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ME Fundamentals 1 and 2: a new course sequence for first-year mechanical engineering

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Abstract

With programmatic evaluation and recent aggregated college-level data informing our need for immediate action, our mechanical engineering program is implementing two new courses for first-year students. Mechanical Engineering (ME) Fundamentals 1 and 2 is a fully coordinated sequence designed to actively engage students and equip them with the knowledge, skills, and abilities (KSAs) necessary for a career in the mechanical engineering profession. Two courses are built from the ground up using various course planning tools, leveraging numerous best practices in engineering education. We describe the twelve-month collaborative design process for the course sequence and offer candid discussion of key challenges faced. During Fall 2022, ME Fundamentals 1 is piloted with a cohort of 39 first-year students, who will continue as a cohort in ME Fundamentals 2 during Spring 2023. The pilot cohort represents approximately 16% of the total enrollment of first-year mechanical engineering students at our institution. The literature supports the importance of first-year experiences with the major; however, our current ME program of study does not directly engage our majors until mid-way in year two as sophomores. While our pilot implementation is not conducting a rigorous engineering education research plan, we are undertaking various direct measures of course delivery and student achievement with cognitive and affective domain learning objectives. We anticipate conducting longitudinal tracking of the cohort as they progress through the major, with the hypothesis that we retain a higher percentage of students in the major because of this first-year experience in mechanical engineering.

Keywords

First Year, Retention, Course Design

Introduction

The curriculum design for an ME program can vary significantly with respect to the upper-level ME technical discipline content; however, the first and second years are frequently dominated by courses that meet general education requirements for a given state as well as the required number of hours in mathematics and/or sciences that support the major for ABET accreditation. Since 2000, our program has undergone both minor and major redesign due to a variety of circumstances:

- reduction in the number of credit hours for the degree, from 136 to 128 credit hours, driven by state legislative decisions
- direct entry into discipline major as a first-year student, bypassing what we had historically offered as a common first-year experience allowing students to explore and discover what might be their best major; this included an Introduction to Engineering course, which was lost from the curriculum
- university's adoption of an Introduction to University life course and subsequent abandonment of this course after 10 years of data did not show significant improvement in student retention. Note: Our department experienced constant challenge staffing this one-hour course with ME faculty, so students were never really assured an introduction to the major by an ME faculty.

This brings us to today, where students selecting the ME major and becoming an ME major in their first year at our institution do not actually experience a course taught by an ME faculty until mid-way through their second year. They are lacking any formal introduction to the major of engineering, much less mechanical engineering, during their first year.

College Level Data

A recent review of college-level data provided by the college administration shows fall-to-fall retention of first-year students in the ME major. Our ME department retention rates are variable, from a high of 72% (FY16) to a low of 55% (FY20). A linear curve fit indicates a decline rate of approximately 10 percent from Fall 2015 to Fall 2020, see Figure 1. This trend over five years is alarming in a climate of funding being based on student retention. Our overall enrollment in ME is strong, with approximately 700 undergraduates and with more than 200 first-year ME majors starting in a typical year. However, the idea that we are failing to retain from 32% (FY15) to 45% (FY20) of our first-year students prior to even seeing them in an ME course taught by an ME faculty is troubling.

