Work in Progress: Mapping Pretest Data to Learning Outcomes to Enhance Industrial Engineering Program Assessment

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Abstract

Assessment of course learning objectives and mapping to program goals continues to be an important focus area for engineering departments. In an effort to collect and analyze course prerequisite knowledge to improve student academic success, in 2012, Northwestern's Industrial Engineering (IE) department implemented a pretest policy for core IE undergraduate courses. Instructors that taught these classes developed the pretest questions and linked them to Accreditation Board for Engineering and Technology (ABET) student outcomes, which were then vetted and approved by the department faculty. The questions were added to an online assessment portal to help capture pretest data to support program educational objectives. In 2020, the department transitioned out of ABET accreditation and developed specific IE program learning goals and outcomes.

The work in progress describes the effort to analyze historical quantitative pretest data mapped to legacy ABET student outcomes and develop a mapping system to the new IE program learning goals and outcomes. We describe an approach that consists of mapping the 2021-2023 pretest data to the new IE learning outcomes and examining the data based on the updated mappings. Results suggest that some concepts may be more challenging for students as evidenced by a lower pretest pass rate, whereas other class pretests have a consistently high pass rate. However, said observations are not well explained by the quantitative data. Future plans to implement a qualitative data collection phase for a mixed-methods study are discussed in a continued effort to improve program assessment.

Background and Introduction

An ABET article on curriculum reform emphasized the importance of engineering programs to be proactive and innovative in designing and delivering curriculum that is "outcome-based, informed by real-world business needs that give students core discipline knowledge while retaining a student's ability to explore individual interests [1, p. 4]." A component of the ABET accreditation process, criterion 3, requires programs to document student outcomes that support their educational objectives [2]. Research studies have illustrated how Industrial Engineering (IE) departments have redesigned their curriculum to become ABET accredited to better assess and evaluate student outcomes and course learning outcomes [3], while others have reported how to incorporate assessment in the curriculum during the development of new IE programs [4]. Frameworks that align IE professional competencies to the undergraduate curriculum have also been presented [5]. Other studies have not focused on ABET, but instead on a curriculum renewal model to enhance all or parts of existing IE academic programs [6]. A plethora of scholarship exists within and outside of IE focused on curriculum assessment. One reason may be that designing undergraduate engineering curricula is a complex process that requires concurrent assessment of student cognitive ability and content mastery [7]. There is no one-size-fits-all approach to assessment.

Assessment of course learning objectives and mapping to program goals is a top priority in Northwestern's IE department. Since 2012, students must complete a pretest for core IE courses. For students, the pretest serves as an opportunity to review relevant prerequisite concepts. For faculty, the pretest is a curriculum assessment tool that links all pretest questions to ABET student outcomes, hence elucidating students' ability to retain course concepts. In 2020, the IE department voted not to continue ABET accreditation and instead create its own curriculum goals and outcomes, which are referred to as "BSIE outcomes" (Appendix A). However, the pretest infrastructure is still set up with all questions linked to the legacy 2017-2018 ABET outcomes (Appendix B). We created preliminary mappings from the legacy ABET outcomes to both the new ABET outcomes and our department-specific outcomes (Appendix C). As such, the goal for this research is twofold. First, we aim to analyze students' performance on the IE pretests for 2021-2022 and 2022-2023 academic years in order to understand the attainment of our course objectives. Additionally, we lay the preliminary groundwork for the mapping of the new BSIE outcomes to the pretest questions. For the context of this paper, we are only referencing the legacy ABET outcomes. Ultimately, the preliminary results and analysis of this research will inform curriculum development and program outcomes for the coming academic years.

Methods

The IE pretests are used to evaluate students' preexisting knowledge prior to taking a course. Students are required to pass the pretest within the first two weeks of each quarter and are allowed to retake the pretest in order to obtain a passing score of 70%. Due to the possibility of multiple attempts, the data was cleaned to only contain results from completed first attempts. The pretests are hosted on a customized website made by the McCormick School of Engineering. The website houses all pretest performance data, which were exported to R Studio for analysis. In this paper, we use a quantitative method to understand the percentage of correct answers per pretest using the website's data. An additional data source was Northwestern's course registration site, which contains student enrollment information. This data was used to identify sample sizes for IE courses across terms and academic years.

