4: Analyze**	**Level 5: Evaluate**	**Level 6: Create**
A. Factual			**LO2, LO3**			
B. Conceptual			**LO4**			
C. Procedural		**LO1**				**LO5**
D. Meta-cognitive						

Table 6: The Revised Bloom's Taxonomy and Learning Objectives.

LO1, associated with the knowledge and skills needed to utilize manufacturing tools and processes, is focused on the procedural knowledge that students need to understand in order to be able to use the manufacturing tools and processes. LO2 and LO3, associated with the AFL and how it operates and the behavior expected there, is focused on factual knowledge that students must apply. LO4, associated with students thinking about what manufacturing processes they will use in the design of a part, is focused on conceptual knowledge about manufacturing process that students must apply in their design. LO5, which is the most important learning objective of the course, associated with using manufacturing processes to manufacture a part, is focused on the procedural knowledge that students use to create something new that did not exist before.

Assessment: Development of an Assessment Triangle

Another tool for aligning the content and assessment is the Assessment Triangle championed in book *Knowing what Student Know* (Pellegrino, Chudowsky, & Glaser, 2001). The Assessment Triangle uses three areas (or corners) to check for alignment when creating an assessment. These three corners are cognition, observation, and interpretation. The cognition corner "refers to a theory or set of beliefs about how students represent knowledge and develop competence in a subject domain" (Pellegrino et al., 2001, p. 44). The observation corner "represents a description or set of specifications for assessment tasks that will elicit illuminating responses from students"

(Pellegrino et al., 2001, p. 46). The interpretation corner "encompasses all the methods and tools used to reason from fallible observations" (Pellegrino et al., 2001, p. 48). For this course, the most important Enduring Understanding is EU2: "To develop the ability to use some of the manufacturing tools and processes utilized in the AFL." Figure 4 below shows the Assessment Triangle for this Enduring Understanding.

Observation

Students will do an end of semester project where they design a part of their choice using knowledge of manufacturing tools and processes they have gained and then manufacture that part in the AFL using the actual tools and processes taught as part of the course curriculum.

Interpretation

Design Portion: students will first submit a drawing at mid-semester of the part they intend to manufacture, and will receive feedback for appropriateness of ability to manufacture and complexity.

Manufacturing Portion: students will be evaluated on the following three areas:

- Professional use of the AFL work flow: project submittal, working with AFL staff, etc.
- Use of a minimum of 4 processes/machines in the AFL to demonstrate knowledge of multiple processes.
- Professional documentation of the manufacturing process including any machines and fixtures/set ups used as well as any difficulties experienced during the process.

Assessment Triangle

EU2: To develop the ability to use some of the manufacturing tools and processes utilized in the AFL.

Cognition

A Zone of Proximal Development (ZPD) cognitive approach to learning is used to help students use manufacturing processes in the design and manufacturing a part.

While it has already been established in this document that students need deliberate practice to improve their skills on the procedural knowledge being asked from them in this course, from a cognitive standpoint, students require one-on-one assistance at their skill level and beyond to successfully accomplish the tasks given to them in this course. This is where the following aspects of Vygotsky's ZPD cognitive approach come to fruition in the AFL:

(1) Working just beyond the students' skill set

Students in the course (and in the AFL) are given tasks that are doable but beyond their skill set, requiring them to be in the "zone" that is just beyond both their skill and comfort. This has been shown to be where effective learning occurs.

(2) Scaffolding

Proper scaffolding is a critical element of the ZPD, and students in the AFL are provided scaffolding through written and verbal instruction, and other supplemental instruction options such as video tutorials for specialized training when needed.

(3) Working with a more knowledgeable other

Students working in the AFL are assigned a Teaching Assistant (TA), or a "more knowledgeable other" to work with each student and assist when they get stuck or have questions. Yet the TA is not there to do the work for the student, and the TAs have been instructed how to work with students in their "zone" just beyond the students' skill set for optimal learning.

Figure 4: Assessment Triangle for Enduring Understanding 2.

Assessment: Development of an Assessment Worksheet

Another tool for aligning the content and assessment is the assessment worksheet, championed in the paper by Streveler et al. (Streveler, Smith, & Pilotte, 2012). The assessment worksheet takes a learning objective and lists out the claim of what students will be able to do by the end of the assessment, the task that students are given, and the evidence that students will provide. Table 7 below shows an assessment worksheet for the two most important Learning Objectives in this course, LO4 & LO5.

