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Assessing ABET Student Outcome 7 (New Knowledge) with Measurement Systems

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Abstract

Team-based projects in a new Measurement Systems course are presented with assessment for ABET Student Outcome 7. The first project is an exploration of strain gages and the second project is an exploration of data acquisition, encoders, and accelerometers. ABET Student Outcome 7 is split into two sub-outcomes. Both projects address the first sub-outcome and project one (strain gages) also addresses the second sub-outcome. A rubric is used to capture multiple dimensions of each sub-outcome with indicators of Unsatisfactory, Minimal, Adequate, or Exemplary (UMAE) and report the percentage of student teams achieving Adequate or Exemplary. Specific to the data presented, additional efforts are needed to improve student assessment of the quality of information and citing sources.

Introduction

A Measurement Systems course was added to the BS in Mechanical Engineering (BSME) program at Lawrence Technological University (LTU) in Fall 2018 with first offering in Fall 2019. This course was created to address a faculty-identified curriculum weakness related to student understanding and application of instrumentation. It also had the benefit of removing some content from the subsequent course on dynamic systems and controls and was expected to improve student performance in that subsequent course. 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 both ABET Student Outcome 6 and Student Outcome 7. Details on the assessment of Student Outcome 6 were previously reported [5]. This work focuses on the assessment of Student Outcome 7.

ABET Student Outcome 7 states that students will have “an ability to acquire and apply new knowledge as needed, using appropriate learning strategies” [6]. This outcome is related to the previous Student Outcomes i (“a recognition of the need for, and an ability to engage in life-long learning”) and j (“a knowledge of contemporary issues”). Unlike the previous outcomes, the new Student Outcome 7 embeds multiple sub-outcomes and assessment requires a new method that captures those sub-outcomes.

Segmentation of Student Outcome 7 into sub-outcomes or Key Performance Indicators (KPIs) is not uniform among institutions. Battistini and Kitch identified "Display an awareness that education is continuous beyond classroom and an understanding for how to apply that new knowledge" and "Select learning strategy suited for the acquisition of needed knowledge" as KPIs [7]. Tsai and Janssen related Student Outcome 7 to existing efforts to embed information fluency within a BSME curriculum with assessment on "location and evaluation of sources" and "citation/attribution" [8]. McCullough and Wigal also related this outcome to information literacy and performed a survey to evaluate students on proficiency in finding information, judging whether information is reliable/credible, citation, and improvement across the curriculum [9].

In this work, the identified sub-outcomes build on the information literacy approach:

1. Acquire new knowledge using appropriate learning strategies
2. Apply new knowledge

The first sub-outcome, acquiring new knowledge, is assessed on indicators of obtaining sources, assessing the quality of information, and citing sources. The second sub-outcome, applying new knowledge, is assessed on problem-specific indicators. Two projects in the Measurement Systems course are presented with components suitable for assessment of ABET Student Outcome 7. Technical and ABET assessment rubrics are presented along with sample results.

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, now includes 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.

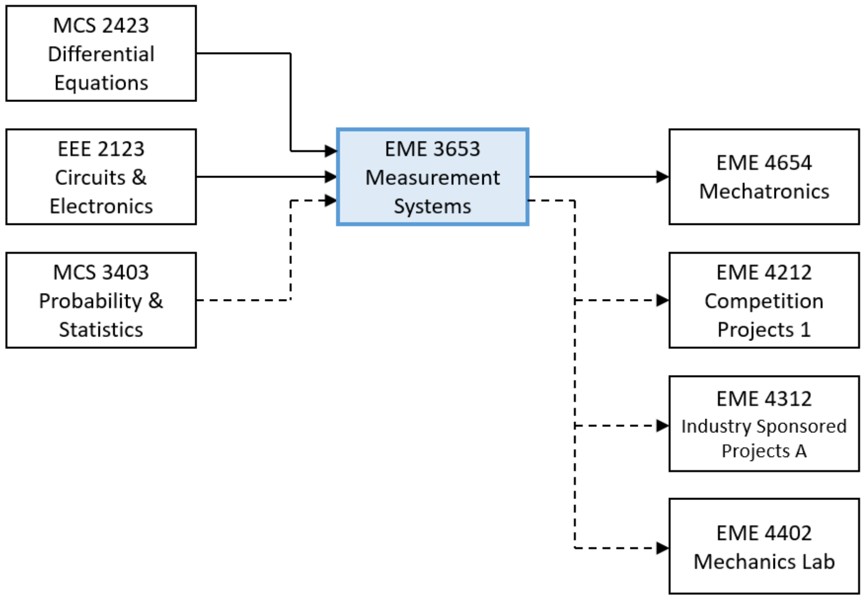

Figure 1. Measurement Systems with prerequisite courses (solid arrows), corequisite course (dashed arrows), and following courses in the LTU BSME program

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. The section-by-section learning objectives were previously reported [5].