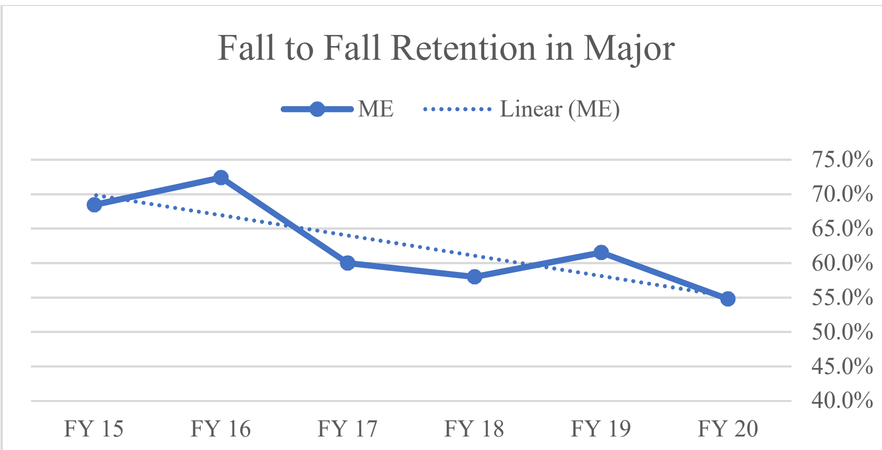

Figure 1. Fall-to-Fall Retention of First-Year Students

Departmental Programmatic Data and ABET

During our continuous improvement cycle reported every six years in our ABET accreditation self-study, we had been taking note of alumni (one-year and five-year) and graduating student feedback regarding respondents' perception of their ability with graphics and solid modeling. Through data collected from exit interviews and annual alumni surveys, students and alumni did not feel adequately prepared with 3D CAD tools. We received numerous suggestions for improvement to offer more training in and usage of SolidWorks, commercial software for parametric solid modeling. The lack of student skills in 3D CAD is also evidenced in the student's inability to produce computer models for Junior and Senior level design courses. The ME faculty is committed to supporting students' development of these skills, which in turn requires more use of CAD tools in upper-level courses. As a department, we took this to mean that students need to complete their first year not only with competency using the CAD software but also with the self-study skills to renew their CAD capability in later courses without direct instructional intervention.

Observations made by faculty mentors and external reviewers during senior capstone projects as well as faculty feedback from other upper-level courses, also indicate our students lack the skill and confidence to use programming for analysis. Currently, we rely on MATLAB as our ME programming language, introduced in the first-year programming course and again in an upper-level third-year course called ME Analysis. Student work in other upper-level courses demonstrates a lack of a systematic approach to problem-solving. Students also lack skills with computational tools such as Excel or MATLAB when applied to analyzing problems in those other courses. Members of our external advisory board have suggested we as faculty, demonstrate and expect the use of Excel to do complex computations, given that many of our students may go to work in industrial settings where MATLAB is not available as a purchased software, however, spreadsheeting software would be available.

Proposed Solution

In the current structure of our ME curriculum, students complete 3 semesters before they take their first departmental ME course, typically Dynamics and/or Professionalism and Ethics, in their second year. During the crucial first year, students are missing the opportunity of connecting to their chosen major of mechanical engineering as well as learn the fundamental skills and basics of how to be a mechanical engineer. In an effort to re-purpose already existing credit hours in the first year, we determined that use of the four credit hours dedicated to Graphics (2 cr-hr) and Programming (2 cr-hr) in the first year might afford us a way to both update the learning expectations of these courses, while simultaneously providing a platform to explore the ME major directly in the first year.

The current Learning Outcomes for ENGR1110 Graphics, taught by General and Basic Engineering, as reported in our most recent ABET self-study report, are that students shall be able to demonstrate: 1) Knowledge of the fundamentals of engineering graphics, including orthographic projections, pictorial views, sectional views, auxiliary views, dimensioning, limits and tolerance values, working drawings, schematics, and standard practices; 2) the ability to document engineering designs through the creation of typical engineering graphics products using sketching techniques, 2D drafting software, and 3D solid modeling software; and 3) the ability to read and interpret typical engineering drawings.

Likewise, the current Learning Outcomes for ENGR1120 Programming indicate that students are expected to have: 1) Knowledge of fundamental computer programming topics, including sequential, conditional, and repetition structures, intrinsic and user-defined functions, data input/output techniques, and arrays; 2) the ability to analyze a problem, break it into discrete steps, develop an algorithm for its solution, represent the algorithm with a flowchart, and convert the flowchart into a working computer program using a high-level computer language; and 3) The ability to analyze and debug programs written in a high-level computer language.

Offering a historical perspective of engineering education change at our institution, we compared these current learning outcomes to those required of an engineering student roughly 30 years ago when two of the authors completed graphics and programming training at this same institution. In 1985, learning outcomes were not explicitly stated. However, the course description for two-quarters of graphics (BE111 and BE112) indicated that the following would be taught: graphical expression and communication designed to fulfill the needs of the modern engineer, specifically engineering geometry, multiview, and pictorial representation, freehand sketching, drafting symbols, elementary original design problems and application. Also, in 1985, a one-quarter course in Digital Computer Programming (BE155) indicated students would be taught Fortran 77 programming, including flowcharting, coding, and running engineering problem solutions.