Objective	Assessment
LO4: generate a design of a part that can be manufactured	**General** An open-ended, summative assessment.
	Claim Students will be able to demonstrate the ability to use manufacturing processes in the design of a part completing an open-ended project requiring students to design a part that is later to be manufactured.
	Task Students will design a part using their knowledge of the AFL machines and/or manufacturing processes taught as part of the course curriculum.
	Evidence Design Portion (10% of project grade): students will submit a drawing at mid-semester of the part they want to manufacture, and will receive feedback for appropriateness of ability to manufacture and complexity. Students will receive full credit for turning in a drawing that is clearly dimensioned per the engineering drawing standards taught in class.
LO5: use manufacturing processes to manufacture a part	**General** An open-ended, summative assessment.
	Claim Students will be able to demonstrate the ability to use manufacturing processes in the design and manufacturing a part completing an open-ended project requiring students to design and manufacture a part.
	Task Students will design and manufacture a part in the AFL using machines and/or processes taught as part of the course curriculum.
	Evidence Manufacturing (90% of project grade): Students will manufacture their part and turn in a short paper documenting the manufacturing process including any machines and fixtures/set ups used as well as any difficulties experienced during the manufacturing process. For the submitted paper, students will be evaluated on the following three areas: - Professional use of the AFL workflow: project submittal, working with

	AFL staff, etc. - Use of a minimum of 4 processes/machines in the AFL to demonstrate knowledge of multiple processes. - Professional documentation of the manufacturing process including any machines and fixtures/set ups used as well as any difficulties experienced during the process evaluated on the criteria of clarity and evidence.

Table 7: Assessment Worksheet for LO4 & LO5.

Assessment: Authentic Assessment Evaluation

Hansen argues that "the only way to assess depth of understanding is to have them perform a task that is identical or similar to what a practitioner in the field has to do when solving a problem, facing a difficult task, or creating a complex product" (Hansen, 2011, p. 87). Hansen lists 6 criteria for an authentic assessment, adapted from Wiggins (Wiggins, 1998). Below, Hansen's 6 criteria are applied to LO5, use manufacturing processes to manufacture a part, to show how authentic assessment is met in this course:

1. Be realistically contextualized:
   The task is realistically contextualized because it asks students to demonstrate an ability to use manufacturing processes in the AFL, requiring students to transfer their knowledge to a real-world context.
2. Require judgment and innovation:
   This task requires judgment and innovation because it challenges students to both design a part to be manufactured, and then requires students to manufacture it. Both of these tasks are typically beyond what a student is able to do on their own, requiring students to figure out some new things for themselves and use judgment.
3. Ask students to "do" the subject:
   This task requires students to "do" the subject, and they will actually be making something by using the manufacturing processes in the AFL. The students will get help along the way to keep them safe, but the students will be the ones "doing" the work. It does not get more real than this.
4. Replicate the challenging situations in which professionals are truly "tested" in the workplace or in their professional life:
   The task replicates the challenging situations in which professionals are truly "tested" for several reasons: first, students' initial designs can almost never be manufactured, requiring students to iterate and work with the AFL to design a part that can be manufactured. Second, none of the students are advanced enough to use the manufacturing process completely by themselves, so they need to seek help and guidance from the AFL staff as they learn and acquire the skills necessary to complete their project. This is part of the Zone of Proximal Development discussed in the Assessment Triangle. Finally, many of the students will not completely finish the manufacturing of their part in the semester (due to the complexity of their design, issues in manufacturing, etc.), but that is not the ultimate goal of the project or the assessment. The students learn that manufacturing is often much more complex that they first imagined.
5. Assess the student's ability to use a repertoire of knowledge and skill:
   This task assesses a student's ability to use a repertoire of knowledge and skill because they are required to use at least four different manufacturing processes (and most use

more than four) to produce their part. Students will learn how important the manufacturing process order is (integrated knowledge) as opposed to the individual knowledge of how a particular process works.

6. Allow appropriate opportunities to rehearse, practice, and get feedback:
   This task allows for appropriate opportunities to rehearse, practice, and get feedback because it is not the final product that is evaluated, but rather the process that is taken to get there. Because of the nature of the tasks, students will have to work closely with the AFL staff and students, receive constant feedback, have opportunities to practice, make mistakes, and not be penalized for it.

Assessment: Rubric for Authentic Assessment

To show the actual details of the how the authentic assessment for LO5 is assessed in this course, the rubric for LO5, use manufacturing processes to manufacture a part, is shown in Table 8 below. Note that this part of the project is graded out of 90 points.