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 team-based projects spaced through the semester. The projects are described in more detail below. The Spring 2022 course schedule is shown in Figure 2.

Week		Class Period 1 (2 hours)	Class Period 2 (2 hours)
1	01/10/22	Introduction / Digital Computational Tools / Circuits Review	Lab 1: Digital Computational Tools / Circuits Review
2	01/17/22	Signals and Systems, Components, Static Calibration	Lab 2: Tranducers & Calibration
3	01/24/22	Digital Data Acquisition	Lab 3: Digital Data Acquisition
4	01/31/22	Group Project: Strain Gages	Group Project: Strain Gages
5	02/07/22	Statistical and Uncertainty Analysis	Lab 4: Uncertainty Analysis
6	02/14/22	Time Domain Analysis	Lab 5: Time Domain Analysis
7	02/21/22	Frequency Domain Analysis - Signals	Lab 6: Frequency Domain Signal Analysis
8	02/28/22	Frequency Domain Analysis - Systems	Lab 7: Frequency Domain System Analysis
9	03/07/22	Spring Break	
10	03/14/22	Self-Directed Problem Formulation	Group Project: Data Acquisition Platforms
11	03/21/22	Group Project: Data Acquisition Platforms	Group Project: Data Acquisition Platforms
12	03/28/22	Noise and Filters	Lab 8: Noise & Filters
13	04/04/22	Modulation / Demodulation / Amplifiers	Lab 9: Modulation / Demodulation / Amplifiers
14	04/11/22	Data Processing, Validation, and Presentation	Lab 10: Data Processing
15	04/18/22	Group Project: Self Directed	Group Project: Self Directed
16	04/25/22	Group Project: Self Directed	Group Project: Self Directed
17	05/02/22	Final Exam	

Figure 2. Spring 2022 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. 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 2020	Full-Time Staff (K)	Daytime	13
	Adjunct Faculty (S)	Evening	4
Spring 2021	Full-Time Faculty (M)	Daytime	15
	Adjunct Faculty (B)	Evening	5
Fall 2021	Full-Time Staff (K)	Daytime	15
	Adjunct Faculty (B)	Evening	13
Spring 2022	Full-Time Faculty (M)	Daytime	13
	Adjunct Faculty (B)	Evening	15

Project 1 – Strain Gages

The first project is an exploration of strain gages, which is admittedly a common trend in BSME instrumentation courses. As described above, enrolled students have taken a prerequisite course on Circuits and Electronics but very few have used strain gages. No lecture or lab exercises on the topic of strain gages are provided prior to this project making the exercise largely one of new discovery that is aligned with ABET Student Outcome 7.

Students are provided with the photo of the cantilever beam experiment shown in Figure 3, a very brief description of strain gages, a list of suggested resources, and a statement of project expectations (e.g., students may need to use the library and to cite using ASME or IEEE style). Project tasks include one information literacy step, two conceptual steps, two analysis steps, and three hands-on steps.

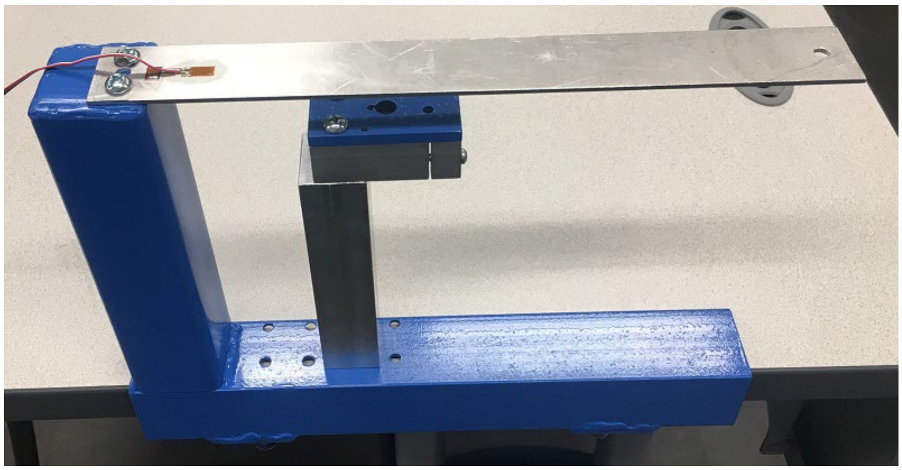

Figure 3. Aluminum beam in a cantilever fixture with installed strain gage.