We note that there has been minimal change in Graphics and Programming in 30 years, except concerning what language and software were used. Therefore, we identified these two courses as likely candidates that could benefit the largest number of our first-year ME students directly with innovative instructional changes. We proposed to offer a two-course integrated sequence called ME Fundamentals 1 and 2 that would provide both an introduction to the profession of mechanical engineering (through design, analysis, experimentation, teaming, and communication) while simultaneously preparing students to learn and use the computer tools of the profession (Excel, MATLAB, and SolidWorks). We hypothesized that first-year ME students experiencing this sequence of revised courses for Graphics and Programming would build a stronger connection to their intended career in ME, would build integrated skills and abilities that would transfer, and would be more likely to continue successfully in their studies, thereby improving retention.

Course Sequence Redesign and Proposed Implementation

A review of ME curriculum at other universities was undertaken to examine public domain descriptions of their first-year experiences for engineering students. Several curricula were reviewed and four programs that modeled current best practices were selected for deeper study: Purdue, Virginia Tech, Michigan Tech, and UT Knoxville. These programs have similar general education (non-engineering) courses in the first year and have a 2-credit hour engineering course in each semester of the first year. The two new courses we propose have adapted course structure concepts and student support ideas from these model programs.

Implementation Plan A: In February of 2021, we proposed to the ME department and to the college that the ME department offer these redesigned courses in Fall 2021. ME Fundamentals 1 and 2 would each be a 2-credit hour course in the first year, Fall and Spring. The instructional staffing to deliver the courses to 200+ first-year ME students would require one ME faculty, four graduate teaching assistants, and ten undergraduate peer mentors. The courses would implement a weekly 1+2 model of large group seminars and small group collaborative (COLLAB) sessions. A tenured mechanical engineering professor would serve as course coordinator and lead instructor for the one-hour seminars. The coordinator would lead a team of four graduate Tas, and ten upper-level ME majors serving as ME peer mentors who, in turn, facilitate the weekly two-hour COLLAB sessions where the first-year students work in teams to complete the course learning activities. The first-year students would use SolidProfessor (required as a four-year paid subscription, replacing a standard textbook) [1] and Linked-In Learning (LiL) to support their learning objectives through self-study and team project-based activities. To enrich the course content, we proposed use of seminars and project-based learning. Example Seminar topics include a combination of invited industry mechanical engineers and upper-level ME majors speaking to their education paths and work experiences, linking these experiences back to the skills being learned in these first-year courses. Example Project-based activities include ME1 teams creating an assembly of parts using solid modeling and 3D printing where each team member is responsible for one part; once the assembly is constructed, it will be tested for functionality. ME2 teams would create teaching resources for middle and high school students to learn concepts of mechanical engineering, and these projects will be showcased with K-12 school outreach.

The original proposal to offer these two courses beginning in Fall 2021 was rejected due to administrative concerns with respect to finances, curriculum approval process, catalog changes, and compatibility for transfer students. The current Graphics and Programming courses are offered by another unit in the College of Engineering, General and Basic Engineering, and articulation agreements are in place with their course designators. The department chairs in ME and GBE, along with college administration, were concerned about how the ME department would be able to staff the new courses and with what funding for the requested four TA and ten peer mentors. College leadership proposed an alternative plan.

Implementation Plan B: In spring 2022, a compromise was made to offer a pilot version of the two courses during the Fall 2022 and Spring 2023, serving as a step-wise innovation. The ME department would staff two sections of Graphics and two sections of Programming with a tenured professor from ME, along with two undergraduate peer mentors, minus the use of graduate student teaching assistants. Data would be gathered during this pilot implementation to demonstrate the effectiveness of the redesign.