Category	Fully Achieved (2)	Partially Achieved (1)	Underachieved (0)
Professional use of AFL workflow	1) All of the AFL project submittal is done on time, per assignment requirements. 2) The student always follows the AFL code of conduct guidelines and safety contract, and follows the advice and guidance of the AFL staff and TAs. This will be evaluated by AFL staff and TAs during time in the AFL.	1) At least 75% of the AFL project submittal is done on time, and mostly per assignment requirements. 2) The student almost always (>90%) follows the AFL code of conduct guidelines and safety contract, and almost always (>90%) follows the advice and guidance of the AFL staff and TAs. This will be evaluated by AFL staff and TAs during time in the AFL.	1) None of the AFL project submittal is done on time, per assignment requirements. 2) The student does not follow the AFL code of conduct guidelines and safety contract, and does not follow the advice and guidance of the AFL staff and TAs. This will be evaluated by AFL staff and TAs during time in the AFL.
Use of a minimum # of processes/machines in the AFL to demonstrate knowledge of multiple processes	At least 4 processes/machines are used in the manufacturing of the part.	At least 3 processes/machines are used in the manufacturing of the part.	2 or fewer processes/machines are used in the manufacturing of the part.
	Note: feedback will be provided at mid-semester when the engineering drawing is submitted if the part is complex enough to demonstrate knowledge of multiple processes (i.e. at least 4 processes). Part redesign may be required to meet the minimum # of processes.		
Professional documentation of the manufacturing process evaluated	1) A complete (criteria: relevance, subject matter), professional (criteria: clarity, grammar, and	1) A partially complete, mostly professional documentation (at least 75%) of the manufacturing	1) An incomplete, unprofessional documentation of the manufacturing process in

on the criteria of clarity and evidence	punctuation) documentation of the manufacturing process in a pdf report per assignment requirements. 2) Report includes information on any machines and fixtures/set ups used as well as any difficulties (including pictures) experienced during the process.	process in a pdf report, mostly per assignment requirements. 2) Report includes most (at least 75%) of the information on any machines and fixtures/set ups used as well as any difficulties (including pictures) experienced during the process.	a report that is not per assignment requirements. 2) Report does not include the information on any machines and fixtures/set ups used as well as any difficulties (including pictures) experienced during the process.

Table 8: Rubric for LO5 Assessment (Manufacturing a Part in the AFL).

Assessment: Meaningful Assessment Evaluation

Hansen argues that for assessment to be meaningful, it must assess for understanding. Assessment for understanding "requires careful planning and a variety of assessment approaches" (Hansen, 2011, p. 94). Hansen lists 8 principles for meaningful assessment, again adapted from Wiggins (Wiggins, 1998). Below, Hansen's 8 principles, applied mostly to LO5, use manufacturing processes to manufacture a part, show how meaningful assessment is accomplished in this course:

1. Use simulations or real applications:
   The overall assessment plan uses a real application when students choose to design and manufacture a part in the AFL. This task requires students to use knowledge with a purpose and context in mind due to the nature of the required task.
2. Design interactive assessments:
   The overall assessment plan is interactive because it first has a check-in point at mid-semester with the instructor (a part design), and then the manufacturing task pushes students beyond their current capabilities requiring them to interact with others (instructor, staff, and TAs in the AFL, etc.) to accomplish the task.
3. Use reiterative core-performance tasks:
   The overall assessment plan uses reiterative core-performance tasks, specifically the tasks associated with LO1 and LO2, as initial formative tasks early in the semester to build their knowledge in manufacturing tools and processes, followed by a summative task at the end of the semester that builds on their manufacturing knowledge. This will determine if their knowledge is becoming more sophisticated over time.
4. Use assessment tasks that will best evoke inevitability of misconceptions:
   The overall assessment plan uses assessment tasks that will best evoke inevitability of misconceptions by giving students a summative assessment task that is beyond their current knowledge, requiring them to manufacture a part using processes they have not used before. This task will require students to face their misconceptions of manufacturing processes as they encounter new experiences in the process of discovery.
5. Design curricula and build tests around essential questions:
   The overall assessment plan designs the curricula and builds tests around the essential questions of this course, which focuses on what is a manufacturing process. This theme is

constant in all the curricula and assessment of the course, as evidenced by the alignment shown in this document.

