Design and Implementation of a Course in Experimental Design and Technical Writing

Dr. Natasha Smith P.E., University of Virginia

Dr. Smith is an Associate Professor at the University of Virginia.

Dr. Andrew Jason Hill, University of Southern Indiana

Jason Hill is an associate professor of engineering at the University of Southern Indiana. He holds B.S., M.S., and Ph.D. degrees in civil engineering from Tennessee Technological University. His research interests include rainfall-runoff modeling and wetland hydrology.

Dr. Tom McDonald, University of Southern Indiana

Tom McDonald is an Associate Professor in the Engineering Department at the University of Southern Indiana. He serves as the Director for the MS Industrial Management Program. He earned his BSIE and MSIE degrees in Industrial Engineering from Clemson University and his PhD in Industrial and Systems Engineering from Virginia Tech. His research and teaching interests primarily include lean manufacturing, discrete event simulation and modeling, and engineering economy. Tom has been involved in lean manufacturing and modeling of production lines since 1999.

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Abstract

This paper describes the development and implementation of a sophomore level laboratory course entitled "Experimental Design and Technical Writing." The course was created to meet multiple objectives for a Bachelor of Science in Engineering (BSE) program at the University of Southern Indiana. First, stakeholders from the program advisory board identified the importance and need for improvement in the communication skills of graduates. In particular, they expressed a desire for employees to excel with various forms of written memoranda and reports, and the ability to comfortably deliver formal and informal oral presentations. Furthermore, the importance of writing within one's discipline was affirmed at the university level with a 2014 rewrite of the general education requirements for all bachelor degree programs. The new requirements include two "Writing Intensive" experience courses to be 'embedded' within a disciplinary topic. In addition to addressing the need for instruction in technical communication, the new course adds experiential learning and ethics to the sophomore engineering curriculum.

The format of this course is a 3 hour per week, combined lecture + laboratory, worth 2 credit hours. The syllabus has four content modules and an oral presentation module. Content includes experimental methods, design, and technical writing. The experimental methods component includes measurement error, calibration, experimental uncertainty propagation, and statistical analysis of data. Writing and oral presentation assignments are tailored to each module and call for an array of both formal and informal formats. Small section sizes (16 students) allow the instructor ample time to provide detailed reviews of student writing on assignments.

The modular design of the syllabus can accommodate any number of potential experiments as long as they meet the course outcomes. Current content modules include truss design & analysis, measurement uncertainty quantification, ethics case studies, and a pendulum air rocket experiment. The final module is a group presentation on an experiment conducted during the semester. This paper will include additional details on the course modules, student perceptions of the course, and an assessment of student learning.

Introduction

It has long been recognized that engineers need strong communication skills in addition to strong technical skills.[1,2] Engineers typically take a sequence of composition and rhetoric courses during the freshmen year. These courses are followed by other writing experiences more technical in nature, including formal reports in laboratory courses and writing associated with the capstone design experience. Many creative attempts have been made to improve writing frequency and quality in academic programs. One example is the PITCH (Project to Integrate Technical Communication Habits) initiative at the University of New Haven.[3] The goal is to develop communication skills (written, oral, and visual) and professional habits in engineering students using a variety of communication instruments extended throughout all four years of the program.

Conrad and Pfeiffer,[4] among others, noted a growing problem in engineering education, which is a mismatch between the writing students complete in their academic programs and the writing they are expected to produce in the workplace. A 2010 survey of the Engineering Advisory board at the University of Southern Indiana, had similar findings. Board members were asked to score both the frequency and importance of various types of technical communications. The survey results are summarized in Table 1. The results affirm the importance and need for improvement in the communication skills of early career engineers. They expressed a desire for employees to excel with various types of written communication and to have the ability to comfortably deliver formal and informal oral presentations. Shorter reports and informal presentations were found to be more frequent and important. Discussions began regarding the development of a new engineering course with a significant writing component to address these noted deficiencies.

