# A Transition in Progress: Building the Foundation for KEEN Outcomes in First-Year Engineering

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*Abstract* - **Recent years have seen a dramatic growth in the number of first-year engineering programs. With that growth has come a broad discussion of what exactly that experience should entail and how it is best delivered to our students. Several on-going efforts seek to formalize this discussion, developing comprehensive maps of first-year engineering content. Broadly, the current consensus seems to align along some combination of engineering design, modeling, and analysis coupled with the non-technical skill areas of communication and teaming. In a separate effort, several institutions have come together under the Kern Entrepreneurial Engineering Network (KEEN). This cohort seeks to embed into the curriculum particular student outcomes including the Entrepreneurial Mindset (with three core components of Curiosity, Connections, and Creating Value), Communication, Collaboration, Engineering Thought and Action, and Character. The goal at this institution is to incorporate these aspects broadly throughout the curriculum, gradually advancing student abilities along each thread through repeated exposure and practice. Within this framework, the first-year engineering program is a foundational experience. In this paper, we discuss the first steps in a holistic redesign of the first year engineering experience to better align with both of the above mentioned frameworks – to bring the program into alignment with established best-practices for first-year content and to provide the critical foundation for the KEEN student outcomes. We also communicate the lessons learned and the results of some preliminary analysis of student success.**

*Index Terms* – Active learning, Engineering design process, Entrepreneurial mindset, Introduction to engineering course content

## INTRODUCTION

In many institutions, incoming students first experience engineering through some form of an introduction to engineering course or course sequence. The spread of such programs has in recent years accelerated as more institutions recognize the value of a meaningful engineering experience in the first year. Parallel to this growth, an on-going discussion has been probing the question of what should be included in such an experience and how that content is best delivered at the first-year level.

In one comprehensive effort, researchers have begun the task of defining a first-year taxonomy [1]. The effort is based on the outcomes of an analysis and classification of first-year programs from around the country [2]-[3]. Based on their analysis, the authors of the taxonomy identified three core areas of first-year content – engineering skills, such as design, computing, and critical thinking; professional skills, such as teaming, communication, and ethics; and orientation to both the program and profession. Further analysis identified eight groupings of course objectives within this framework – communication, design, engineering technical skills, professional skills, professional topics, advising topics, math skills and applications, and global interest. The researchers further identified subgroupings within each of these categories which may be used to seed content structure in designing a new first-year engineering course [4].

In a separate effort, several institutions have come together under the Kern Entrepreneurial Engineering Network (KEEN). This cohort seeks to embed into the curriculum particular student outcomes including the Entrepreneurial Mindset (with three core components of Curiosity, Connections, and Creating Value), Communication, Collaboration, and Character [5]. The network is working to identify specific and assessable objectives tied with each of those outcomes and to encourage adoption of entrepreneurial thinking into engineering coursework.

## PURPOSE, MOTIVATION, AND SETTING

Ohio Northern University is a small private university in the Midwest with a total enrollment of around 3,500 students. The T.J. Smull College of Engineering is home to 6 programs – Mechanical, Civil, Electrical, and Computer Engineering, Computer Science, and Engineering Education. The student population includes international and underrepresented minority students, but is largely made up of those from small, rural, Midwestern towns.

The first-year engineering experience at ONU consists of three courses – a two-course introduction to engineering sequence and a department-specific orientation course. Both introductory courses are three credit hours while the orientation is a zero-credit-hour pass-fail course. All first-year students in the college except Computer Science students are required to take both introductory courses.

The focus of this paper is on the two introductory courses. In these courses, students are given a broad introduction to engineering topics, including design, analysis, and communication. In the time period under study, students were enrolled in four sections of approximately 30 students each. Each section met for three 50-minute class periods per week. The instructional team consisted of three faculty members each semester, two of whom were consistent across both semesters and one of whom taught multiple sections. Assessments were conducted primarily by use of rubrics, and grades were compared across sections to mitigate inconsistent scoring.