6. Use rubrics that measure the degree of sufficiency and the power of answers:
   The overall assessment plan uses rubrics as shown previously, but more importantly is not looking for right answers and wrong answers in the assessment, but rather looking at the thinking and the process that students use to complete the assignment.
7. Require students to self-assess their previous as well as their present work:
   The overall assessment plan requires students to self-assess their previous as well as their present work in the task of the final semester project of manufacturing a part. This task requires students to use their previous work in the course, self-assess their current knowledge and skills, and proceed into unknown territories where they will either have to learn on their own or get help when the task is beyond their skill set.
8. Assess student self-adjustment in response to human or situational feedback:
   The overall assessment plan assesses student self-adjustment in response to human or situational feedback as students receive feedback from the design drawing and are expected to make changes to their final product. In addition, students receive much feedback during their final project as they manufacture their part and incorporate that into their project. Students are assessed on how they interact with the AFL staff (evaluated by the AFL staff and TAs) in a professional manner in term of feedback and direction on their project.

Pedagogy: Making Learning Whole

The third step in the backward course design model advocated by Hansen is to “plan meaningful learning activities” (Hansen, 2011, p. 22). One of the ways this is accomplished in this course is by utilizing an approach devised by Perkins in the book *Making Learning Whole* (Perkins, 2009), where he describes seven principles of learning that help students “learn by wholes.” Perkins describes “learning by wholes” as taking the best of behaviorist, cognitive, and constructivist learning theories and “incorporating [these] various learning theories into a design framework. Learning by wholes is an integrative approach for keeping in mind and keeping in action many key features of learning toward educating well” (Perkins, 2009, p. 17). Below, each of these principles is applied to this course:

1. Principle 1: Play the Whole Game
   Nothing feels like “playing the whole game” more than creating something and then building it, and that is exactly what students will do in this course. By having the experience of designing a part and then manufacturing it, seeing and feeling it “come alive” before their eyes with their own hands, they are literally getting to play the whole game. This task is also a great “junior game,” as it gives the students an experience realistic to what they could very well see in industry, in industry like conditions. This task is also tied to the enduring outcome of “To demonstrate the ability to use some of the manufacturing tools and processes used in the AFL.”
2. Principle 2: Make the Game Worth Playing
   This course uses three approaches to making the game worth playing for students, all targeted toward increasing the motivating the students to learn about manufacturing (i.e. making the game worth playing). First, as described earlier in the document, through the application process, we seek to find students who are very interested in learning about

manufacturing and will likely be willing to put in extra time for volunteer activities. Second, emphasize with the students how the hands-on activities are the best way to learn more deeply about the manufacturing processes and emphasize the support they get in the AFL when they come in to learn and utilize the equipment. And finally, we provide choices to the students in their project in they both get to design any part they want to (we provide guidance to make sure it is not too complex), and they can use any manufacturing process they want to during the manufacturing phase. We have seen that when the students have these choices, they are much more invested in their project and completing it on time.

3. Principle 3: Work on the Hard Parts
   The difficult concepts in this course, discussed previously in this document, are understanding how to use the manufacturing processes (the machines and tools) and how the processes fit together to produce something useful. This course uses two approaches for working on these hard parts for students. First, we provide the opportunity for distributed, deliberate practice for students when they participate in the volunteer activities in the AFL. When students participate in these activities, they get the opportunity for hands-on activities that provide the type of deliberate practice they need that begin to put them on the road toward becoming an expert (or at least an expert relative to other students in the lab). Second, as identified in the cognition corner of the assessment triangle in this document, the AFL is set up to be a Vygotskian "Zone of Proximal Development" environment where students get frequent, actionable feedback from a more knowledge other as the students work in their "zone" just beyond their current skill set. It is acknowledged that if students do not participate in the volunteer activities in the AFL, they will not become as proficient, yet the key point is that they have the opportunity to do so.
4. Principle 4: Play Out of Town
   This course uses two approaches for playing out of town for students. First, focusing on the students' ability to transfer knowledge and skills from the classroom to contexts beyond, the project where students design and manufacture a part requires transfer from the classroom into the lab. The optimal part about this transfer is the change in setting to a more practical lab atmosphere reinforces the concepts that were discussed in class and helps the transfer become solidified through deliberate practice. Second, focusing on the abstraction that happens in other applications, is that a small part of every class is dedicated to a discussion of other applications of either the manufacturing processed being discussed, or a similar manufacturing process they might encounter in industry, but not in the AFL. In addition, when we group of students does a presentation on the prior week's topic at the start of class, one of the criteria is that students must discuss an application not discussed in class, so students are required to find their own abstractions.
5. Principle 5: Uncover the Hidden Game
   There are two hidden games that we focus on with students in this course: (1) the concept of design for manufacturing, which is essentially once students have some fundamental manufacturing knowledge, they should now be much better designers. This topic is covered by spending a whole class period on it later in the semester once students have a solid manufacturing knowledge base. In addition, most students will have experienced how many times they had to modify their design of their own part to make it manufacturable, so the frustration of designing for manufacturing is fresh is their mind.

