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A Review of Multi-Disciplinary Introduction-to-Engineering Courses and Unified-First-Year Engineering Programs

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A Review of Multi-Disciplinary Introduction-to-Engineering Courses and Unified-First-Year Engineering Programs

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Abstract

To better align the expectations of incoming freshmen with their choice-of-major, the authors are developing a common first-semester engineering course to introduce students to all engineering opportunities while it is still possible for them to change majors and maintain their original graduation timeline. In this paper, the authors provide an extensive review of introduction-to-engineering courses and unified-first-year engineering programs across the United States. A summary of lessons learned will guide development of a new all-discipline introductory course at the authors' home institution and position it as the cornerstone of a unified all-discipline freshman year.

Introduction & Motivations

Incoming freshmen often select their engineering discipline without a deep understanding of the implications for future studies and career opportunities. Without exposure to multiple disciplines, students can find themselves frustrated as they discover that their chosen major is not as rewarding or is not providing career opportunities as expected.

Currently, at the authors' institution, all freshmen complete a discipline-specific introduction-to-engineering course. As is true at many other institutions, the engineering majors are isolated, i.e. there is little overlap between curricula. On the other hand, some institutions have implemented a common first year across their disciplines which includes an introduction-to-engineering and problem-solving course in the Fall followed by a computer-aided problem-solving course in the Spring. Other schools split this difference; they offer a common Fall-semester introduction or a common Spring-semester computer-based problem-solving course. The authors' institution will offer a (new) non-discipline-specific introduction in the Fall; each discipline will build on this introduction in the Spring with its own (existing) computer-applications course.

To implement a freshman course common to all engineering majors, a careful balance must be struck between materials which are not discipline-specific (and tend to lack depth) vs. materials which are specific to individual disciplines (and allow for deeper study of a particular major). Before attempting to strike this balance across five different majors in a single freshman course, the authors surveyed openly-published literature to become maximally aware of the efforts of peer institutions which have developed common-intro courses to unify their engineering programs in the freshman year. In this paper, the authors provide an extensive review of introduction-to-engineering courses and unified-first-year engineering programs across the United States. A summary of lessons learned will guide development of an introductory course at the authors' home institution and position it as the cornerstone of a unified all-engineering-major freshman year.

Initial Information-Gathering and Development of Course Objectives

Recurring objectives for first-year engineering courses at many institutions include [1]

- professionalism -- respecting what engineers do and the differences between them, appreciating the history of engineering, becoming grounded in professional ethics,
- computer-based calculation -- growing comfortable with statistics and estimation, using analytical reasoning, taking and recording proper measurements, becoming familiar with a computer-aided-design tool, programming using a text-based language, and
- design -- working with a team, using sound judgment in a laboratory environment, communicating ideas clearly including writing technically.

Retention data, in particular the attitudes of students who leave engineering majors, reveal that the structure of engineering majors and the culture of engineering courses are more responsible for attrition than personal inadequacy or aptitude for other disciplines or the appeal of other majors [2]. In response, some engineering programs have devoted significant class time in the freshman year to adjusting to college life, managing stress, and taking advantage of vocational opportunities such as internships, while providing only a cursory overview of the different engineering disciplines. With success in *college* as well as in *engineering* in mind, the authors have drafted three highest-level course goals; they are listed in Figure 1.

Course Goals.

This course has three main aims:

Curiosity	To foster a love for engineering through an introduction to the disciplines, subdisciplines, and careers that await diligent engineering majors.
Connections	To equip students to successfully integrate into the School of Engineering learning community establishing academic and personal habits that will lead to academic success.
Creating Values	To support engineering students confident and knowledgeable commitment to a specific engineering major resulting in joy in the classroom and the achievement of life-long goals.

Figure 1. Highest-level course goals, from the syllabus drafted by the authors for their *Introduction to Engineering* course to be piloted in Fall 2023.

Many faculty and employers believe that 4-year engineering schools often do not prepare students to (a) work with others, (b) find collaborative solutions, (c) discuss open-ended problems, or (d) have patience with exploring fuzzy concepts [3]. Thus many first-year courses have been restructured to focus less on the "nuts-and-bolts" of engineering and more on developing skills for academic success, instilling a sense of community, and generating enthusiasm for engineering [4]. Under the assumption that "contact is more important than content," the highest-level goals are to create a supportive academic environment, to motivate students, and to provide them with information on how to be successful in their major. Emphasis is placed on increasing students' willingness to study in groups, minimizing the stigma of asking others for help, and encouraging professional behavior. One approach is to view the engineer as a decision-maker and communicator with potential for success in any discipline, i.e. without any discipline-specialization in the freshman year [5].