Methods of Course Design

As instructors, we often approach course design with a focus on the inputs, such as textbook content and favored lessons and activities. Undertaking formal course design, we are encouraged to apply the backwards design method, which focuses on the output - beginning with the desired results and noting what students need to learn rather than what instructors want to teach. The three stages of backwards design [2] include identifying desired results (learning goals and objectives), determining acceptable evidence (assessments), and planning learning experiences and instructions (activities and materials). Rather than students learning for the sake of learning, they are given a clear purpose that ties to their overall course goals. We adapted a Course Structure Planning Guide from the University of Illinois Center for Innovation and Learning [3] as a curriculum map for Mechanical Engineering Fundamentals 1. We identified six goals and objectives for the course and created a weekly outline with main topics and weekly objectives that aligned to the overall course goals. Then, we created assessments to ensure proficiency in the weekly objectives. Finally, we planned the in-class activities and listed materials students would need, such as learning modules, software, and hardware.

Cognitive and Affective Domain

When designing instruction, one must consider what type of learning is taking place. Learning domains, created by Benjamin Bloom and his colleagues, are some of the most well-known distinctions that refer to the specific types of learning[4]. Using the cognitive and affective domains in instructional design can benefit students when developing learning objectives and planning assessments. The cognitive domain involves thinking about facts, terms, patterns, etc. Bloom's taxonomy of the cognitive domain consists of six hierarchical levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. In the lowest level (knowledge) learners can remember or recite information without understanding it. In the highest level (evaluation) students can make judgments based on materials using higher-order thinking and synthesizing the information. Meanwhile, the affective domain deals with emotional responses. The levels range from least to most committed and include receiving, responding, valuing, organizing, and internalizing[5].

The modified learning outcomes for ME Fundamentals 1 and 2 now include both the cognitive and affective domains to support an instructional design aimed at developing students' knowledge, skills, and abilities for more than Graphics and Programming. Students are now developing awareness of the ME profession and becoming prepared for success in further undergraduate studies.

Revised Learning Outcomes

The revised Learning Outcomes for ME Fundamentals 1 and 2 are presented below. The choice of verb aligns with useful tables of cognitive and affective domain descriptors [6], [7]. The detailed sub-descriptors offer an explicit statement of what competencies will be measured. Note the sequencing of level of expectation from the first course to the second course, for example, in the change from Explain to Apply for outcome 1 (analysis thinking) and outcome 2 (design thinking).

ME Fundamentals 1 (pilot delivery in two sections of ENGR1110 Graphics, Fall 2022)

1. Explain analysis thinking.
    a. Identify a problem and break the problem into solvable parts.
    b. Use evidence (units, equations, variables) to develop solutions.
2. Explain design thinking and the engineering design process.

a. Deconstruct an existing engineering product and reverse engineer the object for manufacture as an assembly of parts

3. Explain team roles and value of teamwork.
   a. Contribute to team products and discussions.
   b. Cooperate in group activities.
   c. Reflect on both personal and team's problem solving/design approach and process for the purpose of continuous improvement
4. Program and annotate simple equations and algorithms in a spreadsheet tool (Excel)
   a. Visually represent data and derive meaningful information from data
5. Model simple objects in 3 dimensions (Solidworks) – meets ENGR1110 objectives
   a. Read and interpret engineering drawings
   b. Define: orthographic projections, pictorial views, sectional views, auxiliary views, dimensioning, limits and tolerance values, working drawings, schematics, and standard practices
   c. Document engineering design using sketching techniques, 2D drafting software and 3D modeling software (Solidworks)
6. Devise self-study plan(s), with goals, objectives, activities, and timeline.
   a. Implement self-study plan(s) and present outcomes

ME Fundamentals 2 (pilot delivery in ENGR1120 Programming, Spring 2023)