(2) the knowledge about the order of manufacturing processes to complete a finished part. This knowledge is difficult to teach because it is unique to the part design. Rather, it is something that has to be experienced, which will happen for the students during their project when they manufacture a part.

6. Principle 6: Learn from the Team
   In this course, the students have three opportunities to learn from the team to enhance learning by working with others. First, utilizing the pedagogies of engagement during class time, students will be involved in group discussion together, both as a "Think-Pair-Share" activity and while working in groups on example problems. The "Think-Pair-Share" activity, which is typically held toward beginning of class reviewing the topic of an instructional video (when used) that students are expected to watch before class that introduces the topic to be covered that day, will give the students and opportunity to reflect on their own, discuss it with their classmates, and then the topic of the video will be discussed as an entire class (additional details are provided in the lesson plan). While working in groups on example problems, students will have the opportunity to work in ad-hoc groups (3 – 4 students) to solve example problems that cover the fundamental conceptual understanding of the topic so that the instructor can check for understanding and clear up misconceptions of key points. Second, students will work in groups when they work on their Tag Team Presentation when it is their turn to prepare and make a presentation on the previous class materials. The Tag Team Presentation activity consists of a group of 3 to 4 students making a 5-minute presentation at the beginning of class that covers the key points from the previous week's topic. Beside succinctly covering the topic, students are required to provide an application of the topic not covered in class, and all students must contribute equally to the oral presentation (additional details are provided in the syllabus). Finally, students will work within ad-hoc groups in the AFL when they work with the staff and teaching assistants on their projects (and volunteer activities). Everything in the AFL happens with students working with and learning from others.
7. Principle 7: Learn the Game of Learning
   This course uses two approaches for learning the game of learning. First, focusing on the self-reflection, the students will experience this during the Think-Pair-Share activity and during the Tag Team Presentation activity described in Principle 6 above. Second, focusing on self-regulated learning, students will experience this if they volunteer for the AFL hands-on activities, and during the manufacturing project, as each project is unique and will require unique learning for every student. This combination self-reflection and self-regulated learning will promote opportunity for students to later access the AFL in their career and be more prepared, and life-long learning opportunities for students.

Pedagogy: Sample Lesson Plan

As this course is a 1-credit hour course and only meets once per week for 50 minutes, class time is very precious. Therefore, when possible, the course utilizes a "flipped classroom" model where some of the materials (the initial introductory materials) are presented in a short video outside of class that students are expected to watch. In addition, to facilitate optimal learning, group discussions and student reflections will be utilized in cooperative learning pedagogies.

Table 9 below shows a sample lesson plan. Note that in particular, Perkin's Principles 3, 4 6, 7 are emphasized.

Time Allotted (min)	**Activity**	**Perkin's Principle**
Prior to class (10 min)	Watch Instructional Video: students are expected to watch a short video that will introduce the topic of the Waterjet/Laser Cutter.	4
5	Tag-Team Presentation: a group of students presents a 2-slide summary of the previous week's content. The 5-minute presentation is expected to cover the key points from the previous week's topic. Besides succinctly covering the topic, students are required to discuss an application of the topic not covered in class, and all students must contribute equally to the oral presentation Additional details are provided in the syllabus. • Specific Example: the previous week's content is Tool Identification/Material Selection, which will be the topic of the students' presentation.	6
5	Class Discussion of Tag-Team Presentation: the instructor will lead a class discussion on the Tag-Team Presentation discussing the new application discussed in the Tag-Team Presentation, reinforcing the most important point of the entire lesson, and answering any remaining questions that students have on the topic. • Specific Example: the instructor will reinforce how to calculate feeds and speeds for the tools and materials selected, which is the most important point from the Tool Identification /Material Selection topic.	6
7	Think-Pair-Share on the Content of the Video: individually, students will reflect on the content of the video (2 min) by being prompted about the key learning objective of the video, then pair with another student to share their thoughts (2 min), then some students will share their thoughts with the entire class and we will discuss the key points. • Specific Example: students will be provided with the following prompts/questions: compare and contrast how a waterjet cuts material vs how a laser cuts materials. What materials can be a waterjet cut that a laser can't, and vice-versa? Why?	6, 7
12	Instructor Covers Additional Material: the instructor will cover (through lecture) additional material that that is key to the topic of the day. Key connections and the importance of other topics will be emphasized. • Specific Example: the instructor will lecture about the key points of the basics of how to use the waterjet and laser	3