Nevertheless, there is broad agreement that students ought to proceed into their sophomore year armed with a set of skills common to all engineering disciplines, such as [6]

- representing data graphically (e.g. via hand-sketching or computer modeling),
- performing rudimentary engineering analysis (e.g. using mathematics and physics),
- constructing and testing working prototypes (e.g. structural/mechanical/electrical), and
- documenting failed attempts and viable solutions (e.g. using spreadsheets and slides).

To broaden freshmen students' perspective regarding engineering and to help them develop skills relevant to *all* engineering disciplines, the authors have drafted 8 course learning outcomes; they are provided in Figure 2.

Course Learning Outcomes.

1. Describe and illustrate formative content, comparative analysis, design outcomes, design cycle, societal impacts, and career opportunities for engineering and each of the disciplines and subdisciplines. (B1)
2. Describe the ethics of the engineering profession. (B1)
3. Evaluate team performance using project management, leadership, and team dynamics concepts. (B5)
4. Describe the learning process and the learning resources available to the student. (B1)
5. Demonstrate self-directed lifelong learning through reading, interpretation, and synthesis. (B3)
6. Articulate the requirements for professional licensure and success in a future career. (B2)
7. Practice sustainable engineering problem solving techniques, engineering analysis and design processes. (B3)
8. Communicate ideas, engineered solutions, and designs using technical communication skills including oral presentations, written reports, and graphics. (B3)

Figure 2. Learning outcomes, from the authors' draft syllabus for *Introduction to Engineering*. Each outcome is mapped to its level along Bloom's taxonomy (in parentheses).

Understanding Freshmen & Devoting Appropriate Resources to Them

Challenges that faculty face in conveying such skills to freshmen include (a) that Generation-Z learners have a short attention span, (b) students want immediate feedback, and (c) students are persistent in their belief that they do not need to study more than they already do [7, 8]. Particularly for freshmen, teachers are advised to develop short, content-focused presentations followed by interactive activities and assessment. Colleges are encouraged to invest in small recording studios -- document cameras, face cameras, tablet computers, lapel microphones, and acoustic panels -- so that professors can record short (10-15 minute) lectures which students can access later should they need to review course material [7]. If lectures are recorded ahead-of-time, professors can "flip the classroom," i.e. they can ask students to watch videos as tutorials *before* class so that the scheduled class period may be used for interactive activities [9]. With videos provided as a library of course content, a similar treatment for the "textbook" would be as a collection of lessons and examples curated by previous/current intro-freshman instructors [10].

Faculty and administrators recommend restricting the pool of instructors for freshmen courses to those with clearly-demonstrated enthusiasm for their discipline [11]. A course which samples different disciplines can be taught by a team of professors who rotate lectures and introduce discipline-specific tools [12]. Alternatively, such a course can be taught by professors who stay with their class (i.e. without rotation); such faculty must be conversant in disciplines outside their native specialization; this often requires professors to step outside their natural intellectual comfort zones [13].

Classes may be structured by punctuating large-group lectures with small-group breakout activities [13]. "Lectures" may still be interactive if they are delivered in a computer lab with each student following along on his own machine [14]. Many traditional lectures could be substituted with small-group discussions facilitated by student-peer mentors, i.e. upperclassmen who are particularly studious and enthusiastic [2], although considerable time must be spent in vetting such student-teachers [15]. For small-group activities, students can be sorted into interdisciplinary teams; to build a sense of cohesiveness, each student can stay in his team for the entire semester [12]. Team activities are best addressed at senior-capstone-type lab benches, e.g. with one computer and open desktop space for drawing/assembling [14].

There appears to be a consensus that a standalone intro-freshman engineering course should contain a mix of lectures, labs, and discussion [4, 16–18]. One strategy is to begin the course with several-weeks-worth of general modules focused on problem-solving and using computers, followed by shorter (student, self-selected) discipline-specific modules [19]. The discipline-specific assignments reinforce themes presented in the generic module. "Discussion" modules can center on softer-skill topics like how-to-register-for-courses, how-to-study, and career awareness. "Labs" are more technical; they can address problem-solving using mathematics (e.g. matrices, plotting) and computer tools (e.g. Matlab, MathCAD) [4].

Assessment

Graded assignments may consist of individual written homeworks, group projects, and quizzes; traditional written exams are generally avoided. Students might keep a weekly journal of reflections, e.g. regarding campus activities in which they have participated or academic difficulties they have encountered and overcome [4]. Ambitious programs ask each student to create a portfolio of work (including narrated audio/video reflections) which helps him/her to identify as an engineer [10].