The suggested resources include links to a description of strain gage installation [10], two videos of strain gage installation [11, 12], and a video of strain gage soldering [13]. All links are from StrainBlog, an "an online community for everyone involved in the high-precision measurement of stress and strain" [14] provided by Micro-Measurements. All videos reference Micro-Measurements products (e.g., neutralizer and adhesive), which is convenient because the students are provided with the same products.

The first three steps of the project (information literacy and conceptual) may be completed during the available lab time or not. These are provided as follows:

- Identify all sources used in this report. For each source, explain why you believe the source to be credible. Cite your sources appropriately using ASME or IEEE citation style. Continue to cite sources wherever they are used in the remainder of the report. *Failure to cite sources will result in a zero for the project.*
- Describe the function of a strain gage in your own words. Use appropriate figures, equations, and text. At a minimum, describe the operation of a strain gage, several styles of strain gages and appropriate applications for each, gage factor and describe why it matters, and why the substrate material matters for strain gage selection.
- Describe the function of a bridge circuit in your own words. Use appropriate figures, equations, and text. At a minimum, describe the design and operation of a bridge circuit, the balancing the bridge circuit, calibrating the bridge circuit, temperature compensation, the three-wire quarter bridge circuit, and applications of bridge circuits beyond strain gages.

Unsurprisingly, most student teams aim for the minimum on these steps and respond only to the specific prompts without considering any other factors. These steps of the project are aligned with the first sub-outcome of ABET Student Outcome 7: acquire new knowledge using appropriate learning strategies.

The next two steps of the project task students with analysis of a bridge circuit, quarter bridge, and half bridge. For the bridge circuit, students are provided with a schematic and asked to determine the output voltage as a function of input voltage. For the quarter bridge and half bridge, students are provided with resistor values of R_0 and $R_0 + \Delta R$ as appropriate and are asked to derive the output voltage as a function of strain. Student teams are encouraged to use the large classroom whiteboards to derive the solutions, which has the beneficial side effect of letting multiple teams easily compare notes.

Finally, the students install a strain gage on an aluminum beam, build a three-wire quarter bridge circuit, calibrate the resulting measurement system with known weights, and compare the calibration results to their prior knowledge of cantilever beams. Minimal instructions for beam surface preparation and strain gage installation are provided by the instructor, but the videos and other online resources provide plenty of detail. Each student team is provided with a kit, as shown in Figure 4, containing several of the necessary items (e.g., neutralizer, rosin solvent, pencil, tape, gauze pads). Items that are not easily distributed to the kits are shared between teams (e.g., large can of degreaser, spool of wire, soldering iron). An example of a student-installed strain gage is shown in Figure 5. These steps are aligned with the second sub-outcome of ABET Student Outcome 7: apply new knowledge.

Figure 4. Strain gage kit provided to student teams.

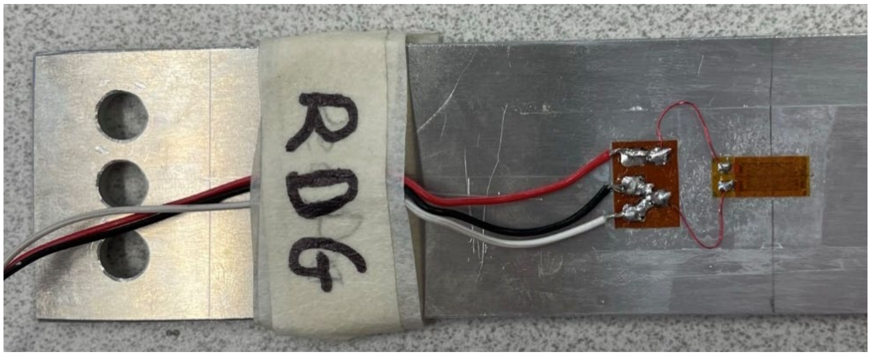

Figure 5. Example of student-installed strain gage.