The previous iteration of the first semester course consisted of a series of discrete modules, each culminating in a small project and focused on some aspect of engineering. Topics included developing criteria and constraints, performing static and kinematic analyses, performing a much abbreviated engineering design cycle, an introduction to circuit analysis, and working with foundational engineering units and formulas. The second course centered on a semester-long, open-ended project tied broadly to the topic of poverty alleviation, delivered with little supplemental instruction to allow each team to pursue a design solution in the manner they best saw fit. Feedback on the courses revealed that many students saw no unifying thread among the individual modules and believed the projects to be either too short and simplistic to be interesting, or too ill-defined for successful completion at a first-year level. Students also remarked that the course seemed disconnected from their later studies, some perceiving it as a compilation of "engineering previews" that were already included in later courses; unfortunately, others viewed the course assignments as a loose collection of busy work. The primary motivation behind the redevelopment of the course sequence was to bring the college's first-year experience into alignment with current best practices.

As a recipient of a KEEN Institution Grant from the Kern Family Foundation – which is funding a multi-year, cross-disciplinary effort to deploy entrepreneurial content throughout the engineering curriculum – the first-year engineering course sequence is undergoing modifications to lay the groundwork for acclimatizing the college's students to KEEN-related outcomes.

## COURSE DEVELOPMENT PROCESS AND OUTCOMES

To identify which content was most critical to cover in the first-year course sequence, college faculty were asked to rate 33 topics on a five-point scale, with 5 indicating very important to cover and 1 indicating not important. The results of the survey indicated that the ten most important concepts, all receiving an average 4.0 rating or higher, were written reports, teamwork, the formal engineering design process, ethics, oral and visual presentations, units and dimensions, relevance of the engineering profession, basic shop training, spatial visualization, and graphing. The topics identified as least important, all receiving an average rating below 2.5, were the "engineering preview" topics of circuits, thermodynamics, statics, and kinematics. While there was a general consensus that such topics were useful as contexts for covering other material, there was no need to explicitly cover that content.

Based on these results – coupled with instructor experience in other programs and a review of the literature – a framework for the two courses was established. The first course, ENGR 1041, introduces the engineering design process through a semester-long, team-based design project. As the semester progresses, the stages of the engineering design process are discussed and various supporting content is delivered. Supporting content topics include engineering ethics, MS Excel for engineering analysis, visual modeling including spatial visualization and AutoCAD, physical modeling including basic shop techniques and low-fidelity prototyping, design of experiments, and mathematical modeling including descriptive statistics, linear regression, and histograms. All supporting content is delivered in conjunction with a relevant phase of the design process. For example, AutoCAD is covered when students work to finalize their designs while woodshop skills are covered before students begin the prototyping phase.

The second course, ENGR 1051, revisits the design process but focusses on the contexts which surround engineering. Students complete another team-based design project, but supporting content includes project management tools, introductory MATLAB skills, and engineering contexts such as globalization and sustainability. Elements of the design process are also revisited in additional depth, for example, by introducing additional concept generation strategies. Throughout both courses, teamwork, communication, and professionalism is emphasized. Communication as applied here includes creation and delivery of posters and oral presentations, the writing of memos, lab reports, and technical design reports, and supporting skills such as formatting of tables, charts, and equations for use in the mediums listed above.

To better define this framework, the following course outcomes were developed:

ENGR 1041 – Introduction to Engineering 1

- CO-1: Apply the principles of engineering design and analysis to the solution of engineering problems.
- CO-2: Develop visual, physical, and mathematical models in support of the engineering design and analysis process.
- CO-3: Collect, analyze, and present data in appropriate formats such as figures, graphs, and tables.
- CO-4: Begin to develop professional habits necessary for success as a practicing engineer, including engineering ethics, written and oral communication, and working effectively with diverse teams.

ENGR 1051 – Introduction to Engineering 2

- CO-1: Apply the principles of engineering design and analysis to the solution of engineering problems.
- CO-2: Utilize effective project management techniques to complete an engineering design project.

- CO-3: Apply appropriate communication tools to report on aspects of an engineering design project.
- CO-4: Demonstrate professional habits necessary for success as a practicing engineer, including engineering ethics, written and oral communication, and working effectively with diverse teams.

Content is delivered through lecture and active learning, supplemented by experience through the design project. The courses are constructed such that each content area ties directly in with a related project task, providing a grounding for the material and a unifying thread throughout the semester. Assessment is conducted through individual problem sets, team-based project milestones, and individual written exams.