Table 1: Summary of results from a communication survey of the Engineering Advisory Board (sample size = 11)

Form of Communication	**Frequency[1]**		**Importance[2]**	
	Average	Standard Deviation	Average	Standard Deviation
Formal Research Reports	3.10	0.88	1.90	0.32
Executive Summaries	2.89	0.93	2.22	0.67
Technical Memoranda	1.82	1.97	1.82	0.60
Progress Reports	1.73	0.47	2.18	0.75
Design Proposals	2.45	1.04	2.18	0.60
Design Reviews	2.27	0.90	2.09	0.54
Proposals	2.55	1.37	1.70	0.82
Formal Presentations	3.00	0.77	2.18	0.40
Informal Presentations	1.73	1.01	2.00	0.77
Incident/Accident Reports	3.00	1.48	1.82	0.98

[1] 1=Weekly, 2=Monthly, 3=Quarterly, 4=Yearly, 5=Never

[2] 1=Critically important, 2=Important, 3=Somewhat important, 4=Unimportant

Other weaknesses were identified in the curriculum through on-going ABET outcome assessment activities. Our curriculum lacked any courses in the sophomore year with a significant experiential learning component. Experiential learning is a highly valued component of the program with a positive effect on student retention and success. Outcome assessment activities had also identified a need to cover ethics during the sophomore year. Finally, in 2014, the university revamped the general education curriculum required for all bachelor degree programs; a component of the new curriculum requires students have two "Writing Intensive" embedded experience courses, the first of which is intended to be at a sophomore level, after they have completed two English composition courses. For a course to be "writing intensive", writing assignments must count for a minimum of 35% of the total course evaluation in a three-credit hour course, or its equivalent. At least one assignment must involve instructor review of student drafts, followed by revision and resubmission by the student. For university assessment of writing intensive courses, student writing for a key assignment is graded with regard to four categories: (1) statement of the thesis, (2) paragraph development, (3) complexity of thought, and (4) command of the written English.

A new course titled "ENGR291 Experimental Design and Technical Writing" was developed to address these known deficiencies in our curriculum. In the context of experimentation, design can be interpreted as the design of an experimental plan to solve a stated problem. This includes developing measurement protocols, study methodology, quantifying experimental uncertainty, and data-reduction. In laboratory courses that support engineering science courses (examples include strength of materials and fluid mechanics), time constraints can limit inclusion of experimental design and detailed guidance on technical writing.

This paper describes the development and implementation of this unique course. The following sections will present the course design, provide detailed module descriptions, and summarize course assessment of learning outcomes.

Course Design

The course targets sophomore engineering students. Prerequisites include a two course English composition sequence required for all programs at the university, and a freshman design sequence required for all engineering majors. In addition to meeting the university-wide "Writing Intensive" requirement, the course was designed to be part of the engineering core curriculum for the Bachelor of Science in Engineering (BSE) degree. In this program, students take 36 hours of courses covering core engineering content and then select 35 additional hours of technical electives in order to specialize in one of five disciplines: civil, electrical, industrial, mechanical, and mechatronics. ENGR 291 is also required for recently introduced discipline specific degrees in Mechanical and Manufacturing Engineering, and is part of proposed curricula for future programs in Civil Engineering and Electrical Engineering.

The format for the course includes two combined lecture + laboratory periods, with a total contact time of 3 hours. It is worth 2 semester credit hours. Course content includes experimental methods, design, and technical writing and is designed around five modules: four content modules and an oral presentation module. Each of the content modules has an experiential learning activity paired with one or more required writing assignments. The writing assignments vary in scale, purpose, and format. Small section sizes (16 students) allow the instructor ample time to provide detailed reviews of student writing. In addition, class time is devoted to outlining, draft writing, and peer review. The experimental methods content includes measurement error, calibration, experimental uncertainty propagation, and statistical analysis of data, all incorporated into the content modules. Finally, students give multiple oral presentation during the course culminating with a final group presentation based one of the experiments conducted.

The modular design of ENGR 291 can accommodate any number of potential experiments as long as they meet the course outcomes. These include “Writing Intensive” outcomes mentioned in the previous section as well as ABET outcomes concerned with experiment design & analysis, professional responsibilities & ethics, communication, and lifelong learning (B, F, G, and I).[5] In the sections that follow, the modules implemented during three consecutive semesters, from Fall 2017-Fall 2018 are outlined in more detail.