Most published literature recommends that a large portion of first-year students' grades be based on projects -- generally team efforts [5, 6, 10, 18, 20–23]. Assignments can tie back to a unifying theme, e.g. autonomous robotics [20]. Projects may be structured such that small modules combine across the semester to form a larger design, e.g. assembling a portable electronic device for measuring the height of an object [12]. Such projects can combine multiple learning objectives and even multiple disciplines, e.g. using an electronic strain gauge to measure beam deformation [6]. Assignments can mix historical engineering, forensics, and current/emerging problems; each activity can be structured such that the students need to identify the tool(s) that an engineer (who is not necessarily specialized) would need to solve the problem-at-hand [22]. Certain case studies can illustrate the full design process, e.g. the Wright brothers airplane [21]. Projects which require advanced math/physics are typically avoided [21] or necessary (bare-bones) math/physics principles are taught immediately before tackling each project -- a theory-and-application technique called "just-in-time" instruction [6].

A draft of the authors' assessment criteria and weighting for each category are provided in Figure 3. The weightings will likely change before the *Introduction to Engineering* course is piloted as well as between the pilot and the second time that the course is offered.

Expected Performance Criteria	% of Grade
Plickers Quizzes	2%
Individual Assignments	15%
Subdiscipline Projects	36%
Interdisciplinary Capstone Project	10%
Discussion Boards	22%
Field Reports (11)	1% each
Student Notes	
Student Presentations (5% each)	15%
Total	100%

Figure 3. Grading categories and distribution of weights contributing to the overall score, from the authors' draft syllabus for *Introduction to Engineering*.

A number of papers list different projects appropriate for first-year engineering students [5, 6, 10, 18]. Most are team-based [18]. Many contain an element of competitiveness [6]. Some projects cleverly integrate skills from different disciplines [5]:

- use a (provided) large slingshot to launch a softball to hit a target,
- design and build a data scanner to read and execute commands in binary format,
- design and implement a microprocessor-based controller to adjust flow into a mixture, or
- design and build truss-like structures to meet load and deflection specifications.

Some engineering programs "book-end" their curricula by requiring freshmen to complete small-scale versions of senior capstone projects [10]. The authors intend to train freshmen engineering majors not only to complete projects (successfully) but to communicate (clearly) the results of their work, as directed in the syllabus section provided in Figure 4.

Student Presentations.

At the end of each subdiscipline project, each student will make on one (1) minute presentation about something connected to the project; an interesting case study, a future class, how current course content will be used in later classes, etc. The presentations will provide students with the opportunity to explore and practice professional presentation skills including visual aids (PowerPoint or board illustrations).

Figure 4. Sample section excised from the authors' draft syllabus.

Keeping the Course "Lively" -- Keeping the Freshmen Engaged

A uniquely instructive type of project is to *reverse*-engineer and rebuild an existing consumer product [21, 23]. For this type of assignment, students disassemble a finished product (e.g. small power tool, disposable camera, mechanical-ball mouse), sketch the pieces and how they come apart / are put back together, and then reassemble the product [21]. Faculty select products based on simplicity-of-design (i.e. number-of-parts), safety, cost, and availability. Immediately following disassembly, the students are asked to write a report detailing the number of parts, how they fit together, and why each part is necessary. In this moment, many students realize the scope of what they *don't* know about the behavior of "simple" engineered products, and they develop a deeper appreciation of engineering as a synthesis of materials, harnessed mathematics and science, and cost considerations -- all of which they will learn in later courses. Before reassembly, the students can measure and catalogue the parts, draw or otherwise model them in software, reassemble them (in simulation and/or physically), and write a report about how, why, and how *well* the re-assembled product works [23].

To break up a semester or modulate its pace, faculty can discuss their research or consulting work or prior employment [24] or they can invite full-time practicing engineers to speak to the class [13]. Aspiring engineers are particularly interested in hearing from recent graduates (i.e. *young* professionals); their talks help students to more easily envision "life after school" [17].

Tools that instructors might use to assess the quality of their freshman-intro course are [16]

- pre-course surveys (pre-existing knowledge & pre-conceptions),
- real-time computerized student assessment (throughout the semester),
- common midterms across sections (taught by different faculty),
- common instructor evaluations (for every module),
- post-module surveys, and
- post-course surveys.