The calibration of the measurement system has some obvious weaknesses. First, the provided resistors are chosen for low cost and are not sufficiently precise to get highly accurate results. Given how frequently small components in the lab must be replaced, this was accepted as a reasonable tradeoff. Next, despite reciting definitions of the concepts, students generally do not balance the bridge circuit or include a calibration resistor. With only two class sessions and potentially several attempts at strain gage installation, time can be short at the end of the project and this often falls into advice for next time. Also, no amplifier is used with the bridge circuit because amplification is introduced in a later lecture. If the material or projects were reordered it would make sense to include a simple breadboard differential amplifier or a purchased strain gage amplifier. The decision was made that an early hands-on experience would be more impactful than waiting until the students had all the appropriate background knowledge.

Despite the weaknesses, during an informal course evaluation, students ranked this project as one of their favorite activities for the semester. This project also provides a foundation for strain gage usage in the subsequent Mechanics Lab.

Project 2 – Condition Monitoring

The second project is an exploration of data acquisition, encoders for rotational position measurement, and accelerometers. Prior lecture topics and lab exercises introduced digital-to-analog conversion, time and frequency domain system analysis and time and frequency domain signal analysis. Therefore, this project is an opportunity to combine previous concepts. Project tasks include one information literacy step, four conceptual steps, two software setup steps, and two hardware implementation steps.

The "hook" for this project is condition monitoring. As in the first project, the first steps are a combination of information literacy and comprehension:

- Identify 5-10 technical or non-technical sources related to condition monitoring (note: sources may use other names of the same concept, use your judgement). For each source, explain why you believe the source to be credible. Cite your sources appropriately using ASME or IEEE citation style. Continue to cite sources wherever they are used in the remainder of the report. *Failure to cite sources will result in a zero for the project.*
- Describe the function and operation of condition monitoring in your own words. Use appropriate figures, equations, and text. At a minimum, describe the objective and

benefits of condition monitoring, applications of condition monitoring, hardware and software components, and several data analysis techniques.

- Describe the function and operation of encoders in your own words. Use appropriate figures, equations, and text. At a minimum, describe absolute encoders, incremental encoders, and quadrature encoding.
- Describe the function and operation of accelerometers in your own words. Use appropriate figures, equations, and text. At a minimum, describe types of accelerometers (e.g., AC vs. DC response), accelerometer designs (e.g., compression vs. shear), the effect of mounting types, and IEPE.

This portion of the project is aligned with the first sub-outcome of ABET Student Outcome 7: acquire new knowledge using appropriate learning strategies.

Students are also provided with a case study on condition monitoring to review. Students are asked to identify stakeholders and explain how each stakeholder benefited or may benefit in the future from the application of condition monitoring in the case study. While not assessed in this work, this step aligns with the KEEN framework to define an entrepreneurial mindset [9]. Future work may explore student demonstration of an entrepreneurial mindset during the course of the project or semester.

The hands-on component of this project uses the NI myRIO platform [15]. The myRIO is a portable reconfigurable I/O device including a processor, FPGA, analog I/O, digital I/O, and more. The myRIO is programmed using LabView, which is new to students enrolled in the Measurement Systems course. Therefore, the software setup portions include step-by-step directions to create a VI (virtual instrument) capable of reading encoders and accelerometers.

A motor with encoder, as shown in Figure 4, is used to test the software. Students manually rotate the motor to calibrate the encoder and use a handheld 1g accelerometer calibrator to calibrate an accelerometer. Students then collect acceleration data from the bearing blocks on two motors (“old” and “new”) and compare the FFT to identify differences. Based on the faulty design of the “old” motor stands, the bearings are damaged and should present different frequency content. Students are also asked to discuss how encoders and accelerometers could be applied to condition monitoring.

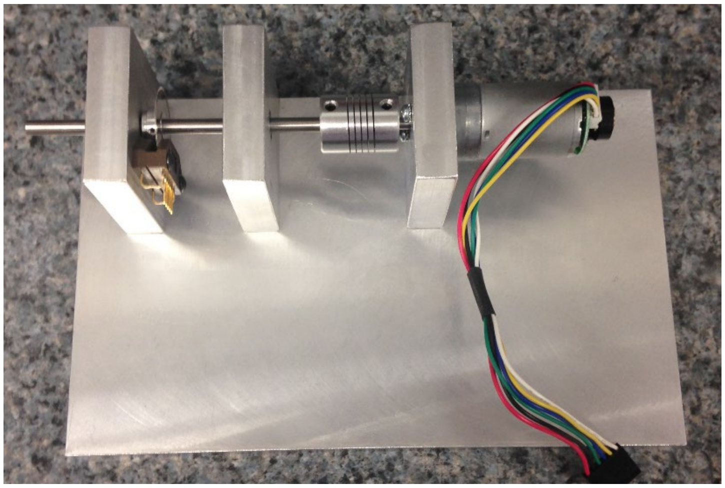

Figure 6. Motor with encoder hardware used in project two.

