Drivers and Impacts of a 'Clean Slate' Foundational Engineering Curriculum Redesign at a Large Southwestern University

Randy Hugh Brooks, Texas A&M University

Howdy,

After 23 years in Telecom building LD, internet, and email platforms and networks, I observed that the front line personnel that I was hiring didn't have what I considered to be skills that they should be bringing to the table. I began investigating why, and that led me to high school.

Alas, I began my journey in Education in 2010 inhabiting the classrooms of Lovejoy High School, where my two daughters attended. I redubbed my PreCalculus course as Problem-Solving with Brooks and was also afforded the opportunity to lead an impactul Project Lead the Way (PLTW) Principles of Engineering (PoE) course, a project-based learning survey of the engineering discipline.

Since the Summer of 2015 I have been privileged to work with the Texas A and M Sketch Recognition Lab (TAMU SRL) to evaluate a couple of online tutorial tools (Intelligent Tutoring Systems (ITS)) currently under development, Mechanix and Sketchtivity, that provide immediate constructive feedback to the students and student-level metrics to the instructors. I presented on this work at the state and national PLTW Conventions and at CPTTE in 2016.

I also spent 5 semesters beginning the Fall of 2015 taking online courses learning how to construct and deliver online courses. This resulted in a MSEd from Purdue University in Learning Design and Technology (LDT).

This widely varied background prepared me well for my next big adventure. Beginning in August 2018 I became the Texas A and M Professor of Practice for the Texas A and M Engineering Academy at Blinn College in Brenham. Texas A and M Engineering Academies are an innovative approach to providing the planet with more Aggie Engineers.

I am focused on enhancing the high school through first-year college experience and am an engaged member of the Texas A and M IEEI (Institute for Engineering Education and Innovation).

My foundations were set by an upbringing on the family ranch near Joshua, Texas and 4 memorable years at Texas A and M where I met my wife, I led Bugle Rank #7 in the Fightin' Texas Aggie Band (Class of '86 Whoop!), and dove into Telecom Engineering. Once in Telecom, my learning continued at MCI, Vartec, and Charter.

Drivers and Impacts of a 'Clean Slate' Foundational Engineering Curriculum Redesign at a Large Southwestern University

Abstract

This paper will address the research question: "What is the perceived impact and constructs of a 'clean slate' foundational engineering curriculum change at a large southwestern university?"

The large southwestern university engineering leadership team chose to address the need for change using a deliberate "re-building strategy" [1]. This choice involved invoking "a process oriented approach to the remaking of a curriculum…, involving external stakeholders. This applies sound systems engineering principles to the engineering curriculum itself" [1].

"The re-building strategy…is a fundamental change of academic view linking academia with societal context and needs…by emphasizing a shared set of values, identity and commitment. It is about educating engineers who will become change agents after graduation, with an understanding of stakeholder needs and the wider societal impact of engineered systems within the innovation process' [1]. Although the need to re-build the curriculum was identified based on deficiencies, the desire to produce graduates equipped to impact society, or change agents, became the vision" [2].

This qualitative study shares multiple teaching assistant and instructor perspectives regarding the impact of the wholesale curriculum redesign, detail components of the newly created curriculum, and concludes with an exploration of a framework for addressing and managing the need to maintain an evolving curriculum going forward. Due to the many impacting factors over the past three years, such as layered deployment of student success courses and the challenges of the pandemic, limited time will be spent exploring the previous curriculum or performance metric comparisons among cohorts as isolating particular findings to attribute to the redesign would be questionable. As such, this paper will focus on the new program design and include insights from select instructors and teaching assistants that experienced both curriculums.

"As further support of the tenets of the approach strategy, 'the development of the new first-year engineering program at the University of Massachusetts Dartmouth began with a review of the education literature. The literature is consistent, and often overwhelming, in the following conclusions:

- Active and collaborative learning techniques can result in higher performance and longer information retention compared to the traditional methods.