The only set of data that required additional manipulation was the ABET outcome data. Because McCormick's custom website has only formally stored data on students' performance on pretest questions mapped to legacy ABET outcomes, we map the other outcomes using this information as a baseline in this paper. Efforts have been made to map pretest questions to the current 2022-

2023 ABET outcomes and complete a more thorough mapping analysis (Appendix C). First, based on the sample size and percentage of correct answers, the number of correct answer data points was calculated for each legacy ABET outcome. From there, the sample size and number of correct answers were used in tandem with the mappings to determine the percentage of correct answers for the BSIE outcomes.

Results

The preliminary quantitative results for students' pretest performance in the 2021-2022 and 2022-2023 AY are outlined in this section. The two figures outline the aggregate percentage of students who answered correctly on the pretests based on two dimensions: the ABET and BSIE results (Fig. 1) and the prerequisite course (Fig. 2). Tables I and II illustrate the percentage of students who answered correctly for select pretest questions.

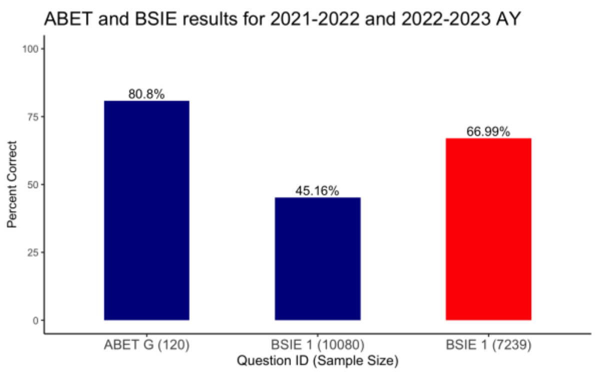

Fig. 1: ABET and BSIE Percentage of Correct Answers

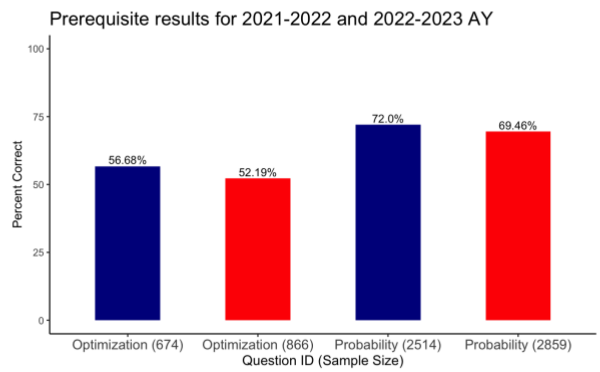

Fig. 2: Prerequisite Percentage of Correct Answers

Color	Corresponding Academic Year
	2021-2022
	2022-2023

TABLE I
Pretest Question Results and Learning Outcome Mapping

Q#	Question Content	% Correct in 2021-2022 AY	Sample Size	% Correct in 2022-2023 AY	Sample Size	Legacy ABET Outcome	BSIE Outcome
49	Interpret histogram results	75.93	54	87.30	63	G	3, 5, 6
56	Explain standard deviation to a non-technical audience	83.02	53	77.42	62		
147	Identify loss function for support vector machine	92.31	13	85.71	28		
135	Identify outliers in a dataset	52.63	19	44.59	74	F	2, 3, 5, 6

TABLE II
Pretest Question Results for Conceptual Areas of Strength and Weakness

Q#	Question Content	% Correct in 2021-2022 AY	Sample Size	% Correct in 2022-2023 AY	Sample Size
95	Interpret dual prices for a linear program	12.24	49	19.35	62
96	Identify reduced costs	38.78	49	30.65	62
104	Interpret dual prices and reduced costs	32.10	28	38.46	26
108	Interpret dual prices and reduced costs	42.86	28	23.08	26
55	Calculate conditional probability	89.71	68	90.67	75
39	Interpret variance	91.30	69	88.16	76
156	Explain the Law of Large Numbers	95.59	68	93.42	76

Analysis of Results

In this section, we analyze the results across three dimensions: ABET and BSIE outcomes, conceptual areas of strength, and conceptual areas of weakness. Note that the two academic years are often discussed in tandem because the overall conclusions are similar across both years. All specific quantitative data are reflected in Table I.