	cutter in the AFL and key connections to reinforce use of Computer Aided Design (CAD), as both machines require a digital drawing, and introduce Computer Aided Manufacturing (CAM), as both machines require basic CAM to use.	
10	Students Work in Groups on Example Problem: students will work in ad-hoc groups (3 – 4 students) to solve example problems that cover the fundamental conceptual understanding of the topic so that the instructor can check for understanding and clear up misconceptions of key points. • Specific Example: students will be provided with different material examples and geometries and asked to determine if the examples can be processed on the waterjet, the laser cutter, or both, and which process would be better, and to explain why.	6
7	Students Report Solution to Class and Group Discussion: students will report out solutions to the example problems and we will discuss how the solutions we arrived so that all students have the opportunity to understand and ask questions.	6
4	Students Complete Reflection on Class Topic: at the end of class, students will be provided a prompt where they are asked to reflect on the class topic and their understanding of it and how it relates to other knowledge gained in the course. Students will turn this for their attendance grade, and receive full credit for completing it. • Specific Example: students will be given the following prompt to reflect on: How is the cutting speed (feed rate) of the waterjet related to feed rate of a cutting tool we learned about last week in a CNC mill? What key information is needed to know in both situations?	7

Table 9: Sample Lesson Plan for Class 7 (Waterjet/Laser Cutter).

Pedagogy: Elements from the Course Syllabus

Elements relative to the course pedagogy are included from the course syllabus.

Course Goals
ENGR 103: AFL – Intro to Manufacturing explores the field of manufacturing from the perspective of an engineer. This introductory course, geared for First-Year Engineering students, highlights common manufacturing processes utilized within the Artisan and Fabrication Laboratory (AFL). The AFL mimics an industry-like setting with state of the art machines and tooling. Ultimately, after the completion of this course, students should be able to use many of the manufacturing tools and processes in the AFL.

Learning Objectives

Following completion of this course, students will be able to:

- LO1: identify appropriate procedures associated with the knowledge and skills needed to utilize manufacturing tools and processes.
- LO2: demonstrate the ability access the AFL.
- LO3: demonstrate the ability to work within the AFL's safety culture.
- LO4: generate a design of a part that can be manufactured.
- LO5: use manufacturing processes to manufacture a part.

Required Materials

No text is required. Safety glasses are required for all students working in the AFL. Therefore, glasses must be purchased for this course. These are available at campus bookstores, and via a number of online vendors. Safety glasses should be ANSI Z87+ rated. Typically, chemistry lab goggles do not meet this standard. Safety glasses will not be provided by the AFL.

Assessment

There are three main assessments in this course: (1) students will be assessed on their participation in the class to promote a vibrant learning environment via their attendance in class, participation in group and class discussions, and completion of a small group presentation. (2) students will be assessed on their knowledge of the AFL and of background knowledge required to utilize manufacturing tools and process via three short homework assignments during the semester. (3) students will be assessed on their ability to demonstrate their knowledge of manufacturing processes via an end of semester project.

Course Grading/Criteria

There three main assessments in this course will use the following grading percentages and criteria in the determination of the final grade:

Class Participation (30%):

- Attendance in class (15%): attendance in class is required and imperative, as group discussions will be held every week. Three are 13 classes in the semester, with each class being 1/13 * 15% for attendance points. There are no excused absences.
- Participation in group and class discussions (5%): in-class participation is very important for student learning, will be a key part of this class, and it is expected that students participate fully. Students will be evaluated by engagement in in-class activities and discussions and not being distracted by technology (cell phones, computers for working on other things, etc.). Students will be given one warning by the instructor before points are deducted.
- Completion of a small group presentation (10%): students will be assigned to a group at the start of the semester and be expected to present a short two-slide presentation as a group on the topic from the previous class. Students will be assessed on the content (2.5%), professional preparation and presentation per assignment requirements (2.5%), full team involvement (2.5%), and discussion of applications not discussed in class (2.5%). Additional details of the assignment will be provided.

Homework (30%):

- HW1 (10%): students will be assessed on their knowledge of the AFL that requires students to register for the AFL, pass the AFL Safety Quiz and sign the Safety Contract and Code of Conduct, and complete all AFL machine process quizzes for access to the AFL. Full points will be awarded for students that complete all tasks, no points will be awarded unless all tasks are complete. Note: each quiz requires a 100% to pass, but it can be taken as many times as needed to get a 100%.
- HW2 (10%): students will be assessed on their knowledge and skills with engineering drawings and geometrical dimensioning & tolerancing. Student response will be assessed on the criteria of: completion with reasonable answers (10%), completion with unreasonable answers (0%), and no completion (0%).
- HW3 (10%): students will be assessed on their knowledge and skill of materials & tooling selection. Student response will be assessed on the criteria of: completion with reasonable answers (10%), completion with unreasonable answers (0%), and no completion (0%).