- Integrating math, science, and engineering courses is an effective means to teaching students to deal successfully with cross-disciplinary problems" [2] [3].

Introduction

The evaluation process modeled the guidance found in "Response strategies for curriculum change in engineering" from Kolmos, Hadgraft, and Holgaard [1]. "For a model of systemic change, the combination of the what (in which directions are we going), and the how (how to implement the changes) are important elements" [1]. Foundational to the success of a re-build, "there are two dimensions that need to be addressed: both the curriculum and the culture. Leaderships of change need to make transformation happen from the individual to the organizational level with a focus on both the curriculum as well as the culture" [1]. "The learning and curriculum change is that engineers should become more employable and be able to apply their knowledge to practical and relevant problems from the engineering workplace" [1].

Kolmos, Hadgraft, and Holgaard also emphasize that "the re-building strategy is an overall response to both industrial and societal/political agendas that focus on the education of academics as change agents with a deeper awareness of the impact of new innovation on different organizations and actors. The re-building strategy requires that disciplinary borders must be negotiated, as it requires both bigger units and involvement of practice" [1].

Regarding initial drivers for redesign, "Cahill, Ogilvie, and Weichold summarize that a cross-disciplinary team at the university analyzed first-year student grades across multiple disciplines and found 'that the pass rates of the ENGR courses were typically above 90%, while pass rates of the MATH and PHYS courses were typically between 70 and 75%" [2] [4]. "A six member committee comprised of three engineering professors, with expertise in electrical, mechanical, biomedical, civil, and computer science, and three science professors, with expertise in chemistry, physics, and math, convened during the summer of 2016 to investigate the source of a more than 30% failure/drop rate for students in the physics mechanics course. After identifying several contributing elements, they merged a proposed solution with many other student experience enhancements, which were already being considered, to drive a first-year experience curriculum rebuild. The committee came forward in March 2017 with recommendations to be implemented beginning fall 2018" [2].

The previous engineering curriculum consisted of 2 semesters of project-based learning courses. A 1-hour lecture session and a 3-hour lab session each semester using MATLAB and LabVIEW for some programming work, exploring and applying various design processes and problem-solving strategies, viewing departmental videos and industry seminars, and finishing with construction of a marble-sorting final project, all in a team-based environment.

The new curriculum design expanded the focus on programmatic-thinking to consume the entire first semester course (1-hour lecture, 3-hour lab) as students learned Python while addressing varied challenges to include cross-curricular problem-solving using concepts from their calculus and physics courses. The exploration of engineering departments and industry seminars was expanded to include more detail and live interactions.

Semesters two and three are also common for all first-year engineering students. Each is a 1-hour lecture and 3-hour lab where the lab activities are synced with the lecture concepts in their concurrent Physics course. The engineering course lecture sessions provide additional support for their lab concepts while also introducing other key engineering elements such as engineering ethics, project management, creativity in engineering, working with Arduinos, and rigid body statics. The second semester is mechanics and the third semester is electricity and magnetism.

Background

The following chronology was constructed with guidance from the large southwestern university Senior Associate Dean for Academic Affairs during an interview with the author.

In spring 2016, the Physics Mechanics course multi-semester revealed a trend of a failure/q-drop rate approaching 30%. This is a foundational course for engineering students, and, as a result, many engineering students were opting to take this course at other colleges and transfer the hours or abandoning their engineering vision completely. To investigate the sources and ramifications of this alarming failure/q-drop rate, at the direction of the Dean of Engineering, a faculty committee was formed during the summer of 2016.

The committee consisted of three engineering professors and three science professors. The committee members had expertise in the following fields:

Science: Chemistry, Physics, Math

Engineering: Electrical, Mechanical, Computer Science, Civil, Biomedical

Many impactful insights were identified by the committee including:

- A math prerequisite requirement for the Physics course was not being enforced.
- Physics course material was not engineering-centric.
- Physics/Engineering/Math courses were not cross-disciplinary.
- Grading feedback in Physics courses was not student-centric.