The hands-on component of the project is not well aligned with the second sub-outcome of ABET Student Outcome 7 (applying new knowledge) as it relies more on synthesis of several proceeding course topics instead of application of new knowledge from the conceptual portions. However, the repetition of the first sub-outcome (acquiring new knowledge) provides an opportunity for students to receive feedback and demonstrate immediate improvement. This style of information literacy and conceptual project steps is continued in the subsequent dynamic systems and control course.

Project 3 – Self-Directed Project

The third project is a scaffolded, multi-week summative experience for the course. Students individual identify topics of their own interests using da Vinci lists, work in teams to select a problem to pursue, and develop a measurement system to address the selected problem. Assessment for both ABET Student Outcome 6 (experimentation) and demonstration of behaviors associated with an entrepreneurial mindset was previously reported [5].

Assessment Method

For each project, student teams submit a written report within one week of completion of the in-class work sessions. The project-specific scoring rubric is made available to students prior to the start of the project. Each project-specific rubric includes both technical and writing dimensions. The technical portions of the project one and two rubrics are available in Appendices A and B.

As discussed above, the sub-outcomes for ABET Student Outcome 7 are given by:

1. Acquire new knowledge using appropriate learning strategies
2. Apply new knowledge

As described above, student work in project one is aligned with both sub-outcomes while student work in project two is only aligned with the first sub-outcome. The technical dimensions of the project one technical rubric are mapped to the sub-outcomes of ABET Student Outcome 7 as shown in Table 2. The technical dimensions of the project two technical rubric are mapped to the first sub-outcome of the ABET Student Outcome 7 as shown in Table 3.

Table 2. Mapping of sub-outcomes to project one technical rubric dimensions

Sub-Outcome	**Technical Rubric Dimension**
Acquire new knowledge using appropriate learning strategies	Obtain and Use Sources
	Understanding Strain Gages
	Understanding Bridge Circuits
Apply new knowledge	Analysis of Strain Gages and Bridge Circuit
	Strain Gage Installation
	Test Strain Gage with Bridge Circuit
	Cantilever Beam Calibration

Table 3. Mapping of sub-outcomes to project two technical rubric dimensions

Sub-Outcome	**Technical Rubric Dimension**
Acquire new knowledge using appropriate learning strategies	Obtain and Use Sources
	Understanding Condition Monitoring
	Understanding Encoders
N/A	Reading Encoders with LabView
	Understanding Accelerometers
	Reading Accelerometers with LabView
	Using Accelerometers for Condition Monitoring

Only the project one results are used to assess ABET Student Outcome 7. An argument could be made that the repetition of the first sub-outcome would lead to better student results if project two were used for assessment of that sub-outcome. However, this comes at a cost of additional record keeping for adjunct faculty that are already busy with full-time engineering careers in addition to teaching responsibilities. Therefore, only project one will be considered below for assessment of ABET Student Outcome 7.

After scoring each dimension on the technical rubric, a second ABET-specific rubric is applied. The ABET-specific rubric provided in Appendix C also includes dimensions for each sub-outcome. The dimensions of this rubric are mapped to the sub-outcomes as shown in Table 4. Rather than provide a numeric score on each dimension, the scores are grouped into indicators of Unsatisfactory (0-59%), Minimal (60-74%), Adequate (75-89%), or Exemplary (90-100%) [16].

Table 4. Mapping of sub-outcomes to ABET-specific rubric dimensions

Sub-Outcome	**ABET-Specific Rubric Dimension**
Acquire new knowledge using appropriate learning strategies	Obtain Sources
	Assess Quality of Information
	Cite Sources
Apply new knowledge	Apply Strain Gage Function Knowledge
	Apply Strain Gage Installation Knowledge
	Apply Bridge Circuit Function Knowledge
	Apply Bridge Circuit Analysis Knowledge

Given the similarity of the technical rubric and ABET-specific rubric, the marking of the second rubric does not present a significant burden. It would simplify the marking of the ABET-specific rubric is the technical rubric dimension "Obtain and Use Sources" were split into three separate dimensions to match the "Obtain Sources", "Assess Qualify of Information" and "Cite Sources" of the ABET-specific rubric. The "Understanding Strain Gages" and "Understanding Bridge Circuits" dimensions of the technical rubric were not included on the ABET-specific rubric but could be added to assess student teams' ability to summarize information from multiple sources.

