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WIP: Student-Guided Project for Measurement System Development with ABET and EM Assessment

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WIP: Student-Guided Project for Measurement System Development with ABET and EM Assessment

Abstract

A team-based student project in a new Measurement Systems course is presented with assessment for both ABET Student Outcome 6 and demonstration of behaviors associated with an entrepreneurial mindset. The technical assessment aligns with ABET Student Outcome 6 by splitting the outcome into six sub-outcomes and assessing each on a rubric for student project reports. This method allows each sub-outcome to be measured, evaluated, and reported. After three semesters, all student teams were performing at or above minimal level, but more study is warranted. The entrepreneurial mindset assessment is performed using a student survey to self-identify the extent to which example behaviors associated with an entrepreneurial mindset were demonstrated. Survey data was only available for one semester in which the project was adjusted for COVID-19. Student responses to questions about the open-ended and real-world nature of the project and demonstration of example behaviors associated with curiosity had mixed results. Students did demonstrate a number of example behaviors associated with other dimensions of an entrepreneurial mindset. Additional data will be collected in the coming semesters.

Introduction

The Mechanical Engineering faculty at Lawrence Technological University (LTU) added a new required three-credit course to the Bachelor of Science in Mechanical Engineering (BSME) program called "Measurement Systems" in Fall 2018. This course was created to address a faculty-identified curriculum weakness related to student understanding and application of instrumentation. It was also intended to improve student preparation for dynamic systems and controls. Measurement and instrumentation courses are often included in engineering curricula either as a stand-alone course [1, 2] or in conjunction with other topics in the curriculum [3, 4]. This course was developed as a stand-alone course to supplement existing lab courses on mechanics, thermal sciences, and mechatronics.

Concurrently with the development of the new Measurement Systems course, the LTU BSME program moved from the now defunct ABET Student Outcomes a-k to the new ABET Student Outcomes 1-7 for the 2019-2020 academic year. The new Measurement Systems course was identified as an appropriate course to assess ABET Student Outcome 6 that states that students will have "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" [5]. This outcome differed slightly from the previous Student Outcome b; thus, a new assessment was developed.

A final significant factor in the course development was the multiyear effort at LTU to incorporate entrepreneurial education throughout the engineering curriculum [6, 7, 8]. As a partner school in KEEN, LTU uses the KEEN framework to define an entrepreneurial mindset

(EM) [9]. Entrepreneurially minded learning (EML) activities, as championed by KEEN, combine problem-based or project-based learning activities with student skills associated with an entrepreneurial mindset. For example, these additional skills might include integrating information from many sources to gain insight, conveying engineering solutions in economic terms, and identifying unexpected opportunities to create value. EML activities emphasize "discovery, opportunity identification, and value creation with attention given to effectual thinking over causal (predictive) thinking" [10].

Within engineering and the KEEN framework in particular, an entrepreneurial mindset is not the same as entrepreneurship. Unlike business schools that have historically focused on wealth-creation or firm-creation [11], the engineering-specific entrepreneurial mindset is about thinking like an entrepreneur. This means the application of the KEEN framework to engineering practice, but not necessarily the creation of new business [12].

In this work, a course project to develop a measurement system for the purpose of addressing a student-created problem was implemented. This scaffolded, multi-week project serves as a summative experience in the newly developed Measurement Systems course. In addition, the project provides students with an opportunity to explore their curiosity. Student work was assessed for ABET Student Outcome 7. A post-survey was used to assess student perceptions of their own demonstration of an EM. The ABET assessment reflects student learning and the EM assessment reflects student behaviors.

The ABET and EM assessments are used to address three research questions. First, are students meeting ABET Student Outcome 7? Second, does the self-directed project appeal to students and result in demonstration of student curiosity? Third, what other dimensions of an EM are demonstrated during the self-directed project?

Measurement Systems Course Organization

The course under consideration, EME 3653 – Measurement Systems, was created as a third-year (i.e., junior-level) required course for students enrolled in the LTU BSME program. Measurement Systems was developed with two prerequisites (Differential Equations and Circuits & Electronics) and one corequisite (Probability & Statistics), as shown in Figure 1. Mechatronics, a course focused largely on dynamic system modeling and control, moved from having Circuits & Electronics as a prerequisite to having Measurement Systems as a prerequisite. Other courses, including the capstone sequences (Competition Projects 1 and Industry Sponsored Projects A) and Mechanics Lab, now include Measurement Systems as a corequisite.