1. Apply design thinking
   a. Contribute to the design process
   b. Design high quality technical solutions that meet client and user needs
2. Apply analysis thinking
   a. Predict results through analysis thinking
   b. Use evidence to make appropriate predictions using a mathematical model
   c. Analyze and model data using regression methods
3. Explain experimental methods
   a. Outline experimental processes
   b. Identify options for computational experiments
   c. Identify options for physical experiments
4. Use Engineering Communication Methods
   a. Explain results of analysis and experimentation
   b. Effectively communicate engineering concepts, ideas, and decisions, using written, visual, and oral approaches
   c. Read and create flowcharts as visual representations of a process
   d. Produce shop drawings and 3-D models for simple machine parts
5. Practice Teaming
   a. Apply team roles
   b. Cooperate in group activities
   c. Respect collaborative processes
6. Apply programming in MATLAB and Excel
   a. Implement direct and coded file commands, input and output formats, and logic structures
   b. Develop code solutions that address engineering questions and follow professional programming standards
   c. Explain and implement basic and intermediate programming structures: sequential structures, selection structures, repetition structures, and nested structures.
   d. Create adaptable, reusable programming routines

Competency-Based Assessments for ME Fundamentals 1 and 2

The decision to use competency-based assessment for the ME Fundamentals 1 and 2 courses is driven by the authors commitment to create authentic assessments with rapid feedback. Frequent assessment can lower students stress levels instead of the typical big-stakes assessments (2 tests and a final) where students often wait weeks to receive feedback. With frequent in-person competency assessment using pre-communicated rubrics, students can receive immediate feedback which helps alter their learning course before students are too far behind. Frequent, low stakes assessments can measure student ability while also allowing multiple opportunities to learn in multimodalities (in-person competency checks, practice problems, video tutorials, multiple quiz attempts). In the learning management system (LMS) gradebook, it will look like there are a lot of assessments (and there are) but they are worth fewer points each and students can easily attain the points by completion of assignments and by exploring other opportunities for learning (Solid Professor/LinkedIn Learning). This can be perceived as a gamification of the classroom through use of a points system where students start at zero and "earn" points by completion of assignments rather than "lose points" through larger stakes grading. These assessment strategies support Student Centered Learning which leads students to be more autonomous. Students tend to perform better when they feel more in control of their learning. Student-centered learning also increases student motivation and self-efficacy[8].

Mid-Semester Evaluation

While end-of-semester evaluations allow faculty to glean feedback from students at the culmination of a course, Small Group Instructional Diagnostics (SGIDs) [9], [10] offer students a chance to voice suggestions around mid-semester where changes can be made to improve instructional practices and current student learning. SGIDs were first implemented at the University of Washington by Dr. Joseph Clark and Dr. Mark Redmond (1982) to generate feedback from midterm small group discussions about a course and was designed for instructional improvement rather than administrative evaluation. In a study completed at Brigham Young University (BYU), 90 percent of the faculty who were interviewed felt midcourse evaluations improved student learning [11].

At Tennessee Tech University, the Center for Innovation in Teaching and Learning (CITL) facilitates SGID evaluations during the Fall and Spring semesters and utilizes online survey tools to provide confidential feedback to an instructor. After registering for a SGID to be conducted between weeks 6-8 of the semester, the facilitator schedules a premeeting with the faculty, where the process and questions are discussed. During the SGID session, typically 30 minutes duration, the faculty member leaves the classroom and students answer four SIGID survey questions individually, see below.

SGID Survey Questions:
1. Briefly describe what you like about the course–the characteristics that you believe support your learning.
2. Briefly describe what you dislike about the course–the characteristics that you believe hinder your learning.
3. What suggestions can you offer that would enhance your learning?
4. What can you (as a student) do to improve your learning?

The facilitator then groups the students (4-6) and asks them to reach a consensus on each question. Next, the CITL team creates a second survey where students will agree, disagree, or remain neutral on statements from the group responses. Students have 24 hours to complete the second survey. Finally, the facilitator takes information from the individual, small group, and whole group surveys and sorts the responses into overarching pedagogical themes. The report is given to the faculty member within 48 hours. The feedback offers a consensus of what students believe both support and hinder their learning as well as suggestions for enhancing the course. The nature of the comments from the SGID are much richer, more reflective, and more actionable than the end-of-semester evaluations.

The outcomes of the SGID for ENGR1110 and changes made to instructional plan based on the student feedback will be shared as part of a future publication.

