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Assessment of ABET Student Outcome 7 in Micro and Nano Manufacturing Class

Dr. Sriharsha S. Sundarram, Fairfield University

Dr. Sriharsha Sundarram, PhD is an Associate Professor of Mechanical Engineering at Fairfield and the Brinkman Family Foundation Professor of Micro and Nano Manufacturing. He teaches courses in design, mechanics, and manufacturing. His current research interest is in the area of micro/nano manufacturing, specifically large-scale processing of advanced micro/nano-structured materials with applications in energy, thermal management and biomedicine. He also serves as the technical advisor for Fairfield University's Off Road Racing Team.

Assessment of ABET Student Outcome 7 in Micro and Nano Manufacturing Class

Sriharsha Srinivas Sundarram
Department of Mechanical Engineering
Fairfield University

Abstract

ABET's student outcome 7 requires that students have "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies". The Mechanical Engineering Department at Fairfield University identified ABET 7 as one of the student outcomes that was not addressed by many courses except for senior design. Micro and Nano Manufacturing, a senior elective and graduate level course was identified as one of the courses though which ABET student outcome 7 could be assessed. This was implemented in the form of assignments with different learning strategies: weekly discussion board and midterm project that students work on individually and a group presentation on emerging technologies. This paper discusses the implementation of these assignments and student performance on each of these assignments in three sections spread across 2023 and 2024. The weekly discussion and group presentation on emerging technologies focus on the acquire knowledge sub outcome whereas the midterm project focuses on both the sub outcomes, acquire and apply. The weekly discussion board requires students to answer two questions relevant to the class topics' by finding journal articles published in the last 3 years that address the issue at hand. The group presentation requires the student groups to present on one emerging technology and the information can be obtained from a variety of sources such as journals, magazines, and technical reports. The midterm project requires students to research and understand the working mechanism of a micro fluidic mixer and apply the knowledge to design a serpentine micromixer. Student performance on each of these activities is rated as either Poor, Below Expectation, Meets Expectation, and Above Expectation. The assessment data shows that the percentage of students achieving Meets and Above Expectation on the apply and acquire sub outcomes of ABET 7 is above the departmental threshold of 75%. The assessment data shows that further work is needed in weekly discussion board on citing sources properly and in midterm project on identification of correct components, both of which are specific to this work.

Corresponding Author: Sriharsha Srinivas Sundarram, ssrinivassundarram@fairfield.edu

Introduction

ABET changed the definition of student outcomes (SO) in 2017 and went from a – k to 1 – 7. One of the changes in this process was the replacement of the student outcome k, "recognition of the need for, and an ability to engage in life-long learning" with 7, "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies". Multiple studies have reported on the assessment methods for ABET SO 7 and the approaches vary significantly based on the context. One approach to assess ABET SO 7 is the information literacy

approach whereas the other approach is based on lifelong learning. McCullough and Wigal [1] used a survey to assess the information literacy of students. The survey assessed student preferences in "searching for information, awareness of potential indicators of source reliability, ability to conduct effective and efficient searches of electronic databases, and proper citation of different types of references". Mynderse [2] also employed the information literacy approach and assessed ABET SO 7 as 2 sub-outcomes in a Measurement Systems course. The acquire new knowledge sub outcome was assessed on indicators of obtaining sources, assessing the quality of information, and citing sources; whereas, the applying new knowledge outcome was assessed on problem solving indicators. Szatmary [3] presented a set of tools for assessment of ABET SO 7, with special emphasis on assessment in a capstone class. The article suggests that ABET 7 goes beyond information literacy. Watkins [4] discussed implementation of ABET SO 1 – 7 outcomes in a two-semester capstone design class. In specific, ABET SO 7 was assessed during the first semester. Battastini and Kitch [5] separated ABET SO 7 into 2 key performance indicators: (i) "display an awareness that education is continuous beyond classroom and an understanding for how to apply that new knowledge" and (ii) "select learning strategy suited for the acquisition of needed knowledge". Tsai and Jannsen [6] reported on the collaboration between departments of Mechanical Engineering and Library on assessment of ABET SO 7. The goal was to incorporate information fluency into the curriculum by developing assignments that require students to locate, evaluate, and apply information in an efficient and ethical manner. As seen from the above discussion, majority of the schools have implemented assessment of ABET SO 7 through some form of an assignment.