Module 1: Truss Design & Testing Module

This module has two phases, each with a different kind of writing assignment. In the first phase, students analyze a given roof truss and conduct experiments on a small-scale physical model to validate their analyses. Most students in the course had prior experience with truss analysis, so this activity proved to be an effective vehicle for them to observe basic concepts in uncertainty. A short discussion to introduce the module primes students with questions about how engineers design for safety and whether models, physical or analytical, could be trusted to predict ‘real world’ behavior. The first assignment requires they analyze a truss with given loading. Then small groups build a physical model using members and connectors from a PASCO bridge kit. Fig. 1 is an example of the PASCO roof truss model without loading; the inset provides a close-up of the connections and shows load cells used to measure member forces. They then installed load cells connected to Capstone software to measure member forces.[6] Finally, groups needed to calculate the error between their experimental results and analytical predictions. Follow-up lectures introduce the concept of systematic vs. random errors in measurements and an assignment requires they develop a validation plot with error bars to account for the manufacturer stated uncertainty of the load cell. A sample is shown in Fig. 2.

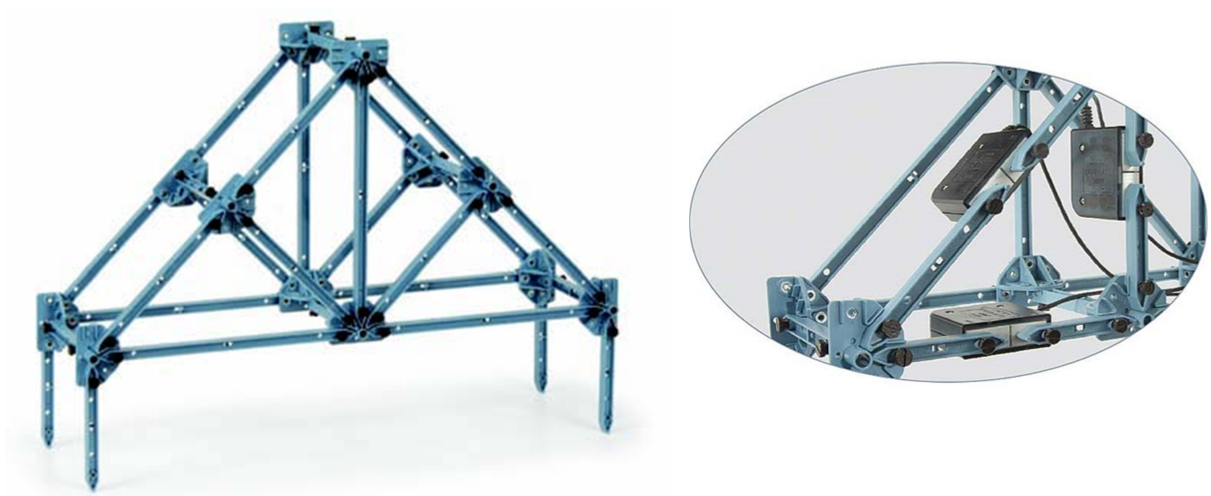

Figure 1: Roof truss constructed with parts from a PASCO bridge kit. The inset provides a close-up of connectors and shows load cells placed to measure member forces. Load cells are connected to a an amplifier (not shown) which is linked via USB to a computer with PASCO Capstone software (not shown). Images are from www. pasco.com.

The first writing assignment is to generate a full engineering report to assess the validity of the roof truss model. This is an individual assignment, but the instructor leads the class through brainstorming sessions for the four major aspects of the report: Introduction, Methods, Analysis of Results, and Conclusions. An abstract is also required. The introduction includes motivation for the experiment as well as background behind the analysis. The methods section focused on the experimental set-up and relevant equipment specifications such as load cell uncertainty. The results section addresses the central question on whether the analysis was validated by the experiment. This includes a inspection of the graphical comparison (as in Fig. 2) for evidence of systematic errors. One point of emphasis was that errors are introduced in the model as well as in the experiment. The class discusses underlying assumptions which might not apply for either the physical model or a 'real world' structure. For example, the analysis treats all members as pin-connected and therefore two-force. This simplification could be a source of error, particularly if the PASCO connectors were tightened to restrict small rotations. Two class-periods have been used for group peer review and revision of draft sections before final submission.