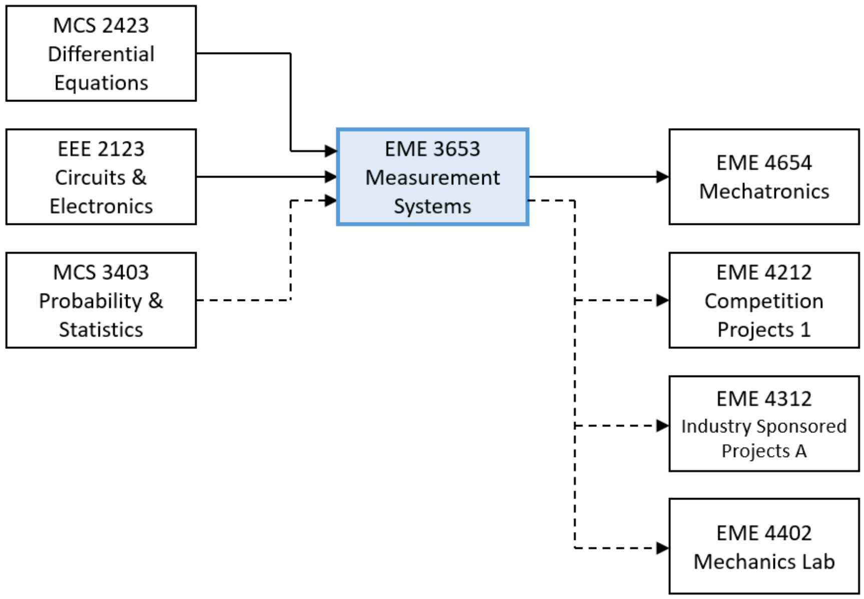

Figure 1. Measurement Systems with prerequisite courses (solid arrows), corequisite course (dashed arrows), and following courses in BSME program

The course development started from a set of course-wide learning objectives, provided below. A more detailed list of section-by-section learning objectives with associated Bloom's taxonomy levels are provided to students with the course syllabus. These section-by-section learning objectives are provided in Appendix A.

At the end of this course, students should be able to:

- Conduct uncertainty analysis
- Perform basic statistical treatment of experimental data
- Distinguish between signals and systems
- Analyze signals in time and frequency domains
- Describe the effects of noise and filters on measured signals
- Apply digital computational tools to solve measurement problems
- Design measurement systems that include transducers, signal conditioning elements, and digital data acquisition
- Design and implement experiments utilizing measurement systems common to mechanical engineering
- Explain the importance of measurement systems to modern society

Measurement Systems sessions are held two days per week during the 16-week semester. In most weeks, the first session is a two-hour lecture and the second session is a lab experiment that reinforces lecture concepts. There are also three projects spaced through the semester. The projects are described in more detail below. The Spring 2021 course schedule is shown in Figure 2. Due to COVID-19, the Spring 2021 semester did not include a spring break.

Week		Class Period 1 (2 hours)	Class Period 2 (2 hours)
1	01/18/21	Introduction / Digital Computational Tools / Circuits Review	Lab 1: Digital Computational Tools / Circuits Review
2	01/25/21	Signals and Systems, Components, Static Calibration	Lab 2: Tranducers & Calibration
3	02/01/21	Digital Data Acquisition	Lab 3: Digital Data Acquisition
4	02/08/21	Group Project: Strain Gages	Group Project: Strain Gages
5	02/15/21	Statistical and Uncertainty Analysis	Lab 4: Uncertainty Analysis
6	02/22/21	Time Domain Analysis	Lab 5: Time Domain Analysis
7	03/01/21	Frequency Domain Analysis - Signals	Lab 6: Frequency Domain Signal Analysis
8	03/08/21	Frequency Domain Analysis - Systems	Lab 7: Frequency Domain System Analysis
9	03/15/21	Self-Directed Problem Formulation	Group Project: Data Acquisition Platforms
10	03/22/21	Group Project: Data Acquisition Platforms	Group Project: Data Acquisition Platforms
11	03/29/21	Noise and Filters	Lab 8: Noise & Filters
12	04/05/21	Modulation / Demodulation / Amplifiers	Lab 9: Modulation / Demodulation / Amplifiers
13	04/12/21	Data Processing, Validation, and Presentation	Lab 10: Data Processing
14	04/19/21	Group Project: Self Directed	Group Project: Self Directed
15	04/26/21	Group Project: Self Directed	Group Project: Self Directed
16	05/03/21	Final Exam	