The Mechanical Engineering Department at Fairfield University switched from the old a – k outcomes to the new 1 – 7 outcomes in 2018. A need was identified for additional courses to address ABET SO 7 as it was being addressed only by the senior design course. Micro and Nano Manufacturing, a senior and graduate level cross listed course was identified as one of the courses in which ABET SO 7 could be assessed. This article discusses the implementation of this initiative which adopts an information literacy approach and the corresponding assessments.

Course Information

Micro and Nano manufacturing has been offered at Fairfield University since Spring 2016. The pre requisites for this course are Materials Science, Chemistry I, and Physics II. The course comprises of 26 meetings, each 75 min in duration. Out of the 26 meetings, 5 meetings are reserved for labs and 2 meetings for the final project presentation. Until 2021, the main assignments were home works, midterm project, lab workshop reports, and final project. With the change to new ABET student outcomes 1 - 7 and the need for the Mechanical Engineering program to have additional courses to assess ABET 7, new assignments were developed along with revisions to the existing assignments. The revised course learning outcomes upon incorporation of the new assignments and the corresponding mapping to ABET SO 1 – 7 is provided below, with the new assignments and assessments discussed in the following sections.

1. Explain micro/nano manufacturing principles and terminology = “ABET SO 7”
2. Develop process plans for fabricating parts with small feature sizes = “ABET SO 2”
3. Justify selection of a particular fabrication technique for a given application = “ABET SO 2”
4. Produce effective reports = “ABET SO 3”

Weekly Discussion Board

The weekly discussion board replaced the homework assignments. As part of the weekly discussion board, students are asked to answer 2 questions relevant to the class topics’ by finding journal articles published in the last 3 years that address the issue at hand. Students submit an eight-to-ten-line response for each question including any relevant schematics, graphs, and equations. A total of 9 discussion boards are assigned which correspond to the topics shown in Table 1. Sample questions from each week are also included in Table 1.

Table 1. Weekly discussion board topics and sample questions

Week	Topic	Sample Question
1	Introduction to micro and nano systems	Identify a Polymer Lab on Chip device and provide a summary on fabrication and operation of the device.
2	Material issues in micro and nano manufacturing	Provide a summary of an article where size effect in micro/nano manufacturing is discussed.
3	Metrology	Discuss an application where surface roughness dictates the performance.
4	Principles of micro and nano fabrication	Provide a summary on state of soft lithography. Include information on: principle of fabrication, materials commonly used, smallest feature size, and applications.
5	Lithography	Provide a summary on status of extreme UV (EUV) lithography technique. Include information on: smallest feature size that can be made and constraints in developing/adopting extreme UV lithography technique.
6	Laser micro machining	Find one application of laser nanofabrication. Provide a summary including schematics.
7	Mechanical micro machining	Provide a summary of an article that discusses on minimum chip thickness determination in mechanical micro machining. Include any relevant equations.
8	Nano imprinting	How would you fabricate a PMMA structure that has a conical profile with a height of 150 μm and a 20° angle using soft lithography?
9	Polymer nanocomposites	Pick a nano particle not discussed in class and provide a summary including (a) dimensions, (b) manufacturing technique, (c) property enhancements that can be achieved, and (e) applications.

Majority of the students are exposed to these topics for the first time in this course unless they have had some exposure as part of their internship or in the workplace. Hence, this assignment clearly ties into the *ability to acquire knowledge using appropriate learning strategies* portion of ABET SO 7. In order to prepare students for the weekly discussion board, the instructor guides the students on using the library website during the first lecture. The aspects covered as part of this tutorial are different approaches to finding articles: search with either keywords, author name, or title of the paper. Students are taught to evaluate the quality of the journal by using metrics provided by Scimago, especially the quartile of the journal. In addition, students are taught to use a citation tool, Zotero, to cite sources either in ASME or IEEE style. Students are reminded that any submissions without proper citations will be severely penalized.

Midterm Project – Design and Fabrication of a Micromixer

Micro mixing process is widely encountered in drug synthesis and processing. This is necessitated by the fact that more than one drug needs to be combined to synthesize a new drug. The typical volumes of the drugs used are in the micro/nano liter range. It is a challenge to obtain effective mixing at this scale range because the flow regime is dominated by laminar flow. In order to overcome this issue, a variety of micromixers have been designed and fabricated by various research groups around the world [7]. There are two broad categories of micromixers: active and passive. Active micromixers use an external force to achieve mixing whereas passive mixers require no external force. The different ways in which active and passive mixing can be achieved is briefly discussed in class with suitable examples and schematics. The project focusses on design of a serpentine micromixer, a passive micromixer. This is a 3D micro mixer in the sense that apart from mixing in the planar surfaces, the fluid travels along the normal direction too.