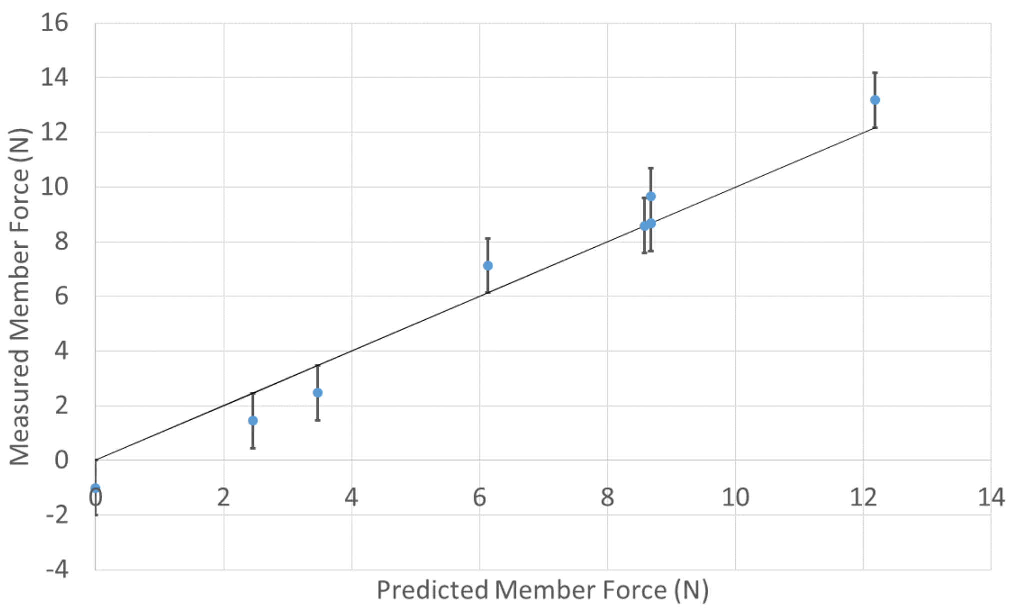

Figure 2: Sample validation data from Roof Truss Experiment showing measured vs. predicted member forces. Error bars reflect a $\pm$1N measurement error from the load cell. Some measurements are (nearly) outside the load cell error. An equal number of points below and above the predicted=measured line shows no evidence of systemic (or bias) errors.

The second part of the module involves the design of a truss to meet a specific set of constraints, and the presentation of this design through a written business proposal. The design constraints include a minimum span and a maximum member force limit. The truss also has to support a minimum load at a specific joint. In addition, groups compete to 'win' the job based on 1) maximizing the load capacity for a force at a specific location and 2) minimizing cost. Unit costs were given for each structural members based on their size, and for each connector. The proposal includes a cover letter to highlight key aspects of the design, a bill of materials and cost projection, and analysis showing maximum load capacity. The business letter gives students practice with a common form of written communication in the workplace. In addition, the proposals are graded on the level of professionalism in which supporting documents (analysis, bill of materials, etc.) are presented.

Module 2: Measurement Uncertainty Module

The overall objective of this module is to learn and apply techniques for quantifying experimental uncertainty. Two short experiments are completed to provide context for applying the various techniques. Each experiment ends with an assignment focused on writing an executive summary.

The first experiment involves the measurement of volumetric discharge (Q) with a nozzle meter. Students are exposed to an explanation of how a nozzle meter works as a measurement device. This includes developing the various equations and explaining the variables involved. Two of the variables in the nozzle meter equation are postulated to have experimental uncertainty. A formal technique, called first-order uncertainty propagation,[7,8] is introduced and used to examine how uncertainty in the two variables influences volumetric discharge. An experiment is conducted using the 4-meter-long laboratory flume shown in Figure 3. The pressure drop across the nozzle meter is measured with the manometer. Students conduct repeated measurements at different discharges to obtain an estimate of the experimental uncertainty. Guidance in the technical literature is used to estimate uncertainty in the other variable. Graphical displays of the results are created by the students and showcased in an executive summary.