Figure 2. Spring 2021 course schedule

Because the lecture and laboratory elements are components of a single section, class size is capped at 16 students per section to accommodate available laboratory equipment. As a new course, initial offerings were counted as elective credit and enrollment was low. Since Fall 2020, both daytime and evening sections are offered to accommodate a mix of traditional and working students. Adjunct faculty teach evening sections while full-time faculty and staff teach daytime sections. The class is offered in both Fall and Spring semesters. The list of course offerings with instructor, timeslot, and enrollment is shown in Table 1.

Table 1. Course sections considered in this work

Semester	Instructor	Timeslot	Enrollment
Fall 2019	Full-Time Faculty (M)	Daytime	7
Spring 2020	Full-Time Faculty (M)	Daytime	12
Fall 2020	Full-Time Staff (K)	Daytime	13
	Adjunct Faculty (S)	Evening	4

Team Projects 1 and 2

The first project is a self-directed exploration of applying strain gages to a beam. Students must first identify sources for answering comprehension-level questions regarding the strain gage and bridge circuit. For instance, "In your own words, define the gage factor and describe why it matters" or "In your own words, describe the purpose and process of balancing the bridge circuit". Next, students analyze the bridge circuit to derive relationships between strain and voltage for the quarter and half bridge configurations. Then, students install a strain gage onto a provided aluminum beam. The basic process is provided but much more detail is available from instructions [13] and videos [14] posted at StrainBlog. Finally, students build a bridge circuit, install the beam in a cantilever fixture as shown in Figure 3, and calibrate the system with known masses. An amplifier is not used because the topic has not been introduced yet in lecture. This project is assessed for ABET Student Outcome 7: “an ability to acquire and apply new knowledge as needed, using appropriate learning strategies” [5].

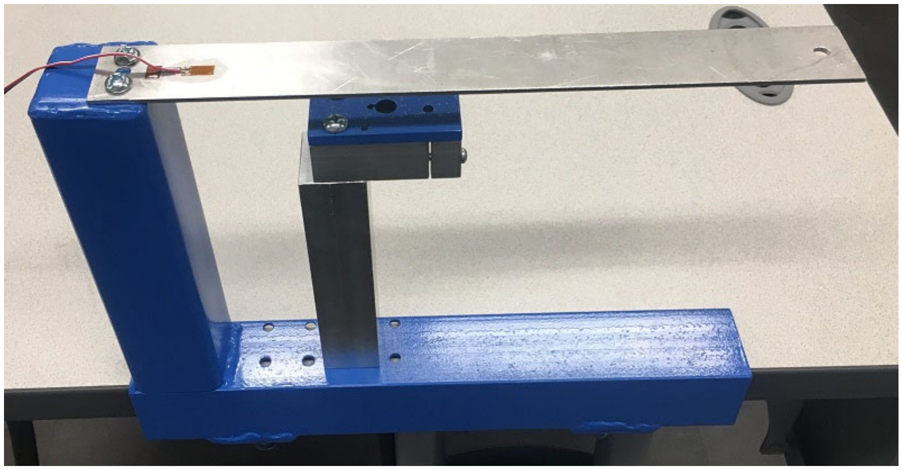

Figure 3. Aluminum beam in a cantilever fixture with installed strain gage.

The second project uses condition monitoring applied to bearing vibration as a means for exposing students to data acquisition and accelerometers. Students develop a simple LabView VI to collect data with an NI myRIO. Next, students implement a more complex VI that is provided by the instructor. The students calibrate the accelerometer and collect data from a bearing block while the motor spins. Students use FFT to make a judgement as to whether or not the bearing is damaged.

Self-Directed Team Project

This self-directed team project is structured to assist students with problem formulation. The project plan is as follows: individual curiosity identification, individual curiosities shared with team, team project proposal and instructor feedback, team project execution and reporting.