Anecdotal Experience with Pilot Implementation

The students are exhibiting a strong collaborative team behavior in the course activities and assignments. We have been using the POGIL strategy[12] to establish team roles of Manager, Recorder, Presenter, and Strategist. During morning class sessions on Tuesdays and Thursdays, all 39 students meet together and we actively engage in topical discussion using a variety of techniques and approaches, such as Think-Pair-Share[13] and Kahoot![14]. In the afternoon COLLAB sessions, the competency assessments are conducted, as individuals on Tuesdays and as teams on Thursdays. The students are deeply engaged in the Team project of Reverse Engineering and in many cases have taken on individual Self-Study Plans to enhance their team abilities for the team project.

Next Steps

Details of the pilot implementation of ME Fundamentals 1 and 2 and future work will be reported in subsequent conferences based on approval of a mixed-methods education research study plan. Such data requires the Institutional Review Board (IRB) review of the proposed assessments, surveys and focus groups, to follow up with the students and their progress in subsequent courses and retention in the major.

References:

[1] M. Bubacz, N. Washuta, and P. Bass, "2018 ASEE Southeastern Section Conference A Flipped-Classroom Format Applied to a Software-Based Course," 2018.

[2] G. Wiggins and J. McTighe, *Understanding by Design*. Association for Supervision and Curriculum Development (ASCD), 2005.

[3] "Course Structure Planning Guide." Illinois Center fro Innovation in Teaching and Learning, [Online]. Available: https://citl.illinois.edu/docs/default-source/default-document-library/course-structure-planning-guide-(word)45550ecb0ab36b54b0abff0000b66f81.docx?sfvrsn=0.

[4] M. Forehand, "Bloom ' s Taxonomy : Original and revised," *Emerg. Perspect. Learn. teaching, Technol.*, p. 12, 2010, [Online]. Available: http://www4.edumoodle.at/gwk/pluginfile.php/109/mod_resource/content/5/forehand_bloomschetaxonomie02.pdf.

[5] A. H. Brown and T. D. Green, *The Essentials of Instructional Design*, 4th ed. New York: Routledge/Taylor & Francis, 2019.

[6] D. Kemmerer, "Action Verbs," *Cogn. Neurosci. Lang.*, pp. 331–356, 2020, doi: 10.4324/9781315764061-19.

[7] L. Anderson, "Bloom ' s Revised Taxonomy : Cognitive , Affective , and Psychomotor," 2000.

[8] M. Henri, M. D. Johnson, and B. Nepal, "A Review of Competency-Based Learning: Tools, Assessments, and Recommendations," *J. Eng. Educ.*, vol. 106, no. 4, pp. 607–638, Oct. 2017, doi: 10.1002/jee.20180.

[9] D. J. Clark and M. V. Redmond, "Small Group Instructional Diagnosis: Final Report," pp. 10–20, 1982, [Online]. Available: https://www.academia.edu/27875374/Small_Group_Instructional_Diagnosis_Final_Report?auto=download.

[10] B. Black, "Using the SGID Method for a Variety of Purposes," *To Improv. Acad.*, vol. 17, no. 20210331, 1998, doi: 10.3998/tia.17063888.0017.019.

[11] W. R. McGowan and R. T. Osguthorpe, "12: STUDENT AND FACULTY PERCEPTIONS OF EFFECTS OF MIDCOURSE EVALUATION," *To Improv. Acad.*, vol. 29, no. 1, pp. 160–172, Jun. 2011, doi: 10.1002/j.2334-4822.2011.tb00629.x.

[12] E. P. Douglas and C. C. Chiu, "Implementation of Process Oriented Guided Inquiry Learning (POGIL) in Engineering," *Adv. Eng. Educ.*, vol. 3, no. 3, pp. 1–16, 2013.

[13] Kaddoura et. al, "Think pair share: A teaching learning strategy to enhance students ' critical thinking," *Educ. Res. Q.*, vol. 36, no. 4, pp. 3–24, 2013.

[14] A. I. Wang and R. Tahir, "The effect of using Kahoot! for learning – A literature review," *Comput. Educ.*, vol. 149, no. May 2019, p. 103818, 2020, doi: 10.1016/j.compedu.2020.103818.