The number of student teams achieving each Unsatisfactory, Minimal, Adequate, or Exemplary for each rubric dimension is listed in a UMAE vector. The UMAE vector for each dimension is further reduced to the percentage of student teams achieving Adequate or Exemplary (% A, E). The % A, E on each project one technical dimension are reported for each course section on a departmental assessment reporting form. The LTU BSME assessment plan used the percentage of student teams achieving Minimal, Adequate, or Exemplary (% M, A, E) measure until Summer 2021. However, the lowest level of achievement associated with Minimal (60%) was significantly lower than was used with assessment of other ABET Student Outcomes. Therefore, the LTU BSME assessment plan replaced % M, A, E with % A, E starting in Fall 2021.

Assessment Results and Discussion

Assessment results for the course sections considered in this work are provided in several ways. Table 5 shows the UMAE vectors for course section previously identified in Table 1 except two. Adjunct Faculty S did not collect data in Fall 2020 and Spring 2022 data was not available at the time of this publication. The LTU BSME program 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 5.

Table 5. Assessment results as UMAE vectors.

	Fall 2020				Spring 2021								Fall 2021							
	K				M				B				K				B			
ABET Outcome Indicators	**U**	**M**	**A**	**E**	**U**	**M**	**A**	**E**	**U**	**M**	**A**	**E**	**U**	**M**	**A**	**E**	**U**	**M**	**A**	**E**
Obtain sources	0	0	4	0	0	2	3	0	0	0	0	2	0	1	0	3	0	2	2	0
Assess quality of information	0	0	4	0	2	0	3	0	0	2	0	0	0	1	0	3	2	1	1	0
Cite sources	1	3	0	0	0	2	2	1	1	1	0	0	0	1	0	3	0	3	1	0
Apply strain gage function knowledge	0	0	4	0	0	1	3	1	0	0	2	0	0	0	0	4	0	0	3	1
Apply strain gage installation knowledge	0	0	3	1	0	0	1	4	0	0	2	0	0	0	0	4	0	0	4	0
Apply bridge circuit function knowledge	0	0	1	3	0	2	1	2	0	0	2	0	0	0	0	4	0	0	4	0
Apply bridge circuit installation knowledge	0	1	0	3	0	1	2	2	0	0	2	0	0	0	2	2	0	3	1	0

Table 6 reports the percentage of student teams achieving Minimal, Adequate, or Exemplary (% M, A, E) and the percentage of student teams achieving Adequate or Exemplary (% A, E) for each course section.

Table 6. Assessment results as % M, A, E and % A, E

	Fall 2020		Spring 2021				Fall 2021			
	K		M		B		K		B	
ABET Outcome Indicators	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**
Obtain sources	100	100	100	60	100	100	100	75	100	50
Assess quality of information	100	100	60	60	100	0	100	75	50	25
Cite sources	75	0	100	60	50	0	100	75	100	25
Apply strain gage function knowledge	100	100	100	80	100	100	100	100	100	100
Apply strain gage installation knowledge	100	100	100	100	100	100	100	100	100	100
Apply bridge circuit function knowledge	100	100	100	60	100	100	100	100	100	100
Apply bridge circuit installation knowledge	100	75	100	80	100	100	100	100	100	25

Table 7 further compacts the data from Table 6 by reporting the minimum achievement of the dimensions associated with each of the identified sub-outcomes of ABET Student Outcome 7. For consistency with the above results, this is also reported in both % M, A, E and % A, E.

Table 7. Assessment results as % M, A, E and % A, E aligned with ABET Student Outcome 7 sub-outcomes

	Fall 2020		Spring 2021				Fall 2021			
	K		M		B		K		B	
ABET Outcome Indicators	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**	**% M, A, E**	**% A, E**
Acquire new knowledge using appropriate learning strategies	75	0	60	60	50	0	100	75	50	25
Apply new knowledge	100	75	100	60	100	100	100	100	100	25

While the instructors communicate frequently there are often differences in motivations and constraints between students who select daytime sections (instructors M and K) and students who select evening sections (instructor B). Trends presented should not be considered conclusive findings.

All data in these semesters can be assumed to be influenced by COVID-19. LTU started the Fall 2020 and Spring 2021 semesters in-person before transitioning to online. However, in both semesters the transition to online occurred after project one was completed. The Fall 2021 semester was conducted in-person without a transition to online. In each semester, individual students were quarantined and may have participated in project one remotely.