This project focusses on both sub outcomes of ABET SO 7: *acquire* and *apply* knowledge. Students are provided a handout with complete details on the project. In order to prepare students for this project and enable them to acquire the requisite knowledge, the handout includes images of serpentine micromixers as shown in Figure 1 [8], [9]. In addition to this example, students are provided few other references of commercially available micromixers. Majority of these designs are for mixing either 2 or 3 fluids. Hence, the knowledge gained from this portion of the project will be applied to design a mixer with capability of mixing 4 inputs.

The problem statement for the project is as follows: The goal is to develop a serpentine micromixer with the capability of mixing four inputs. The overall size of the mixer needs to be within 40 mm (L) * 10 mm (H) * 40 mm (W) with a maximum permissible channel width of 300 μm and at least 10 directional changes. The device must be fabricated from either a transparent material or have a transparent cover to be able to view the fluids and use a camera to take photographs. The connections to the device must utilize commercially available connectors such as luers, push to connect fittings etc. that are biocompatible.

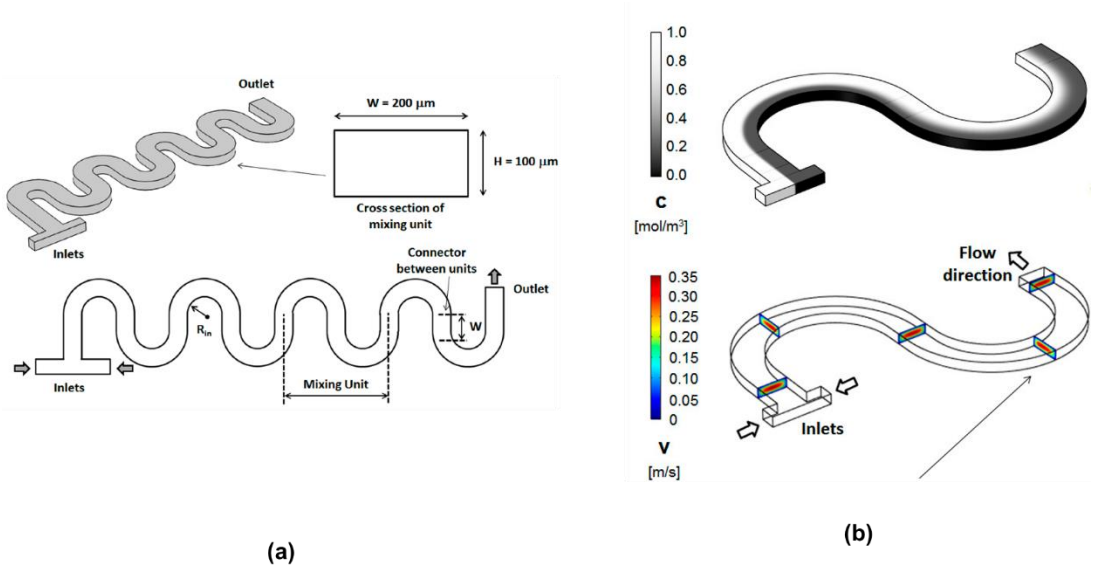

Figure 1. Examples of serpentine micromixers (a) multiple [8], and (b) single mixing unit [9]

1. Design a serpentine micromixer with the capability of mixing four fluids.

a. Provide a solid model (Solidworks/CATIA) of your design with inlets, outlet, and all relevant dimensions clearly indicated.
b. Explain the working principle of your micromixer detailing the main mechanism responsible for effective mixing.
c. Provide details of any device at the macro scale that provided inspiration for this design.

2. Provide a detailed process plan to fabricate the proposed design including information on:

a. Material (’s) from which the mixer is manufactured.
b. Relevant processing conditions for each step such as temperature, tool speed, etc.
c. Discuss the reasons behind choosing the particular manufacturing approach.
d. Provide vendors from which the connectors would be sourced including the part number and cost.