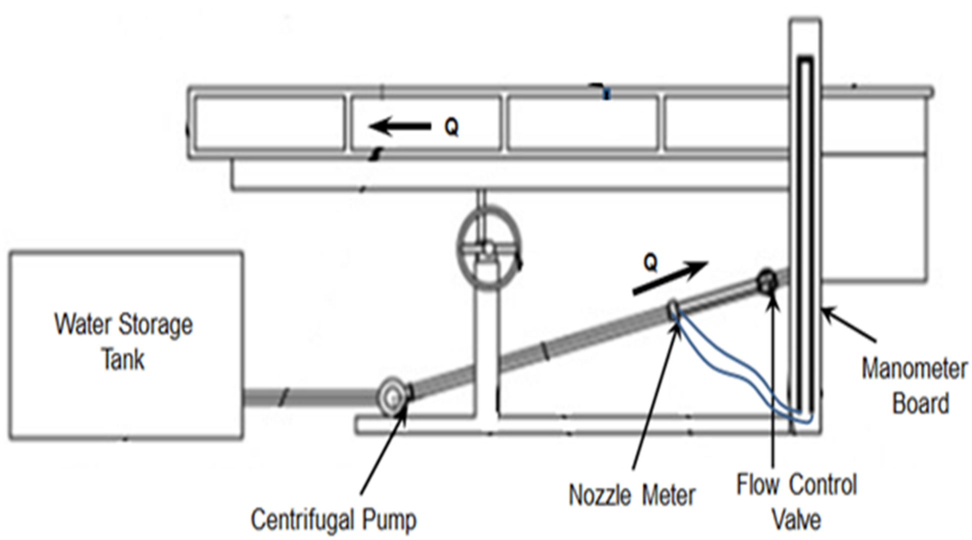

Figure 3: Open channel laboratory flume manufactured by TecQuipment

The second experiment involves determining the modulus of elasticity of balsa wood and the corresponding uncertainty in the estimate. Student groups are asked to design a deflection experiment where a balsa wood beam is loaded and the resulting deflection is measured. Deflection is related to the load magnitude, moment of inertia of the beam cross section, beam length between supports, and the modulus of elasticity. Students take the needed measurements, quantify experimental uncertainty, and propagate the uncertainty through the various equations.

Lecture content for the writing component is focused on writing an executive summary with numerous examples reviewed by the students. Students have prior experience in Module 1 writing an abstract. Compared to an abstract, the executive summary is longer and includes a graphical display of results for both experiments. This module also requires brief, informal presentation of results in class. This module emphasizes two of the forms of communication shown in Table 1.

Module 3: Ethic Case Study Module

The ethics modules introduced the need for professional ethics within all fields of engineering. The introductory lecture and discussion asked the students four basic questions:

1. What is a profession?
2. What does it mean to be a professional engineer?
3. Why are ethical standards of particular importance to the engineering profession? and
4. How are ethical standards enforced for engineering sectors not regulated by states, e.g. the automotive industry?.

As part of the discussion each student was given the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers. Each student group was then asked to discuss and briefly present on one of the six fundamental canons. An out of class assignment was for the students to research the code of ethics for a professional society within their engineering discipline (e.g., ASCE, ASME, IEEE, IISE) and determine how they compare to the NSPE Code of Ethics for Engineers.

To prepare students to write the essays required for the Ethics Module, a handout on what is considered scholarly writing is disseminated and discussed. The handout includes information on publications, authors, and articles. The instructors discuss aspects such as audience, publishers, reading level, data, and references. What peer-reviewed literature means and where to find scholarly articles are also part of the discussion.

The Ethics Module is centered about two case studies 1) the Volkswagen emissions control scandal and 2) an ethics case selected by the students with the approval of the instructor. Each group is given a different article about the Volkswagen emissions control scandal.[9–15] The group then has to write a 500 – 1000 word essay that includes the relevant facts to corroborate the inferences drawn. The essay has to include background and history on nitrous oxide NOx emission standards, where and why the standards were developed, and how they differ in the U.S. compared to the rest of the world. In addition to the NOx history, the essay includes a discussion of the moral obligations of engineers responsible for automotive design. As part of this discussion students are encouraged to comment on the fact that the automotive industry does not require professional engineer's licensure. Lastly, the essay suggests measures that should be taken to ensure accountability to the public. The group is asked to discuss who should be accountable, who holds the responsibility to hold them accountable, and what the appropriate measures to ensure justice are. To conclude the assignment each group has to prepare and conduct a 15 minute oral presentation on the assigned article.