Students are provided with a list of project requirements that connect to the course learning objectives. These requirements are:

a. Experiment planning or data processing must include uncertainty analysis.
b. Measurement system must include a transducer, signal conditioning, and signal acquisition.
c. Measurement system must be calibrated.
d. Measurements must be accurate and precise (within reasonable limits).
e. Measurement system must be used to answer (or attempt to answer) a problem posed by students

First is the individual curiosity identification. Students are provided with a handout that explains, “Leonardo da Vinci made lists throughout his life of interesting observations that he hoped to someday follow up on. One of the most peculiar was to study the tongue of the woodpecker (which only later was found to be quite interesting as a buffer for the brain against the repeated pecking). What things do you find yourself being most curious about? Identify 3-5 big picture topics. For each topic, make a list of at least 5 small curiosities that you would like to explore. Unlike in da Vinci's day, you can probably look these up. As you do, add more to the list. Repeat until you have 5 curiosities that don't have a quick and easy 'answer'." Students are further instructed to rank their curiosities from favorite to least favorite. These will be shared with their project team in the next step. Use of a da Vinci list [15] to elicit individual student questions could be replaced by an in-class QFT with question forming session [16]. This was not done due to the limited number of available class sessions.

Using an in-class session, each student presents their favorite curiosities to their project team in a short elevator pitch. Requiring all students to pitch their curiosities is an effort to ensure that all voices are heard and that teams are not led by only the loudest or most self-confident students. Student teams select their collective favorite curiosity from those that were presented, some combination of those presented, or something completely different.

Each team submits a project proposal based on their collective favorite curiosity. A minimum set of questions to be addressed is provided:

a. What is the problem that you want to investigate? Why is this problem relevant?
b. What is the specific question to be answered? How does it relate to the problem?
c. What knowledge or information resources do you need?
d. What components or equipment resources do you need?
e. How much will your measurement system cost? This is an estimate, but be reasonable.

The team proposal is used by the instructor to both evaluate the project for feasibility and provide initial guidance. This soft scaffolding [17] can be invaluable in keeping students from getting stuck.

Finally, the students design and implement a measurement system to help answer their curiosity. A variety of laboratory resources are available to avoid limiting student design ideas. Four class sessions over two weeks are provided for project work and additional lab access is possible, depending on instructor availability. A written report is submitted with the students' findings.

Entrepreneurial Mindset in Measurement Systems

The KEEN framework begins with the "three Cs" of Curiosity, Connections, and Creating Value [9]. Each element is supported by two example student behaviors that describe typical actions displayed by those operating with an entrepreneurial perspective. For instance, Curiosity is demonstrated by "explore a contrarian view of accepted solutions" and Creating Value is demonstrated by "identify unexpected opportunities to create extraordinary value." The framework continues from the three Cs to Engineering Thought and Action, Collaboration, Communication, and Character. As with the three Cs, each concept is supported by example student behaviors. In total, the framework includes 18 example student behaviors.

In this work, the second research question focuses on Curiosity and the associated example student behaviors: "demonstrate constant curiosity about our changing world" and "explore a contrarian view of accepted solutions". Using project topics that were selected by (and hopefully personally meaningful to) the students themselves is expected to nurture and sustain student curiosity [18, 19]. Instructor questions and feedback were expected to both encourage exploration and prompt contrarian views.

Successful completion of the project, regardless of the student-selected topic, will likely require additional knowledge beyond what is provided in the lectures and labs, persistence through failure, and teamwork. Identification of the other example dimensions of an EM demonstrated over the course of the project is reflected in the third research question.

Assessment Methods

Assessment came in two forms: ABET Student Outcome 6 and demonstration of behaviors associated with an EM. The ABET assessment used a rubric that was applied to student written reports. The EM assessment used a student survey at the completion of the project. Each is described below.

The ABET assessment was created first and data is available for Fall 2019, Spring 2020, and Fall 2020 semesters. The EM assessment was created later and preliminary data is available for the Fall 2020 semester. This is summarized in Table 2. Two limitations appear in the data collection. First, one instructor in Fall 2020 did not collect any data. Second, COVID-19 obviously affected data collection. After LTU went online in Spring 2020, physical experimentation was not possible and only data from the planning stages of the project is included. As planned, LTU again went online for the last few weeks of Fall 2020 and all data was collected. However, much of the experimentation was done off-campus and the project quality suffered.

Table 2. ABET and EM data collection.