ABET and BSIE outcomes

Students seem to excel most at effective communication in an engineering context, which is connected to legacy ABET outcome G (Fig. 1). This is evidenced by three pretest questions. The first two questions (Q# 49 and Q# 56), which appear on the pretest for a discrete event systems simulation course, ask students to explain a complex concept in layman terms (Table I). However, the third pretest question, Q# 147, appears to assess students' memory and understanding of support vector machines, not necessarily communication. It is unclear how the question corresponds with its assigned ABET outcome. In the future, the mapping of pretest questions to learning outcomes should be carefully verified by faculty members before the test is administered to students.

Preliminary analysis was completed for the BSIE outcome results, but it was difficult to make meaningful conclusions. For example, BSIE outcome 1 had the highest percentage of correct answers for the 2021-2022 AY but the lowest for the 2022-2023 AY (Fig. 1). These varying results are a call to action for our department to directly remap all pretest questions to the new BSIE outcomes to obtain clearer results.

Conceptual areas of weakness

In analyzing the courses and prerequisite courses with the lowest passing percentages, it was revealed that students consistently struggle with duality and integer linear programming, which are both covered in the department's introduction to optimization course. Pretest questions with this course as a prerequisite saw the lowest passing percentage (Fig. 2). Notably, the questions with a passing rate of less than 50% tested concepts in duality. This is evidenced by Q# 95, Q# 96, Q# 104, and Q# 108 in both 2021-2022 and 2022-2023 AY (Table II). An interesting factor to consider is that the correct answer for Q# 95, which had the lowest passing percentage out of the entire dataset, was "None of these answers are correct." This answer choice is not often thought to be the correct answer by test-takers, which leads us to contemplate response bias: how the presentation of answer choices can impact an individual's decision-making process, regardless of their actual knowledge of the content.

There are several reasons to potentially explain these results. First, while the aforementioned concepts are covered extensively in the introduction to optimization course, we theorize that they tend to be difficult for students to grasp. This theory may be validated by qualitative student interviews. Second, as a whole, these optimization concepts are not reinforced in other core IE classes. A counterexample is the department's probability class, whose concepts are reviewed and expanded upon in the statistics course, statistical learning course, stochastic modeling course, and more. Thus, as IE students progress through their degree, they are consistently reminded of fundamental probability concepts, such as cumulative distributions, the Central Limit Theorem, and more. In comparison, the optimization course may feel siloed for students, as it is difficult to incorporate optimization models in other core IE classes and prerequisites. As a result, once students begin taking upper-level IE classes, they may have inevitably forgotten many of the concepts discussed in the optimization class.

Conceptual areas of strength

The pretest results also revealed that students perform well on questions that assess the concepts taught in the introduction to probability course, which is the first course that IE majors take. In particular, this was reflected in the pretest for the stochastic modeling course for which the introductory probability course is a prerequisite. This pretest had the highest percentage of correct answers out of all offered pretests (Fig. 2). Students performed well on questions assessing basic probability topics, such as conditional probability and variance (Table II). Interestingly, response bias is once again a potential factor in determining the difficulty of a pretest question—and thus, its passing percentage. For example, Q# 156 asked students to select the answer choice that best describes the concept of the Law of Large Numbers (LLN). The answer choices for the question were as follows:

A. As *n* increases to infinity, the value of $Xbar_n$ approaches the standard deviation σ.
B. As *n* increases to infinity, the value of $Xbar_n$ approaches the mean μ.
C. As *n* increases to infinity, the value of $Xbar_n$ approaches the variance σ^2.
D. Since $Xbar_n$ is a random variable for each *n*, the limit of $Xbar_n$ as n increases to infinity does not exist.

The correct answer to the question is choice B, which relates how the sample mean approaches the true mean as the number of samples increases. However, the alternative answer choices seem nonsensical, so even if students do not have a complete grasp of the LLN, at the very least, they may associate the sample mean with the true mean. We may study this phenomenon further, but we may assume that pretest questions may assess similar concepts, but they are not all the same difficulty level.