Semester Project (40%):
Students will be assessed on their ability to demonstrate their knowledge of manufacturing processes via an end of semester project. Students will design and manufacture a part in the AFL using machines and/or processes taught as part of the course curriculum. At approximately mid-semester, students will turn in their design to be manufactured for feedback from the instructor. Students will then be given permission to begin manufacturing, and at the end of the semester, students will turn in a short paper documenting the manufacturing process including any machines and fixtures/set ups used as well as any difficulties experienced during the manufacturing process. Students will be assessed on the following:
(1) Design Portion (10% of project grade): students will first submit a drawing at mid-semester of the part they want to manufacture, and will receive feedback for appropriateness of ability to manufacture and complexity. Students will receive full credit for turning in a drawing that is clearly dimensioned per the engineering drawing standards taught in class.
(2) Manufacturing (90% of project grade): students will manufacture their part and turn in a short paper documenting the manufacturing process including any machines and fixtures/set ups used as well as any difficulties experienced during the manufacturing process.

<u>Teaching Style and Rationale</u>
This course is designed to be interactive with optimal time for group discussion and reflection to maximize cooperative learning, so it is expected that students come prepared to class and be ready to engage in group interaction and discussion. Most class sessions will follow the following general organization plan below to optimize learning:

1. Prior to Class (10 min): when applicable, students are expected to watch a short video that will introduce the topic to be covered in class.
2. Tag-Team Presentation (5 min): each week, a different group of students will present a 2-slide summary of the previous week's content that focuses on the key aspects of the topic. The 5-minute presentation is expected to cover the key points from the previous week's topic. Besides succinctly covering the topic, students are required to discuss an application of the topic not covered in class, and all students must contribute equally to

the oral presentation. See the Course Grading/Criteria section of the syllabus for more information.

3. Class Discussion of Tag-Team Presentation (5 min): the instructor will lead a class discussion on the Tag-Team Presentation discussing the new application discussed in the Tag-Team Presentation, reinforcing the most important point of the entire lesson, and answering any remaining questions that students have on the topic.
4. Think-Pair-Share on the Content of the Video (7 min): individually, students will reflect on the content of the video (2 min) by being prompted about the key learning objective of the video, then pair with another student to share their thoughts (2 min), then some students will share their thoughts with the entire class and we will discuss the key points.
5. Instructor Covers Additional Material Related to Topic (12 min): the instructor will cover (through lecture) additional material that that is key to the topic of the day. Key connections and the importance of other topics will be emphasized.
6. Students Work in Groups on Example Problem(s) (10 min): students will work in ad-hoc groups (3 – 4 students) to solve example problems that cover the fundamental conceptual understanding of the topic so that the instructor can check for understanding and clear up misconceptions of key points.
7. Students Report Solution to Class and Group Discussion (7 min): students will report out solutions to the example problems and we will discuss how the solutions we arrived so that all students have the opportunity to understand and ask questions.
8. Students Complete Reflection on Class Topic (4 min): at the end of class, students will be provided a prompt where they are asked to reflect on the class topic and their understanding of it and how it relates to other knowledge gained in the course. Students will turn this for their attendance grade, and receive full credit for completing it.

Student Expectations

This is a 1 credit seminar course is should be a fun and engaging way for students to learn about manufacturing. Out-of-class requirements (preparing for class, homework, etc.) are kept to a minimum for optimal learning so that students have time to volunteer for the optional hands-on activities in the AFL, where much of the learning takes place. It is highly recommended (but not required) that students volunteer for the optional hands-on activities in the AFL if one wants to learn deeply about manufacturing processes. It is expected that successful students in this course will exhibit the following traits:

- Show up on time for every class.
- Turn in all work completed to the best of your ability, on time, and with the highest academic integrity.
- Come to class prepared and ready to engage with your classmates and instructor in thoughtful discussion.
- Treat everyone in the class with dignity and respect.
- When working in the AFL, be aware and live up to the safety standards and culture of the AFL (your safety is of utmost importance).

Instructor Expectations

Just as there are expectations for students, you should have expectations for your instructor. In this course, you can expect the following from your instructor:

- Create a learning environment that is welcoming, where students feel they have the right to be heard, and all are respected.
- Assignments will be graded in a fair and timely manner.
- Class materials will be well organized, clear, and available.
- The instructor will answer questions within 24 hours and meet with students as needed to help with issues in the course.