Semester	Instructor	ABET Data	EM Data
Fall 2019	M	Yes	N/A
Spring 2020	M	Partial (COVID-19)	N/A
Fall 2020	K	Yes (COVID-19)	Yes (COVID-19)
	S	N/A	N/A

The new ABET Student Outcome 6 states that students will have "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" [5]. This outcome embeds six different sub-outcomes:

1. Experimental plan (e.g. experiments to be conducted)
2. Develop appropriate experimentation (e.g. sensors and data acquisition)
3. Conduct appropriate experiments
4. Analyze data (e.g. uncertainty analysis, curve fitting)

5. Interpret data
6. Use engineering judgement to draw conclusions

A single score or pass/fail may conflate these sub-outcomes and limit faculty ability to identify needed curricular improvements. Instead, each sub-outcome is assessed and reported.

First, a rubric is used to score the student written reports. The rubric includes both technical and writing dimensions. The technical portion of the rubric is available in Appendix B. The technical dimensions are aligned with the sub-outcomes of ABET Student Outcome 6 and include "Problem Selection and Motivation", "Experimental Plan", "Development of Experimentation", "Conducting Experiments", "Data Analysis", "Data Interpretation and Discussion", and "Conclusions and Future Work".

After scoring each technical dimension, the scores are grouped into indicators of Unsatisfactory (0-59%), Minimal (60-74%), Adequate (75-89%), or Exemplary (90-100%) [20]. This simplified UMAE vector is reported for each sub-outcome on a departmental assessment reporting form.

The EM assessment is distributed to students (via the learning management system) as a survey to be completed. Because mindset is based on behaviors and methods of thinking, indirect assessment via surveys is at present the preferred method of assessment. Students are provided with four general prompts with 5-point Likert-scale responses. Next, students are asked to rate to what extent they demonstrated each example behavior associated with an entrepreneurial mindset; from "not at all" to "throughout most of the project". An example of the survey questions related to example behaviors is shown in Figure 4.

During the course of this project, to what extent did you:

Demonstrate curiosity about our changing world

None at all	slightly	on some occasions	many times	throughout most of the project
1	2	3	4	5

Explore a contrarian view of accepted (i.e., typical) solutions.

None at all	slightly	on some occasions	many times	throughout most of the project
1	2	3	4	5

Figure 4. Survey questions related to the example behaviors associated with Curiosity.

Students also assess the extent to which they worked as a team; from "almost never" to "almost always" and rate whether the project improved their technical skills using a 5-point Likert scale. Finally, a free response section allows students to provide feedback about what they liked or appreciated from the project, what should be changed, and any additional comments. Results from the technical skill and free response sections of the survey are not included in this work.

Assessment Results and Discussion

Student-selected project topics varied substantially. A few are listed below as examples:

- Exploring Full Wave Bridge Rectifier with Capacitor Filter
- Measuring Thrust [SAE Aero Design]
- Vehicle Control and Calibration Analysis
- Song Sound Analysis

- Signal and Efficiency Test of a Robot Vacuum

ABET assessment results for the course sections considered in this work are provided in two ways. Table 3 shows the UMAE vectors for each semester (each having one course section worth of data). Table 4 reports the percentage of student teams achieving Minimal, Adequate, or Exemplary (% M, A, E) levels for each semester (each having one course section worth of data).

Table 3. ABET assessment results as UMAE vectors.

ABET Outcome Indicators	Fall 2019				Spring 2020				Fall 2020			
	U	M	A	E	U	M	A	E	U	M	A	E
Experimental Plan	3	0	0	0	1	1	1	0	0	1	2	1
Development of Experimentation	2	0	1	0	0	3	0	0	0	1	3	0
Conducting Experiments	0	1	1	1	N/A due to COVID-19				0	0	3	1
Data Analysis	0	2	1	0					0	2	1	1
Data Interpretation	2	1	0	0					0	3	0	1
Conclusions	2	1	0	0					0	3	1	0

Table 4. ABET assessment results as % M, A, E

ABET Outcome Indicators	% M, A, E		
	Fall 2019	Spring 2020	Fall 2020
Experimental Plan	0	67	100
Development of Experimentation	33	100	100
Conducting Experiments	100	COVID-19	100
Data Analysis	100		100
Data Interpretation	33		100
Conclusions	33		100

The BSME program at LTU is not large and the small class sizes are further condensed due to assessment of a team project. This is evident in the small number of scores in Table 3 and Table 4. From the available data, it appears that from Fall 2019 to Fall 2020 there was improvement in the team projects across all sub-outcomes. This was likely influenced by improvements in course content (e.g., lecture materials) and clarity of the team assignment due to course coordinator experience. Additional data is needed to see if students continue to perform well on technical dimensions.