A cadre of industry advisors, faculty, and students validated the negative impacts of the findings above while also alerting the committee to additional challenges:

- Students are hindered by not having a strong knowledge of computer programming before entering their upper level courses.
- Engineering Ethics is typically a senior-year course taken while students are focused on their job search and is administered via the Philosophy department. As seniors, students apply their efforts to courses in their field of study and explore employment opportunities; thus, there is concern that integration of engineering ethics into student psyches is not occurring effectively.

"The committee came forward in March 2017 with recommendations, which were immediately fast-tracked to support a fall 2018 rollout:

- The first semester course in engineering, for all students, was a newly developed computer programming course using Python and integrated various calculus and physics evaluations as challenges in the programming lab.
- The second and third semester engineering courses, also new, tie directly to the concurrent Physics courses, Mechanics and Electricity-Magnetism, with a focus on connecting physical engineering lab work to conceptual physics classwork.
- Physics coursework was reconstructed to become more engineering-centric.
- Physics grading practices were adjusted to focus on providing student feedback based on well-communicated Learning Objectives.
- Engineering Ethics is no longer a separate course as key engineering-centric case studies would be integrated into the second and third semester curriculum.
- Enforcement of completing the Math prerequisite before being enrolled in the subsequent Physics course resumed" [2].

A computer science professor was tasked with development of the Python course, and during the summer of 2018, a pilot simulation was held to hone the curriculum prior to launch of the course. The pilot simulation involved 20+ second-year students tasked with the duplicity of addressing the material as if they had no prior knowledge while also offering potential adjustments considering their actual knowledge and experience.

New course sequence

The new curriculum flow and major course activities are depicted below:

ENGR 102 (first semester)

- Computer program design
- Computer program code (Python)
- Construction of multiple calculus-based programs
- Engineering discipline exploration
- Live 'industry talks' from former students

- Departmental information sessions for all majors
- Math/Physics cross-curriculum pre-teach activities
- Team collaboration to deliver weekly team and individual artifacts

ENGR 216 (second semester)

- Physics Mechanics lab
- Introduction to the application of ethics in engineering
- Exploration of creativity in engineering
- Introduction to Statics
- Emphasis on proper lab practices and lab report production

ENGR 217 (third semester)

- Physics Electronics/Magnetism lab
- Application of ethics in engineering
- Student application (artifact) of creativity in engineering
- Emphasis on proper lab practices and lab report production

Custom lab station

In support of the strengthened connection between the Physics lecture and the Engineering lab, the Physics department vetted, then honed, eight 2-week labs for each course (ENGR 216 and ENGR 217) that emphasized the major objectives of the courses.

As the details of the labs were constructed, it became apparent that the lab equipment did not exist to support the needs of the labs. To address this challenge, the Physics department faculty and Physics graduate workers constructed prototypes, improved the prototypes based on feedback from the summer beta-test classes, and launched a company to mass-produce and maintain the new lab tables, Visual Cortex Instruments.

Key components of the custom lab table are:

- Air table creating a near frictionless surface.
- Position-tracking mobile camera with an integrated monitor for video display.
- Python programs created and editable in support of various labs.
- Mobile electric and magnetic sensors.
- Ethernet interface to Linux-based CPU.

Figure 1: Custom Lab Equipment

Visual Cortex Instruments

Hands-on lab work using instrumentation and equipment that requires set-up and calibration builds the lab tool skills that the students will rely on in future courses. The lab steps to manage and work through as a team include the physical set-up and operation, tailoring of the Python programs, discussion and validation of experiment logic and results, and analysis of large data sets gathered during experiments.

The camera system may be mounted in numerous positions and is supported with software tools that track puck positions by reading the center of the colored dots on the pucks. Multiple pucks, with different colored dots, may be tracked simultaneously. This is key for collision momentum analysis. The DAQ (Data Acquisition tool) is an analog-to-digital converter and is used to gather voltage-based changes on many electricity-magnetism labs.