3. Comment on what a typical Reynolds number would be for flow within a serpentine micromixer.

4. Devise an experiment to evaluate the mixing efficiency of your design emphasizing the specific fluids chosen.

5. Search literature to find an equation that enables to quantify the mixing efficiency. Discuss the equation.

Figure 2. Project deliverables

The first phase of the project focuses on acquire knowledge sub outcome of ABET SO 7. Students utilize the provided references and further identify journal articles and other commercially available products to acquire knowledge on the operation of a serpentine micromixer. This first step counts as the information literacy aspect of the project. With this acquired knowledge, students apply it towards designing a micromixer. It has to be noted that the apply portion of the project still has an information literacy aspect to it as discussed in the next paragraph. The prompts provided to students for the project deliverables are shown in Figure 2.

Students design the serpentine micromixer using the knowledge gained from the articles and commercial products identified as part of their literature review. Students work on the design using a CAD package of their choice, but majority of them use SolidWorks as the school has license for this software. Students are also required to discuss the mixing mechanism in their design which once again ties into the literature review aspect of the project. The above two steps are the requirements for Item 1 of the project deliverable. The project is due around the 7th week of a 14-week semester and at that point in time, lithography, laser machining, and mechanical micromachining are covered in class. In addition, students work on laser machining and mechanical micromachining as part of the lab workshop. These experiences allow students to identify a suitable fabrication approach from the above three methods and they develop the process plan. In order to derive the process plan, students will be required to identify sources such as journal articles and product data sheets to identify the relevant process parameters beyond what was covered in the class. As part of Item 2 of the project deliverable, apart from the process plan, students also need to identify vendors for either luers or push to connect fittings that are biocompatible. Majority of the students have not used either of these connectors previously and this requires them to learn about these types of connectors and look up product data sheets to obtain dimensions and incorporate into their design. Items 3 and 5 focus on the acquire knowledge aspect whereas item 4 focuses on apply aspect of ABET SO 7. For the Spring 2024 semester, based on feedback from previous cohorts, a micro mixer fabrication component has been added to the project. Students work in the machine shop and fabricate a simple micromixer using mechanical machining.

Presentation on Emerging Technologies

Students form their own groups for the labs, typically either 3 or 4 members depending on the class size and the same group works on this presentation. Student groups pick a topic of their choice and discuss a new fabrication method or an application where micro/nano manufacturing techniques play an important role. The source can be journals, magazines, white papers, or technical reports with the only requirement that the article be less than two years old. The field of micro and nano manufacturing is constantly evolving and the goal of this exercise is to enable students to identify the latest advancements in this field and report on it to their peers. Some of the topics that students have presented on include: state of the art in drug delivery devices, micro and nano surface topology modifications, fabrication of hierarchical structures by laser interference lithography, and micromotors. Students give a 20-minute presentation

summarizing the results and these presentations are scheduled weekly once towards the latter half of the semester.

Assessment Method and Results

The deliverables for each of the three assignments are different as seen in the previous section. For the weekly discussion board, students submit a 6 – 8 line summary for each of the two questions. The weekly discussion boards are typically due a week after the topic has been covered in class. There are 9 weekly discussion boards and they account for 20% of the final grade. The mapping between the learning objectives for the discussion board and the ABET sub outcomes is shown in Table 2. The midterm project is assigned a month in advance and students work on it individually at their own pace. The midterm counts for 25% of the final grade. The mapping between project deliverables and ABET sub outcomes is shown in Table 3. The presentation on emerging technologies counts for 5% of the grade.

Table 2. Mapping of weekly discussion board learning objectives to ABET 7 sub outcomes

Learning Objective	ABET 7 Sub Outcome
1. Identify and utilize sources	An ability to acquire new knowledge using appropriate learning strategies
2. Cite sources	
3. Understand micro and nano manufacturing principles and terminology	

Table 3. Mapping of project deliverables to ABET 7 sub outcomes

Project Deliverables	ABET 7 Sub Outcome
1. Understand and explain working principle of micro mixer	An ability to acquire new knowledge using appropriate learning strategies
2. Identify luers and push to connect fittings	
3. Identify Reynolds number	
4. Identify equation to quantify mixing efficiency	
5. Design serpentine micromixer with capability of mixing four fluids	Apply new knowledge as needed
6. Detailed process plan with relevant processing conditions	
7. Devise experiment to evaluate mixing efficiency	

Student work is graded and based on their score on the individual components of the rubric, it is rated as either **P**oor (< 60%), **B**elow expectation (60 – 75 %), **M**eets expectation (75 – 90 %), or **A**bove expectation (90 – 100 %). The threshold set by the department for all course assessments is 75% of the students scoring above 75%, which was used to come up with the student rating indicators. The student enrolment data for the sections included in this report and the results of assessment are provided in Tables 4 - 7. It has to be noted that for the Spring 2024 semester, students are yet to submit their midterm projects and hence that data is not available. Also, all groups performed well on the emerging technologies presentation (received full score) and hence the assessment data is not presented. Tables 5 and 6 provide the assessment data from weekly discussion and midterm project respectively for the different components that are being evaluated to assess ABET SO 7. On the other hand, Table 7 provides overall assessment data for the acquire and apply sub outcomes of ABET SO 7.