The individual assignment provides the students with opportunity to research and report on a recent case regarding engineering ethics. The essay is to be 1500 – 2500 words. The students are provided with 18 cases or they could find a case of their own that was within the last 15 years. For the selected topic, the students discuss the role and choices of professional engineers. To help students with formatting and writing the paper, general guidelines are provided for each of the sections of the paper. The introduction provides a synopsis of the event and the outcomes. The next section includes a discussion of the roles of the engineers involved in the design and/or maintenance of the structure or system. Lastly, the students assess the engineering judgments and ethical choices made. Each student is also required to present the findings and assessments to the class in a 3 – 5 minute presentation using appropriate visual aids.

Module 4: Air Rocket Module

The final experiment is completed for module four and involves firing a pressurized air rocket constrained to pendular motion. The inspiration for the experiment was a paper by Kessler.[16] A picture of the experimental setup is shown in Figure 4. A pressurized air rocket (i.e., fire extinguisher) is attached to a circular shaft by a hollow aluminum bar. The rocket freely rotates about the circular shaft. The overall objective of this experiment is to compute thrust and impulse as functions of time for a rocket launch, including uncertainty estimates.

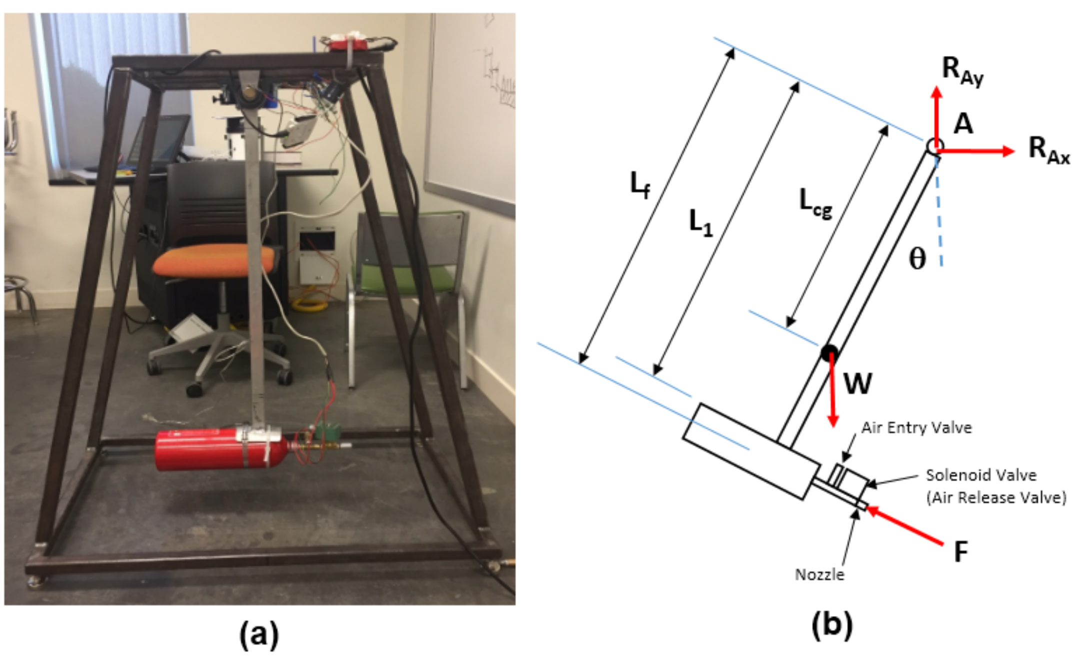

Figure 4: (a) Experimental setup for the pressurized air rocket experiment and (b) Free body diagram of the rocket assembly with relevant forces indicated by red arrows