From the data in Table 4, it does seem unusual that all student teams would achieve 100% M, A, E after only three COVID-influenced semesters. This is likely a combination of luck and the definition of Minimal. As explained above, the Minimal indicator corresponds to a range of 60-74%. This is lower than what is acceptable for some other student outcomes on the LTU BSME assessment plan. As the course matures, it may be appropriate to report only the percentage of scores achieving Acceptable or Excellent (% A, E).

EM-specific student survey results are split into those that address research questions two and three. First, the general statements and EM-specific statements related to research question two (project appeal to students and student demonstration of curiosity) are shown in Table 5. Table 5 reports the percentage of students agreeing or strongly agreeing with the general statements

(% A, SA) and percentage of students demonstrating each example behavior associated with curiosity on some occasions, many times, or throughout most of the project (% OSO, MT, TMP).

Table 5. Students' ratings of general statements and EM-specific statements related to project appeal and student demonstration of curiosity

General Statements	Fall 2020 Strongly Disagree				Strongly Agree	Fall 2020 % A, SA
I consider the results of my project successful	0	0	2	7	3	83
I found my work on the project to be satisfying	0	1	3	4	4	67
The real-world application of the project motivated me to do my best work	0	1	1	7	3	83
The open-ended nature of the project motivated me to do my best work	0	2	4	3	3	50
EM Example Behaviors	**None at all**	**Slightly**	**On some occasions**	**Many times**	**Throughout most of the project**	**% OSO, MT, TMP**
Demonstrate curiosity about our changing world	0	3	4	5	0	75
Explore a contrarian view of accepted (i.e., typical) solutions	2	2	2	6	0	67

EM-specific statements related to research question three (other EM dimensions) are shown in Table 6. Table 6 reports the percentage of students demonstrating each example behavior on some occasions, many times, or throughout most of the project (% OSO, MT, TMP).

Table 6. Students' ratings of EM-specific statements other than those related to curiosity.

EM Example Behaviors	Fall 2020 None at all	Slightly	On some occasions	Many times	Throughout most of the project	Fall 2020 % OSO, MT, TMP
Integrate information from many sources to gain insight	0	1	4	5	2	92
Assess and manage risk (i.e., include contingency plans due to unforeseen circumstances)	1	2	1	4	4	75
Identify an unexpected opportunity for your design	1	3	4	3	1	67
Create extraordinary value for a customer or stakeholder	3	1	2	5	1	67
Persist through failure	0	0	6	3	3	100
Apply creative thinking to ambiguous problems	0	2	2	7	1	83
Apply systems thinking to complex problems	0	1	5	4	2	92
Evaluate technical feasibility	1	1	3	7	0	83
Evaluate economic drivers	5	0	6	1	0	58
Examine societal or individual (stakeholder) needs	4	1	3	3	0	55
Understand the motivations and perspectives of others	1	2	3	4	2	75
Convey engineering solutions in economic terms	1	3	4	4	0	67
Substantiate claims with data and facts	0	0	3	8	1	100

As explained above, due to the recent implementation of the EM-specific survey, only a single course section from Fall 2020 is included and the resulting number of survey responses is very low (N=12). These results should be considered a work-in-progress and not conclusive findings. Future work will include collecting data from additional course sections with (hopefully) less COVID-19 influence.

First the data regarding project appeal and student demonstration of curiosity is considered. As a first step in this work, ratings above 75% are considered to be successful. From Table 5, students agreed that they found their projects to be successful and that they were motivated by the real-world nature of the project. Surprisingly, the open-ended nature of the project, intended to motivate students, produced neutral responses and did not meet the 75% target. The student example behavior “demonstrated curiosity about our changing world” met the 75% target but “explore a contrarian view of the accepted” did not.

Next the data on student demonstration of EM example behaviors other than curiosity is considered. Again, ratings of 75% are considered successful. From Table 6, the example behaviors “integrate information from many sources to gain insight”, “assess and manage risk”, “persist through failure”, “apply creating thinking to ambiguous problems”, “apply system thinking to complex problems”, “evaluate technical feasibility”, “understand the motivations and perspectives of others”, and “substantiate claims with data and facts” met the 75% target. Due to the nature of the projects addressing a personal curiosity and not a customer-provided problem, it is not surprising that those example behaviors linked to a customer (e.g. “create extraordinary value for a customer or stakeholder”) did not meet the target. It is also encouraging that students demonstrated many dimensions of EM without specifically targeting those dimensions.