Table 4. Student enrolment data

Semester	Enrolment
Spring 2023, Section A	19
Spring 2023, Section B	16
Spring 2024	16

Table 5. Assessment results for weekly discussion. Data shown as percentage of students.

Learning Objective	Spring 2023, Section A				Spring 2023, Section B				Spring 2024			
	P	*B*	*M*	*A*	*P*	*B*	*M*	*A*	*P*	*B*	*M*	*A*
1 Identify sources	0	10	16	74	0	7	20	73	0	0	7	93
2 Cite sources	0	32	15	53	0	33	27	40	0	27	27	46
3 Understand principles	5	4	21	70	12	6	28	54	1	6	15	78

Table 6. Assessment results for midterm project. Data shown as percentage of students.

Project Deliverables	Spring 2023, Section A				Spring 2023, Section B			
	P	*B*	*M*	*A*	*P*	*B*	*M*	*A*
1 Understand principle	0	0	5	95	0	0	12	88
2 Identify components	0	21	5	74	0	13	13	74
3 Identify Reynolds No.	0	0	0	100	0	0	0	100
4 Identify equation	0	0	0	100	0	0	0	100
5 Design micromixer	0	5	26	69	0	19	44	37
6 Develop process plan	0	0	42	58	0	6	81	13
7 Devise experiment	0	0	0	100	0	0	0	100

Table 7. Overall results for ABET 7 sub outcomes. Data shown as percentage of students.

Learning Objective	Spring 2023, Section A				Spring 2023, Section B				Spring 2024			
	P	*B*	*M*	*A*	*P*	*B*	*M*	*A*	*P*	*B*	*M*	*A*
1 Acquire	1	9	9	81	2	8	14	76	0	11	16	73
2 Apply	0	2	23	75	0	8	42	50				

The data from the weekly discussion board shows that even though majority of the students have identified the right sources, they did not cite them properly. For example, in Spring 2023 Section A, only 11% of the students were Below Expectation in identifying sources whereas 32% of students were Below Expectation in citing sources. A similar trend is observed in Spring 2023 Section B and Spring 2024. The percentage of students achieving Above and Meets Expectation for citing sources is below the departmental threshold of 75% for all the classes. In order to address this, additional emphasis is being placed on conveying the need to use a citation tool for reference management. On the other hand, more than 90% of students have achieved Above and Meets Expectations for understanding principles which implies that students have found the right articles and answered the questions.

The data from the midterm project is in contrast to the weekly discussion board. It appears that since students have around a month to work on the midterm, their performance is generally better as they take their time to complete the project. The percentage of students achieving Above and Meets Expectation is above the departmental threshold of 75% for all the components being evaluated. It has to be noted that 100% of the students achieved Above Expectation on Items 3 and 4 of project deliverables, which focused on identification of Reynolds number and mixing efficiency equation. There are two areas where more than 15% of the students were Below Expectation; identifying connectors in Spring 2023 Section A and design of micromixer in Spring 2023 Section B. In order to address this, the instructor is providing additional information in the class during the discussion of the midterm project to setup the expectations and help steer students in the right direction.

Table 7 provides cumulative data on the attainment of the two sub outcomes and it can be seen that all the sections have met the threshold of 75% of students achieving Meets and Above Expectations. Delving further into the data, the percentage of students achieving Meets and Above Expectation is almost similar for both the sub outcomes. This implies that students were not only able to acquire knowledge but also apply it.

Conclusions

The paper presented the assessment of ABET student outcome 7 in micro and nano manufacturing, an upper-level and graduate cross listed mechanical engineering course. Student work on weekly discussion board, midterm project, and emerging technology presentation was assessed using a rubric and mapped to ABET 7 sub outcomes. The assessment data shows that the

percentage of students achieving Meets and Above Expectation on the two ABET 7 sub outcomes is above the departmental threshold of 75%. The data also identified areas for improvement such as citing sources and component selection, which are specific to the project that was implemented.

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