The projects are designed so as to provide a structured but open-ended design experience which forces students to apply each of the concepts covered during the course. Generally, students must perform need finding and problem scoping, concept generation and reduction, modeling and prototyping, testing and analysis of their prototype, and reporting of intermediate steps and of the final product. In the first semester, students were tasked with designing, building, and testing a projectile launcher. In the second semester, they were assigned one of four sustainable energy systems to design, build, and test. In both cases, the projects are contextualized with mock clients, requests for proposals, and realistic constraints.

With regards to KEEN outcomes, modifications included embedded activities related to each of the KEEN student outcomes – Curiosity, Connections, Creating Value, Collaboration, Communication, and Character. It is noted that the activities and foundations built into the current iteration of this course were not developed or assessed per KEEN standards or rubrics. Instead, the focus of this preliminary revision was to incorporate the course structure and lay the foundation to fully integrate KEEN outcomes in a future iteration of the course. As currently structured, KEEN related course activities include those outlined below:

- *Curiosity:* Students identified a relevant topic of interest, researched that topic, and then presented a one-minute oral presentation on their selected topic. Topics included famous people in their field, engineering disasters, new or interesting products, or current events.
- *Connections:* Students researched one of the National Academy of Engineering Grand Challenges and a self-selected nation of interest. They then wrote a research paper discussing how their challenge affects their identified nation, how the challenge is currently being implemented there, and how social, political, and other factors within their nation might affect that implementation in the future.
- *Creating Value:* Through the completion of the two design projects, students identified stakeholders, assessed customer needs, and created engineering solutions which addressed those needs. In the second project, students also considered the business case for their product and pitched their design at a campus pitch competition.
- *Collaboration:* Students worked collaboratively with a team on both major design projects, developed team charters, assessed both themselves and team members on the effectiveness of their contributions, and rotated team roles throughout the semester.
- *Communication:* Students were instructed and assessed on proper formatting of charts and tables for presentation and how to properly construct memos, reports, and both formal and informal presentations. Several assignments included a reporting component, including memos, lab reports, and technical design reports. Their Grand Challenge reports were required to be reviewed by both a peer and the campus Writing Center prior to submission. Additionally, students presented in both formal and informal settings, including both with and without visual aids.
- *Character:* Portions of each course grade are assigned to professional expectations. Professional expectation points are allotted in full at the beginning of the semester and then deducted for unprofessional behaviors such as tardiness or absence from class, failure to complete non-graded course activities such as pre-lecture videos or surveys, improper behavior, etc.

Perhaps the largest single content addition was in the second course, ENGR 1051, and specifically focused on Creating Value. Students were instructed and assessed on utilizing project management techniques as a guide towards successful product development. These skills were assessed individually through problem sets and exams as well as embedded into the semester-long design project. Project management techniques and guidelines were incorporated into the course as a means to help students become more direct in their approach towards their creation of a successful solution; without this content, the students were more likely to encounter difficulties as they identified connections among the stated problems, potential societal benefits, and technical feasibility of their proposed solutions. In order to emphasize these connections, posed problems were tied to specific clients and locations.

## STUDENT FEEDBACK

Considering only the general structure and content of the course, student feedback was generally positive. Student evaluations indicated positive reactions to the hands-on and applied nature of the courses, a recognition of the value and relevance of covered material to their future courses, and appreciation of the accumulation of practicable skills so early in their engineering careers. Negative comments focused largely on the disorganization and occasional moving-target with deadlines and expectations which were inherent in deploying a new course for this first time. None of these are believed to be the fault of the course structure itself and should be largely mitigated in future deployments. Students also noted personality and motivational conflicts within their teams, and struggled to adjust to being assessed as a team. During the first course, students noted that the project felt rushed in the early stages while the reverse was observed during the second semester; that is, the students would have appreciated moving up the initial prototyping phase of their sustainable energy products, allowing for more opportunity to refine their designs. Finally, of all of the content delivered throughout the course, only the MATLAB material was negatively received as poorly covered and disconnected from the rest of the course. This was likely due to a separate pedagogical experiment in how that material was delivered and must be reevaluated in future iterations.