Given the two different sub-outcomes and the seven different indicators that were used in project one, simply comparing averages on the overall technical rubric would not be sufficient to identify whether or not student teams were achieving ABET Student Outcome 7. The UMAE vectors provided in Table 5 do a better job of quantizing the results while still making all dimensions visible. Compacting the quantized results into either % M, A, E or % A, E as shown in Table 6 provides a more quickly understandable result that preserves the dimensions for targeted improvements. Further compacting the results to only the sub-outcomes as shown in Table 7 matches the language of ABET Student Outcome 7 but may be overly reduced and again obscure the dimensions.

In the opinion of the author, the % M, A, E or % A, E representation shown in Table 6 hits a "sweet spot" of addressing the breadth of ABET Student Outcome 7 while clearly identifying areas for improvement. The drawback is that the indicators selected in this assessment are clearly problem-specific. For example, the Fall 2020 and Spring 2021 columns of Table 7 show that 0% of teams met the first sub-outcome. From the dimensions shown in Table 6, this was specifically a failure to cite sources. A targeted intervention related to citing sources would be warranted without suggesting that the student teams were incapable of acquiring new knowledge.

Referring to Table 6, the following trends were observed. Generally, student work on applying new knowledge was satisfactory (% A, E > 70%). However, student work on acquiring new knowledge needs improvement. Interventions related to assessing the quality of information and citing sources are needed.

Conclusions

In this work, two team-based projects in a new Measurement Systems course were presented with assessment of technical dimensions that aligned with identified sub-outcomes of ABET Student Outcome 7. Student work was assessed with an ABET-specific rubric with each dimension represented by a UMAE vector. The percentage of students achieving Adequate or Exemplary on each dimension was reported. Specific to the data presented, additional efforts are needed to improve student assessment of the quality of information and citing sources.

References

[1] D. R. Loker and S. A. Strom, "Innovative Laboratory Projects for a Measurements and Instrumentation Course," *2019 ASEE Annual Conference & Exposition,* 2019.

[2] D. Dannelley and E. Bryner, "Fundamental Instrumentation Course for Undergraduate Aerospace and Mechanical Engineering," *2020 ASEE Virtual Annual Conference,* 2020.

[3] E. Bryner and D. Dannelley, "Applied Instrumentation Course for Undergraduate Thermal-fluid Sciences," *2020 ASEE Virtual Annual Conference,* 2020.

[4] D. McDonald, "Data Acquisition in a Vehicle Instrumentation Course," in *2010 Annual Conference & Exposition*, 2010.

[5] J. A. Mynderse, "WIP: Student-Guided Project for Measurement System Development with ABET and EM Assessment," in *2021 ASEE Virtual Annual Conference*, 2021.

[6] ABET Engineering Accreditation Commission, "Criteria for Accrediting Engineering Programs, 2022-2023," 2022. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/#GC3.

[7] A. Battistini and W. A. Kitch, "Make Assessment Straightforward: A Case Study on the Successful Implementation of ABET Student Outcomes 1-7," in *2021 ASEE Annual Conference*, 2021.

[8] W. W. Tsai and A. Janssen, "Information Fluency Instruction as a Continuous Improvement Activity," in *2021 Virtual ASEE Annual Conference*, 2021.

[9] C. McCullough and C. Wigal, "How Prepared Are We for ABET's New Outcome 7?," in *2019 ASEE Southeast Section Conference*, 2019.

[10] Y. Hernik, "Advanced Sensors Technology Strain Gage Installation (Stress Analysis)," [Online]. Available: https://strainblog.micro-measurements.com/content/advanced-sensors-technology-strain-gage-installation-stress-analysis.

[11] Micro Measurements, "Strain Gauge Installation Tutorial (British Version vs. American Version)," [Online]. Available: https://strainblog.micro-measurements.com/media/strain-gauge-installation-tutorial-british-version-vs-american-version.

[12] Micro-Measurements, "Water Bottle Used as a Pressure Vessel (Stress Analysis)," 3 July 2019. [Online]. Available: https://www.strainblog.com/media/water-bottle-used-pressure-vessel-stress-analysis.

[13] Micro-Measurements, "How To Wire A Strain Gage For Maximum Fatigue Life And High Elongation," 20 January 2017. [Online]. Available: https://strainblog.micro-measurements.com/media/how-wire-strain-gage-maximum-fatigue-life-and-high-elongation.