Things to Do to Be Successful in This Course

This course is meant to be fun and exciting, yet at the same time will challenge you. Here is a list of things you can do to help you be successful in this course:

- Attend every class (attendance is critical to both your grade and class discussion)
- Engage with the instructor and AFL staff: ask us questions, seek advice, etc.
- Safety comes first in the AFL. When in doubt, PLEASE ASK!
- Complete all assignments and projects.
- Do not wait until the last minute to start on your manufacturing project. All students (even Senior Design students) underestimate how long it takes to manufacture something. A good rule of thumb is to make your best estimate of how much time you think it will take, then double it, which will be a much more realistic estimation.

Course Schedule

Class	Class Topic	Deliverables Due
1	Intro to AFL/Safety/Lab Tour	
2	What is Manufacturing?	HW1
3	Reading Engineering Drawings/Measuring Tools	
4	Geometrical Dimensioning & Tolerancing	HW2
5	Hand Tools	
6	Tool Identification/Material Selection	Project Design Drawing
7	Waterjet/Laser Cutter	
8	Intro to CNC Programming	HW 3
9	CNC Turning	

10	CNC Milling	
11	Design for Manufacture/Assembly	
12	Intro to Computer-Aided Manufacturing	
13	Advanced Topics in Manufacturing	Final Project

Assessment Data and Student Feedback

Starting first with assessment data for the project in the course, specifically looking at assessment data for the rubric previously discussed in this document for LO5, use manufacturing processes to manufacture a part, is shown in Table 10 below for the Spring 2016 and Fall 2016 semesters.

Semester	**Project Score**		
	0 – 70 pts	**71 – 85 pts**	**86 – 90 pts**
Spring 2016	1 student	1 student	37 students
Fall 2016	1 student	1 student	52 students

Table 10: Assessment Data for LO5 (Manufacturing a Part in the AFL).

Note that almost all students completed the project at a level where they received all of the available points. This is because the assessment is done mostly at a completion level (i.e. checking if a student completed the task successfully), and the fact that the students were highly motivated to complete the assignment as it was both a big part of their grade and they had a lot of fun completing the project.

Next, looking at the overall distribution of grades in the course, the data is shown in Table 11 below for the Spring 2016 and Fall 2016 semesters.

Semester	**Grades**		
	A	**B**	**C, D, F**
Spring 2016	36 students	2 students	1 student
Fall 2016	51 student	2 students	1 students

Table 11: Distribution of Grades for Spring/Fall 2016.

Student feedback for this course is overwhelmingly positive. There are two themes present in the students' feedback on the course:

1. Students expressed how important the volunteer hands-on activities in the AFL were to really understanding the materials discussed in class. They also expressed how much they enjoyed the hands-on activities in the AFL.
2. Students expressed how much the project helped them learn about manufacturing tools and processes by requiring them to both design and manufacture a part. Many expressed how this project was much more work than they anticipated initially, but how it was one of the best educational experiences they have had.

Summary

The preceding describes the development and implementation of a 1-credit hour seminar course for first-year engineering students designed to give an introduction to manufacturing from an engineering perspective by utilizing the tools and processes that are part of the university's "maker space." The course was designed using a backward design model championed by Hansen, which focuses on student outcomes first, then works backward to use these outcomes to design the content, assessment, and pedagogy. Important outcomes from the content design were to focus on the Big Idea and Enduring Understandings of the course, developed by utilizing a content map to help establish Curricular Priorities. Important outcomes from the assessment design were to identify Learning Objectives that aligned with the Curricular Priorities identified in the content design, so that the assessments measured achievement of the Learning Objectives. This was accomplished by using tools such as the Assessment Triangle, an Assessment Worksheet, and designing for authentic and meaningful assessment. Important outcomes from the pedagogy design were to utilize meaningful learning activities that aligned with the content and assessment design. This was accomplished by utilizing the "learning by wholes" approach, and by planning out class schedules that optimized time for group activities and cooperative learning pedagogies. Finally, assessment data and student feedback were shared that showed that students are accomplishing the desired main learning tasks set forth in the course, plus are enjoying and learning along the way.

Future Work

Like almost all courses, this course goes through continuous improvement every semester based on instructor observation and student feedback. After the course, many students express the desire to "continue on" working in the AFL in a volunteer capacity to continue to develop their manufacturing skills, so we have begun to develop "advanced volunteer activities" for students who want to continue working in subsequent semesters. Another area for continuous improvement is the use of the "flipped classroom" model with the use of videos that students watch before class. This is used for some class periods, but not all, and there is clear feedback from students that they prefer more time for group discussion and working on problems in class and less time on the lecture.

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