Wisdom Passed on from Our Peer Institutions

Some faculty who have tried to unify their first-year courses have reported lessons learned from their experiences. One school started by implementing a 3-credit-hour course required of all engineering majors, but found the resource requirements too heavy and ultimately broke the course into a 1-credit common course and a 2-credit discipline-specific course [25]. Another school removed all "college survival" material (e.g. taking exams, working in teams, managing time) from the engineering course and placed it into a year-long 1-credit-hour seminar [26]. Yet another school divided the freshman-engineering material into 3 required courses [27]:

- Engineering Seminar: 0 credit hours, once-per-week, taken during the 1st semester -- a seminar/colloquium which consists of "what engineers do & how & why", ethics, professionalism, life-long learning, different disciplines -- graded as pass/fail only
- Introduction to Engineering: 3 credit hours, twice-per-week, taken during the 1st semester -- focuses on (team-oriented) hands-on projects, (individual) academic survival skills, rigorous systematic approaches for problem-solving, and "*forward*" engineering
- Introduction to Design: 3 credit hours, twice-per-week, taken during the 2nd semester -- introduces computer-aided design tools, engineering graphics (sketching, tolerances, blueprints), modern computer programs, and *reverse* engineering

The authors intend to begin unifying the first year of their 5 undergraduate majors at their institution -- civil engineering, construction engineering, mechanical engineering, computer engineering, and electrical engineering -- by creating a single course to be completed by every incoming engineering student. The authors' draft course description, which will soon be included in the school's course catalog, is provided in Figure 5.

Course Description.

"Required of Civil, Computer, Construction, Electrical, and Mechanical Engineering freshmen.
"Engineering students will broaden their understanding of the various engineering disciplines and subdisciplines and develop a greater commitment to one engineering major. Various projects, conducted within a collaborative learning environment, focus on creative engineering solutions through technical analysis, critical thinking, teamwork, communication skills, and professionalism. Students will explore practical problem solving, career paths, ethical canons, professional licensure, and other topics key to academic success.
"Laboratory: three hours"

Figure 5. Current version of the *Introduction to Engineering* course description, from the authors' syllabus and their institution's course catalog.

Beyond the authors' 1-year grant, the authors' School of Engineering might follow in the footsteps of other colleges -- previously funded by the National Science Foundation -- to unify both semesters of the freshman year and possibly the first two years of each major [28]. In doing so, incoming students would not need to declare a particular discipline as part of their major [5]; each student would enter college classified as an *engineer* only and declare the desired discipline during the sophomore year.

While student retention may be improved by implementing different strategies (e.g. performing outreach to high schools, maintaining social cohorts throughout the 4-year program, exposing undergraduates to research, providing remediation opportunities), the strategy which appears to retain the greatest percentage of students is to integrate courses across departments, including departments outside of the engineering school [29].

Unified Student Cohorts and Collaboration Between Faculty

Some schools co-enroll groups of students in the same schedule, year-to-year [11]. The students stay in the same (engineering, math, science, history, English) courses throughout their 4-year program. At least one school identifies students entering college without calculus ("behind" in math) and unifies their schedules as a type of "intervention" program which helps them to build a study-group earlier than their non-unified counterparts [30]. Another program requires students to pass an exam to earn entry into an "advanced" cohort with a unified schedule, essentially an engineering-specific honors program [31].

To enable synchronized schedules and overlapping course content, some schools have created Integrated Learning Blocks -- groupings of courses spanning multiple departments within which assignments are directly linked [32]. One example couples the intro-freshman-engineering course with a history course and an English-composition course: the student could study a noteworthy event (e.g. an engineering accident) in the history course, interpret relevant data in the intro-engineering course, and generate a report explaining what happened & lessons learned & potential solutions & cultural ramifications in the composition course.

To link course objectives, faculty must meet regularly to coordinate assignments [30]. Such synchronization is a heavy demand on professors' time. One program reported linking 2nd-semester calculus and 1st-semester physics with an introductory-engineering course by assigning projects which span all 3 courses, such as a tennis-ball launcher and an amphibious solar-powered vehicle [33]. Another program linked a 2-semester intro-engineering course to math and physics, with emphasis on technical-writing in the intro-engineering course as a way to link to English-composition also [34]. One extensively-developed program implemented an engineering design-clinic: a project-oriented sequence of 8 courses (i.e. spanning all 4 years) which tilts heavily towards practice and procedure in the freshman year but much more heavily towards theory and design in the senior year [35].

Short- and Long-Term Goals

The aforementioned efforts [28–35] are well beyond the scope of the authors' internally-funded 1-year grant. The authors intend to implement some ideas which have already seen success:

- emphasize that many skills are essential to engineers of all disciplines,
- strike an appropriate balance between lectures and interactive activities,
- ensure that assignments and projects span multiple disciplines, and
- require hands-on projects to be completed in teams.

Also, the authors intend to implement their own ideas which will allow a common-intro course to be successful at their home institution, given their unique constraints on space, time, technology, and other resources. In the near-term, the authors will agree on 4 sets of learning objectives, assignments, readings/videos, and presentation materials -- 1 set for a general-engineering curriculum and 3 separate sets for discipline- (department-) specific curricula. Over the next several months, the authors will collect and refine their course materials, and they will agree on method(s) for delivery of those materials. The authors intend to pilot their *Introduction to Engineering* course in the Fall of 2023.

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