A final note about the data is that COVID-19 presented a significant disruption to student projects. Spring 2020 projects were not completed at all and Fall 2020 projects were moved online earlier than expected. Additional data will be collected before significant changes to the course or project will be considered.

Conclusions

In this work, a team-based student project in a new Measurement Systems course was presented with assessment for both technical skills and demonstration of behaviors associated with an entrepreneurial mindset. Over the course of the staged project, students individually identified curiosities, developed a team project proposal from their curiosities, developed a measurement system to address their curiosities, and reported on the results. The technical assessment aligned with ABET Student Outcome 6 by splitting the outcome into six sub-outcomes and assessing each on a rubric for student written reports. These dimensions were each converted to an UMAE vector. After three semesters, all students were performing within M, A, E, but more study is warranted. The EM assessment was performed using a student survey to self-identify the extent to which example behaviors associated with curiosity and other EM dimensions were demonstrated. Student responses regarding curiosity were mixed and a number of sample behaviors associated with other EM dimensions were demonstrated. Assessment data was likely influenced by disruptions caused by COVID-19 and additional data will be collected in semesters without COVID-19 disruptions.

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Appendix A – Course Learning Objectives

Overall
At the end of this ***course***, students should be able to:

- Conduct uncertainty analysis
- Perform basic statistical treatment of experimental data
- Distinguish between signals and systems
- Analyze signals in time and frequency domains
- Describe the effects of noise and filters on measured signals
- Apply digital computational tools to solve measurement problems
- Design measurement systems that include transducers, signal conditioning elements, and digital data acquisition
- Design and implement experiments utilizing measurement systems common to mechanical engineering
- Explain the importance of measurement systems to modern society

Introduction
At the end of this section, students should be able to:

- (1) Identify the instructor.
- (1) Locate the course syllabus on Canvas.
- (3) Calculate their grade using the provided grading scale.

Computational Tools Review
At the end of this section, students should be able to:

- (2) Describe variables in the context of MATLAB.
- (2) Describe functions in the context of MATLAB.
- (2) Describe matrices in the context of MATLAB.

Circuits Review
At the end of this section, students should be able to:

- (2) Describe the behavior of resistors, capacitors, and inductors.
- (2) Describe the behavior of diodes, transistors, and op-amps.
- (3) Apply Ohm's Law, Kirchhoff's Laws, and op-amp Golden Rules to analyze steady-state behavior of op-amp circuits
- (4) Perform node and mesh analysis on simple RLC circuits.

Systems and Signals and Calibration
At the end of this section, students should be able to:

- (2) Describe the components of measurement systems.
- (2) Differentiate between analog and digital sensors.
- (1) Identify several types of transducers.
- (2) Differentiate between signals and systems.
- (1) Differentiate between continuous and discrete systems.
- (2) Describe the purpose of static calibration.

- (3) Perform static calibration on a measurement system.
- (3) Identify nonlinearities in input-output data.
- (2) Describe a traceability ladder.

Digital Data Acquisition
At the end of this section, students should be able to:
- (2) Describe the difference between unipolar and bipolar binary encoding.
- (3) Convert numbers from decimal to binary and from binary to decimal.
- (3) Determine ADC code for a given input voltage.
- (3) Determine DAC output voltage for a given code.
- (2) Describe clipping in the context of A/D conversion.
- (2) Describe aliasing in the context of A/D conversion.
- (3) Select an appropriate sample rate for a known signal.
- (5) Select an appropriate ADC for a measurement system.

Statistical and Uncertainty Analysis
At the end of this section, students should be able to:
- (2) Distinguish between error and uncertainty.
- (2) Differentiate between systematic and random errors.
- (2) Describe sources of error in measurement systems.
- (3) Calculate design-stage uncertainty.
- (3) Calculate single-measurement result experiment uncertainty
- (3) Calculate multiple-measurement result experiment uncertainty.
- (5) Use design-stage uncertainty to identify improvements in measurement systems.
- (5) Apply detailed uncertainty analysis to measurement systems.