[14] Micro-Measurements, "StrainBlog," [Online]. Available: https://strainblog.micro-measurements.com/.

[15] NI, "What Is myRIO?," [Online]. Available: https://www.ni.com/en-us/shop/engineering-education/portable-student-devices/myrio-student-embedded-device/what-is-myrio.html.

[16] J. K. Estell, "Workshop - Streamlining the Assessment Process with the Faculty Course Assessment Report," *37th Annual Frontiers In Education Conference - Global Engineering: Knowledge Without Borders, Opportunities Without Passports,* 2007.

Appendix A – Project 1 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**
Obtain and Use Sources (10%)	Fails to select or assess quality of sources. Fails to use references. Fails to cite sources.	Selects and assesses quality of some technical or non-technical sources. Uses some references. Cites some sources correctly.	Selects and assesses quality of appropriate technical or non-technical sources. Uses references throughout document as appropriate. Cites all sources correctly.	
Understanding Strain Gages (15%)	Incomplete or not attempted.	Demonstrates a partial understanding of the principles and operation of strain gages.	Demonstrates clear understanding of the principles and operation of strain gages.	
Understanding Bridge Circuits (15%)	Incomplete or not attempted.	Demonstrates a partial understanding of the principles and operation of bridge circuits.	Demonstrates clear understanding of the principles and operation of bridge circuits.	
Analysis of Strain Gages and Bridge Circuit (15%)	Incomplete or not attempted.	Partial analyzes strain gages in bridge circuits for quarter and half bridge configurations.	Clearly analyzes strain gages in bridge circuits for quarter and half bridge configurations.	
Strain Gage Installation (10%)	Improperly installs strain gages.	Partially follows tutorials to properly install strain gages.	Follows tutorials to properly install strain gages.	
Test Strain Gage with Bridge Circuit (10%)	Improperly builds bridge circuit.	Partially follows tutorials to properly build bridge circuit.	Follows tutorials to properly build bridge circuit.	
Cantilever Beam Calibration (15%)	Incomplete or not attempted.	Partially calibrates cantilever beam with some data representation, fitted curve, or validation using beam calculations.	Calibrates cantilever beam with data representation, fitted curve, and validation using beam calculations.	
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.	

Appendix B – Project 2 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**
Obtain and Use Sources (10%)	Fails to select or assess quality of sources. Fails to use references. Fails to cite sources.	Selects and assesses quality of some technical or non-technical sources. Uses some references. Cites some sources correctly.	Selects and assesses quality of appropriate technical or non-technical sources. Uses references throughout document as appropriate. Cites all sources correctly.	
Understanding Condition Monitoring (15%)	Incomplete or not attempted.	Demonstrates a partial understanding of the principles and operation of condition monitoring.	Demonstrates clear understanding of the principles and operation of condition monitoring.	
Understanding Encoders (15%)	Incomplete or not attempted.	Demonstrates a partial understanding of the principles and operation of encoders.	Demonstrates clear understanding of the principles and operation of encoders.	
Reading Encoders with LabView (10%)	Incomplete or not attempted.	Partially implements encoders with myRIO and demonstrates understanding of the interface.	Correctly implements encoders with myRIO and demonstrates understanding of the interface.	
Understanding Accelerometers (15%)	Incomplete or not attempted.	Demonstrates a partial understanding of the principles and operation of accelerometers.	Demonstrates clear understanding of the principles and operation of accelerometers.	
Reading Accelerometers with LabView (10%)	Incomplete or not attempted.	Partially implements accelerometers with myRIO and demonstrates understanding of the interface.	Correctly implements accelerometers with myRIO and demonstrates understanding of the interface.	
Using Accelerometers for Condition Monitoring (15%)	Incomplete or not attempted.	Partially applies understanding of accelerometers and frequency-domain signal analysis to measure performance of bearings.	Applies understanding of accelerometers and frequency-domain signal analysis to measure performance of bearings.	
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.	

Appendix C – Project 1 Student Outcome 7 Rubric

ABET Outcome Indicators
Check ONE box per dimension.

	Unsatisfactory (U) (0-59%)	**Minimal (M) (60-74%)**	**Acceptable (A) (75-89%)**	**Excellent (E) (90-100%)**
Obtain Sources				
Assess Quality of Information				
Cite Sources				
Apply Strain Gage Function Knowledge				
Apply Strain Gage Installation Knowledge				
Apply Bridge Circuit Function Knowledge				
Apply Bridge Circuit Analysis Knowledge				