Detailed equations for thrust, impulse, and experimental uncertainty are provided by Kessler.[16] Work for this experiment is completed in four different submodules (4a, 4b, 4c, and 4d). Module 4a details the measurement systems, including the various sensor specifications and data processing details. Students are shown a LabVIEW interface that displays sensor output and taken through a rocket launch in groups of 3-5 students. For Module 4b, student groups independently determine the input parameters needed to compute thrust and impulse. For example, the lengths L1, Lf, and Lcg must be determined (Figure 4). Module 4c focuses on experimental uncertainty in thrust and impulse. Student groups are asked to share their results with the class through an informal presentation. It is interesting to see the variability in the results due to variation in the input parameters. The final submodule (4d) focuses on writing a comprehensive report. Limited guidance on writing the final report is given to the students. This is final major writing assignment for the course.

Module 5: Oral Presentations

As part of the coursework requirements, students have to prepare and present multiple formal and informal presentations. Two of the presentations are discussed in the Ethics Module. For their last formal presentation, the students have to give a 15-minute group presentation on one of the following topics from previous course modules:

- Design of a truss bridge;
- Comparison of measured axial forces in a roof truss to theoretical values;
- Measurement of volumetric discharge with a nozzle meter;
- Modulus of elasticity of balsa wood; or
- Thrust and impulse from an air rocket.

All presentations were graded using the same modified version of the "Oral Communication VALUE Rubric" developed by the Association of American Colleges and Universities.[17] The VALUE rubric has the following five categories/concepts for evaluating the oral presentation:

1. Organization – how well ideas and supporting material is grouped and sequenced;
2. Language – sentence structure, terminology, and vocabulary;
3. Delivery Techniques – use of voice, gestures, posture, and eye contact;
4. Supporting Material – examples, explanations, analogies, statistics, and other kinds of information to support the principal ideas; and
5. Central Message – the main point or "take-away".

Feedback was provided to each group and individual for each of the presentations.

Assessment

Two types of assessments are presented in this section. The first assessment is a course-level assessment that is completed each semester for all engineering courses as part of our on-going ABET accreditation and continuous improvement process. A second assessment is presented that is used for a university-level assessment of the core curriculum (Core 39).

A survey was administered at the end of the course in Spring 2017 and completed by all students in the class. The survey included a statement of the ABET learning outcomes and corresponding performance indicators and asked the students to evaluate how well they were achieved using a scale ranging from 1 to 10 with 10 representing "strongly agree" and 1, "strongly disagree." Average scores were converted to a percentage (0-100%). For comparison, a classroom composite score, derived from specific writing assignments, was computed for each performance indicator. A description of each artifact and the corresponding learning outcomes and performance indicators is shown in Table 2.

The results are displayed in Figure 5. All student scores were above 80%, indicating the students felt they achieved the course learning outcomes. Classroom composite scores compared favorably to the survey results (generally within 5 percentage points).