Time Domain Analysis
At the end of this section, students should be able to:
- (3) Classify time-domain signals.
- (3) Quantify time-domain signals in terms of mean, RMS, and norm values.
- (3) Calculate step response of first and second order systems.

Frequency Domain Analysis (Part 1: Signals)
At the end of this section, students should be able to:
- (2) Describe the application of Fourier series.
- (3) Calculate Fourier series approximations for periodic signals.
- (2) Distinguish between DFT and FFT.
- (2) Describe the significance of FFT.
- (3) Apply FFT using MATLAB.
- (4) Use FFT to identify significant frequency components of measured signals.

Frequency Domain Analysis (Part 2: Systems)
At the end of this section, students should be able to:
- (3) Perform calculations with complex numbers.
- (2) Explain the meaning of the frequency response function.

- (3) Calculate the frequency response function for a given system.
- (4) Determine the steady-state response of a system to a known sinusoidal input

Noise and Filters
At the end of this section, students should be able to:
- (2) Describe noise in the context of measurement systems.
- (3) Characterize noise using signal-to-noise ratio.
- (2) Describe sources of noise.
- (2) Identify remedies for common sources of noise.
- (2) Differentiate between low-pass, high-pass, band-pass and band-stop filters.
- (5) Select appropriate filters for a measurement system.

Modulation, Demodulation, and Amplification
At the end of this section, students should be able to:
- (2) Describe applications of modulation and demodulation.
- (3) Apply amplitude modulation and demodulation.
- (2) Describe applications of amplification.

Data Processing, Validation, and Presentation
At the end of this section, students should be able to:
- (2) Differentiate between verification and validation.
- (4) Identify outliers in measured data.
- (4) Apply linear regression to measured data.
- (4) Quantify error between predicted quantifies and experimental results.

Bloom's Taxonomy Levels
(1) Knowledge is defined as remembering of previously learned material.
(2) Comprehension is defined as the ability to grasp the meaning of material.
(3) Application refers to the ability to use learned material in new and concrete situations.
(4) Analysis refers to the ability to break down material into its component parts so that its organizational structure may be understood.
(5) Synthesis refers to the ability to put parts together to form a new whole.
(6) Evaluation is concerned with the ability to judge the value of material (e.g. statement or research report) for a given purpose.

Appendix B – Project Technical Rubric

	TECHNICAL PERFORMANCE LEVELS (1-10 or 1–15 point scale)			
Technical Dimensions (Weight)	**Does Not Meet Expectations (1-6 or 1-9)**	**Meets Expectations (7-8 or 10-12)**	**Exceed Expectation (9-10 or 13–15)**	**Points**
Problem Selection and Motivation (10%)	Incomplete or not attempted.	Motivates the larger problem and selects one element to explore.	Clearly motivates the larger problem based on personal or societal needs. Selects a reasonable element of the problem to explore in more detail.	
Experimental Plan (15%)	Incomplete or not attempted.	Develops a limited experimental plan including experiments to be conducted.	Develops a complete experimental plan including experiments to be conducted, required repetitions, and design-stage uncertainty analysis	
Development of Experimentation (15%)	Incomplete or not attempted.	Designs or develops some experimentation.	Designs or develops experimentation including sensor selection, sensor interface, and data acquisition platform.	
Conducting Experiments (15%)	Incomplete or not attempted.	Uses developed instrumentation to conduct experiments and record some data.	Appropriately uses developed experimentation to safely conduct planned experiments including recording data.	
Data Analysis (15%)	Incomplete or not attempted.	Performs some data analysis using some software tools.	Performs appropriate data analysis using available software tools (e.g. MATLAB). Examples include detailed uncertainty analysis, curve fitting, and dynamic system modeling.	
Data Interpretation and Discussion (15%)	Incomplete or not attempted.	Discusses and interprets data analysis.	Discusses and interprets data analysis to bring meaning to numerical results.	
Conclusions and Future Work (15%)	Incomplete or not attempted.	Attempts to answer the original question. Suggests some future work.	Answers (within reason based on data) the original question. Addresses areas of concern within work completed. Suggests reasonable future work to improve or extend results.	
Figures, Tables, and Equations (10%)	Fails to produce professionally formatted figures, tables, or equations using any appropriate software tools.	Mostly produces professionally formatted figures, tables, and equations using some appropriate software tools.	Professionally produces and formats figures, tables, and equations using appropriate software tools.	