Insights on deployment

Following are comments from multiple perspectives regarding the course content and deployment. These are organized by sources rather than concepts to allow for a full view from a perspective as reference. Consider how the various sources view programming, coding, and teamwork as you filter through the entries.

Having just completed a half-decade as a Project Lead the Way (PLTW) high school teacher, preceded by 23 years in Telecom, and experiencing first-hand the power and permeation of programming for driving the future, I was pleased to find that coding and programming were the core of the new first semester course.

With the re-build, the university had addressed many of the concerns which I had heard from former high school students as they returned from their first year at most any engineering college. Very few students now begin academically comfortable in my classrooms where they are directed to work in teams while they code and produce quality lab reports. This validates that the curriculum is directed where it needs to be as coding, collaboration and research reporting will be key for all students as they progress through their careers.

The new curriculum drives students into engineering activities very quickly such that they have a very clear view of what engineering entails by the end of their first semester. This is beneficial in that they can make an informed decision as to whether or not engineering is their future. Those that are positively impacted and engaged find that the first semester immersion places them in a good position (vocabulary, vision, skillsets) to explore and discuss summer internship options.

Following are comments from two professors that have taught students both the previous curriculum and the new curriculum:

- "The previous foundational courses had minimal coding using MATLAB, which is still used in some following courses, but did not supply the programming foundation required to code confidently. Students were left to develop this ability on their own when needed later in their collegiate career" [5].
- "Having just completed two decades in the auto industry, I was surprised that foundational courses did not include significant coding, so, previously, I had my students complete programming activities beyond those in the initial standard curriculum" [6].
- "My career was spent programming within teams, so the new design is right on target as to what careers will be like" [5].

The deployment of peer teaching assistants (TAs) to grade the new courses provided an ideal source of evaluation. They had just completed their first two semesters of college with the previous curriculum, and were then contracted to provide guidance and grading support in the new classes. They were tasked with learning Python just ahead of the new students, which provided a running commentary of comparison to their first year courses.

Peer teaching assistants are insatiable learners, so the opportunity to explore and guide a new curriculum deployment was enthusiastically embraced. They provided constructive feedback regarding aspects of their first-year courses while comparing and contrasting the new experiences with their own.

Following are comments received from peer teaching assistants that completed their first-year using the previous curriculum, then assisted with teaching the new curriculum.

- “Though I was frustrated initially about having to learn a new language and then, almost concurrently, grade programs in that new language, I found that programming is portable across languages, so then it just became a quest to pick up new syntax. Learning Python first, as they are, would have been helpful as I was only prepared to code during my third semester because I was a TA for the Python course” [6].
- “Our hands-on team activity was building and programming a robot. Not everyone got to do every role. This new design emphasizes both team and individual activity, which is needed for the next-level classes” [6].
- “I like the idea of introducing some concepts [from other courses] in this early course so that it feels somewhat familiar when they approach them ‘for real’ in their later classes, but if this early introduction is going to be done, it needs to be done with instruction on the basic idea of the concepts before the students are asked to code something based on those concepts” [6].
- “I felt like during my freshman year, I had been taught MATLAB, not computer programming. To my knowledge, the new ENGR 102 curriculum corrects for this by a) teaching in Python, and b) teaching basics of coding a specific language. I believe this to be a much more appropriate approach to teaching coding, especially for students who had no prior experience, such as myself” [6].
- “I think ENGR 102 was a great course to ease students who don’t have any coding experience into coding. There reason for this is because this course solely focused on coding. I took ENGR 111 [previous first semester course] and in this course, we were taught more than just coding which made it hard to just focus on learning that new skill” [6].

Graduate teaching assistants provided another level of perspective as they were years removed from the first-year experience and could evaluate how the new structure foundation would have impacted their career.