To more quantitatively assess student perceptions, a series of seven-point Likert scale questions were developed and posed to freshmen at the completion of the two-course sequence. A total of 79 items were included in the scale. In future works, a full reliability and validity analysis of the scale will be conducted and that list reduced. For the purposes of this study only a preliminary analysis of survey results is presented. The survey was completed by 84 of the course's 120 students (70% response rate).

Those scale items related directly to the course and its effectiveness in improving student understanding are identified in Table I. As can be seen, students largely felt that course had a positive impact on their understanding of the various topics. A number of items were also included to assess the current level of understanding on several areas, with similar magnitude responses.

A more detailed analysis of this data is warranted but beyond the scope of the current study. In future years, a similar survey will be administered at the beginning of the year to provide a baseline dataset for each class. Such a study cannot be undertaken, however, until after the reliability of the survey items is evaluated.

## FUTURE WORK

In terms of the course structure and pedagogy, instructors noted a number of items to adjust but felt that the general structure was a positive change from previous iterations. One major area for improvement is that many lectures were seen as too content heavy. It is proposed that the development of a partially flipped lecture style would benefit this course structure, allowing some content to be moved into pre-lecture modules and providing for more in-class time for active learning. In both semesters, the project logistics and timing need to be adjusted. Early project phases require more time than anticipated and students did not have sufficient time to fully develop their ideas. In terms of assessment, the problems sets in which students submitted memos summarizing their process and results were felt to be more beneficial than initially intended. The expansion of this concept would be an interesting follow-on study to the present work.

Perhaps the greatest area of future work lies in the underlying assessment infrastructure. Course assessment activities need to be mapped to specific learning objectives and up to specific course and program outcomes. Additionally, as the institution-wide KEEN initiative progresses, the KEEN relevant course work needs to be more fully developed and more clearly mapped back to KEEN student outcomes. It is believed that both of these tasks could be effectively met through the application of a standards-based grading approach [6]. In the current iteration, course exams were graded using a standards-based approach in an effort to lay the groundwork for a more comprehensive standards-based grading system in future iterations [7].

TABLE I
STUDENT SURVEY RESULTS

| Survey Item | Avg. | Std. Dev. |
|---|---|---|
| My experience improved my understanding of the engineering design cycle | 5.47 | 1.16 |
| My experience improved my understanding of the importance of communication to both technical & non-technical audiences | 5.42 | 1.24 |
| My experience improved my ability to collect and analyze engineering data | 5.42 | 1.14 |
| My experience made me a more effective communicator | 5.36 | 1.26 |
| My experience improved my ability to make evidence-based engineering decisions | 5.35 | 1.12 |
| My experience improved understanding of engineering analysis (such as mathematical modeling) | 5.29 | 1.29 |
| My experience improved my ability to use design to solve engineering problems | 5.28 | 1.06 |
| My experience expanded my understanding of how engineering solutions are impacted by the contexts of the problem | 5.28 | 1.10 |
| My experience positively impacted my development as an engineer | 5.24 | 1.47 |
| My experience gave me the skills I need to conduct engineering design | 5.19 | 1.27 |
| My experience improved my ability to use computational engineering tools, such as Excel and MATLAB | 5.18 | 1.65 |
| My experience gave me the technical foundation necessary to be successful as an engineer | 5.11 | 1.41 |
| My experience improved my ability identify the social, political, economic, and ethical contexts that might affect the solution to an engineering problem | 5.06 | 1.14 |
| My experience helped me to understand the connections between engineering solutions and their impact on society | 5.05 | 1.13 |
| My experience effectively prepared me for a career in engineering | 5.00 | 1.47 |
| My experience effectively prepared me for upper level courses | 4.75 | 1.46 |
| My experience improved my technical skills, such as machining and electronics assembly | 4.72 | 1.59 |
| My experience gave me the project management skills necessary to be successful in a business setting | 4.61 | 1.40 |
| My experience improved my ability to use computer design tools, such as AutoCAD or SolidWorks | 4.53 | 1.73 |
| My experience effectively prepared me for an internship/co-op in engineering | 4.50 | 1.39 |
| My experience effectively prepared me to be successful in a business environment | 4.24 | 1.44 |
| My experience gave me a better understanding of the business and entrepreneurial contexts of engineering | 4.17 | 1.44 |

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