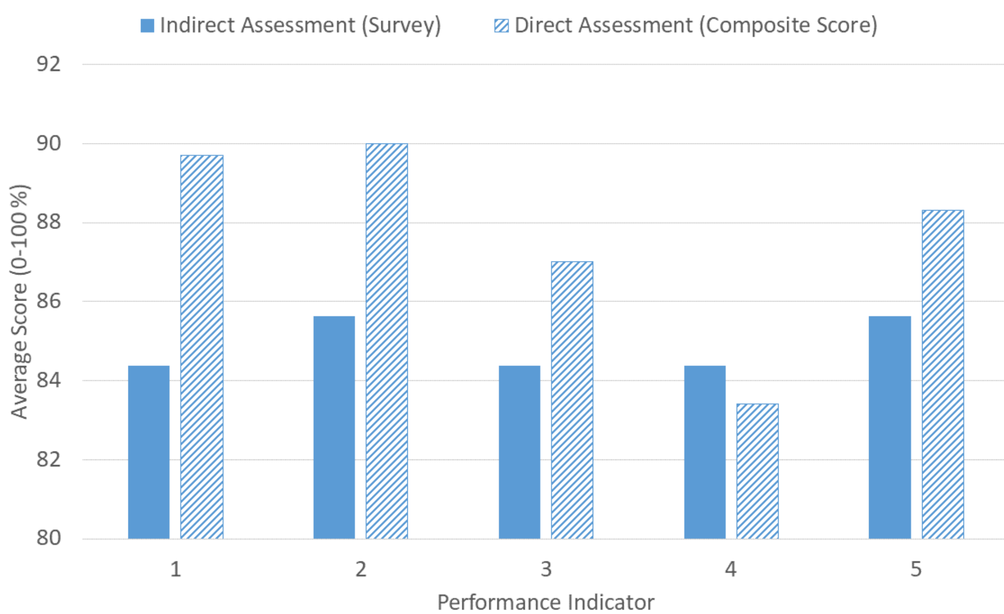

Figure 5: Assessment of ABET learning outcomes, including both a student self-assessment score and a composite score derived from graded writing assignments.

As part of the on-going university-level assessment of the core curriculum, ENGR 291 was assessed during the Fall 2017 semester. The final report for Module 4 (Air Rocket Experiment), considered the culminating writing experience, was identified as the key assignment. A grading rubric, consisting of the four categories summarized in Table 3, was used to evaluate 19 student report submissions. Grades of 0 [Fails to Meet Expectations], 1 [Meets Expectations], or 2 [Exceeds

Table 2: Summary of ABET learning outcomes, performance indicators, and artifact descriptions used for assessment in ENGR291

ABET Learning Outcome and Performance Indicator(s)	**ABET Learning Outcome and Performance Indicator(s)**
Students will have the ability to design and conduct experiments to analyze and interpret data (Outcome B) B.1 Design and conduct an experiment to solve a given experimental problem.	B.1 Average class grade for the final experiment full report submitted during the final exam period (Air Rocket experiment, Module 4)
Students will have an understanding of both professional responsibilities and workplace ethics (Outcome F) F.2 Write a critical essay discussing ethical decisions of professionals involved in an engineering failure.	F.1 Average grade for individual essay on student-selected ethics case study (Module 3)
Students will develop an ability to communicate effectively (Outcome G) G.3 Write two technical reports detailing the design, execution, and results of a laboratory experiment. G.4 Deliver an oral presentation on the final experiment.	G.3 Average grade for the final report of truss bridge experiment (Module 1) and the final report for the air-rocket experiment (Module 4) G.4 Average grade for group oral presentation delivered during the final exam period
Students will have recognition of the need for and an ability to engage in lifelong learning (Outcome I) I.5 Using a variety of sources, research the technical, organizational, and ethical issues related to an engineering failure.s	I.5 Average grade for individual essay on student-selected ethics case study (Module 3)

Expectations] were assigned for each category. The results are summarized in Table 3.

Table 3: Summary of grading rubric results for the culminating report

Report Attribute	Average	Standard Deviation
Paragraph development	1.7	0.48
Statement of the thesis	1.7	0.48
Complexity of thought	1.2	0.42
Command of Written English	1.6	0.50

Fails to Meet (0), Meets (1), or Exceeds Expectations (2)

Conclusions

With the design of "Experimental Design and Technical Writing," the authors have developed a course to enhance the Engineering curriculum by improving student oral and written communication, providing experience with experimentation and design, introducing fundamental concepts in uncertainty, and emphasizing professionalism and workplace ethics. A modular design allows instructors to adapt a variety of experiments and other activities that meet course outcomes. As a sample, this paper has presented specific modules used at the University of Southern Indiana in three successive semesters, from Fall 2016 to Fall 2017. In particular, we demonstrate how the various experiments are integrated with a variety of writing assignments. In addition to traditional laboratory or design reports, these include more compact forms of writing such as business letters, executive reports, and short essays. A key aspect to the course design is the combined lecture + laboratory format with small class sizes. This allows significant class time to be devoted to instruction on writing, developing drafts, peer review, and refinement.

The course was designed to meet multiple ABET outcomes in addition to technical writing requirements from the university-level. Both indirect and direct metrics have indicated success in meeting these outcomes, at least in the short term. The impact of the course on program outcomes will be assessed as part of the departments' three-year assessment/improvement cycle.

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