Future Plans

IE faculty, particularly those who teach the introductory optimization course and those who teach classes that this course is a prerequisite, should consider how to improve student retention of primal and dual linear programming concepts. In the quantitative analysis findings, it is evident that students consistently struggle with questions that test these concepts. Second, IE faculty may want to reevaluate which BSIE outcomes are important to assess on pretests. When the department utilized ABET's program accreditation criteria, the pretest assessment capabilities were more predetermined and regulated, but now that the department establishes its own criteria for assessment, there is more flexibility in which outcomes are assessed on pretests. Furthermore, the mapping of the BSIE outcomes to each pretest question should be intentionally selected by the collective advising of the IE faculty.

Many of the quantitative themes uncovered in this report are not well-explained. For example, why do students retain certain concepts better than others on course pretests? How do students approach pretests and what is their understanding of how pretest questions align with the course? It may be beneficial to conduct a qualitative study to investigate the underlying reasons behind the data. A focus group or individual interviews with faculty and students may elucidate more explanatory diagnoses. Our goal is to use a mixed method approach to analyze, align, and improve pretest assessment with the BSIE learning goals and outcomes.

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APPENDIX A
BSIE OUTCOME DEFINITIONS

Below are the BSIE learning outcomes for AY 2023-2024. Please note that numbers have been added to simplify the connection for the program assessment review process, and not by order of importance for learning and teaching objectives.

1. Students will have a solid foundation in the mathematics of Industrial Engineering and Operations Research (IE/OR) models and supporting quantitative methods by
    1.1. having a firm grasp of the mathematical theory necessary to understand and build such models.
2. Students will appreciate the broad applicability of IE/OR models in engineering and other contexts by
    2.1. understanding the taxonomy of descriptive, predictive and prescriptive models
    2.2. understanding the need to learn new models and methods as needed to solve new problems
    2.3. acquiring sufficiently broad education in math, science, and engineering disciplines to understand where such models might be used
    2.4. gaining the necessary context to understand and address global problems through exposure to social science and humanities disciplines.
3. Students will be able to formulate an IE/OR model of a systems-level problem to support decision-making, with consideration for
    3.1. user-centered design and end-user input
    3.2. available data
    3.3. appropriate choice of modeling and analysis methods
    3.4. model tractability.
4. Students will be able to solve IE/OR models that support decision-making by
    4.1. implementing and solving the model using modern software and programming languages
    4.2. designing and implementing solution methodology as needed
    4.3. rigorously and quantitatively analyzing solutions to the model at a depth supported by available data.
5. Students will be able to critically evaluate IE/OR models and solutions by
    5.1. reviewing literature to place the current problem, model and solution in context
    5.2. identifying shortcomings of the analysis
    5.3. assessing the impact of the limitations of the solutions on organizational goals and objectives
    5.4. recognizing the cost/benefit tradeoffs of implementing the proposed solutions.
6. Students will be able to leverage knowledge from Management Sciences to support the implementation of IE/OR models and solutions by
    6.1. identifying the impact of proposed solutions on individuals, organizations, markets, networks, and societies
    6.2. clearly communicating recommendations and limitations to end users recognizing the challenges inherent in implementing change in organizations effectively leading and working in teams

APPENDIX B
ABET STUDENT OUTCOMES

Below are the legacy ABET student outcomes for engineering programs from 2017-2018[1].

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Below are new ABET student outcomes for engineering programs from 2022-2023[2].

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

[1]Source: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2017-2018/#GC3
[2]Source: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/

APPENDIX C
ABET TO BSIE MAPPING

The mapping in Table III is a work in progress and an attempt to map the Legacy ABET outcomes to the New ABET outcomes, and to the BSIE outcomes. The first mapping was already created by ABET[3].

TABLE III
Legacy ABET to BSIE Outcomes

Legacy ABET Outcomes (2017-2018)	New ABET Outcomes (Applicable beginning in the 2019-20 cycle)	BSIE Goals and Outcomes (2023-2024)
(a) an ability to apply knowledge of mathematics, science, and engineering	Outcome 1	1, 2, 4
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	Outcome 6	1, 2, 3, 4, 5, 6
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	Outcome 2	2, 3, 4, 5, 6
(e) an ability to identify, formulate, and solve engineering problems	Outcome 1	1, 2, 4
(f) an understanding of professional and ethical responsibility	Outcome 4	2, 3, 5, 6
(g) an ability to communicate effectively	Outcome 3	3, 5, 6

[3]Source: https://www.abet.org/wp-content/uploads/2018/03/C3_C5_mapping_SEC_1-13-2018.pdf