- “As a student who took ENGR 111/112, I remember the fluidity and integration between my physics, math, and engineering courses were not very well linked” [6].
- “In the recently modified version of the freshmen and sophomore engineering classes, I have noticed changes in the dynamics of the classroom. The first semester course revolving around coding pushes students to engage with coding at a level that I didn’t

have in my degree until I took an upper-level course. Although it is an introductory coding course, students are being taught how to parse through available information online to help find additional useful tools and guides for solving more real world engineering-based problems. This part of the course is especially beneficial as we are needing to teach students to effectively utilize resources at their disposal" [6].

- "The integration of the engineering labs with the physics courses better engages students with the topics. Whereas some students can become disenchanted with engineering being only a computer-based, coding career, the addition of hands-on labs reinforce and sometimes present the physics/engineering topics in a different light that aids in the students learning" [6].
- "I have seen students that were less engaged in the coding teams step up to be leaders during these [ENGR 216] classes as they felt more comfortable with the physical principles. The labs encourage physical experimentation and can be used to develop more scientifically driven inquiries. The use of lab reports to communicate information learned in the lab was beneficial for creating a feedback mechanism for the students in addition to teaching them how to better communicate in an engineering fashion. Many of the students didn't know how to correctly and scientifically report their experimental data coming in to college. The lab courses were beneficial in helping them to communicate better" [6].

Finally, also included is commentary from the first-year students. Their perspective will prove more valuable as they progress through their collegiate career and evaluate how the foundation laid in their first three semesters has benefited them. From this study's perspective, they had no/limited knowledge of the previous design.

- "Though I spent much of the semester trying to understand what learning to code had to do with engineering, it came together at the end when I had to write a reflection about how my teams worked and what I have learned. My coding fear had been replaced with confidence" [6].
- "Though I learned to code during high school computer science, this was a new environment considering the lab challenge concepts and the need to work as a team weekly" [6].
- "It helped me to better understand what we were learning in calculus when we had a lab about solving for a calculus question using Python" [6].

Future course enhancement opportunities

Regarding ongoing curriculum management following a re-build strategy creating change agents, "student centered curricula based on projects are process-oriented rather than product-oriented; the curricula are adopted over time without the need for Academic Board approval. Academics are immersed in the process of curriculum renewal in every teaching cycle where the specific content in the curriculum can be negotiated among students, academics and the external collaborators. This type of on-going negotiation becomes part of normal curriculum activities" [1].

Speed to deployment of the redesign drove sacrifices in SoTL (Scholarship of Teaching and Learning). "The decision to use department faculty as the lead members of the Implementation Committees had the perhaps-unintended result that focus in the course development process was on what the engineering departments felt the students should know (content), rather than on a course structure which was aligned with educational research on what methods work to improve persistence (method)" [4].

Once the full three-course sequence had been taught, many instructors began evaluating where improvements and adjustments could/should occur and then implemented those enhancements in subsequent classes. A best practice would be to vet these opportunities during summers and deploy the revised curriculum in the fall each year.

A change currently being pursued is to adjust the weekly engineering information sessions to focus more on engineering activities by industry as opposed to the current deployment by major. Students become preoccupied with a particular major without a full understanding of how the different majors fit into various industries. The discovery is that the current methodology reinforces the student focus on getting into a particular major whereas departmental emphasis is to help students find their industry, and then help them evaluate majors within that industry.

Another consideration is development of a pre-college engineering intro course. This is a general course for high school seniors to develop an understanding of what "being an engineer" entails. A second course may also be developed which is tailored to specific elements of the university engineering program.

During rollout, staff-faculty teams also developed two first-year program enhancement student success courses that acquaint students with how the academic college life operates and what being a professional engineer entails. The initial consideration was to incorporate this information in the three-course sequence, but the final design left no curricular room for this material, so they are being layered in as "success seminars."

An important avenue for better managing both student and instructor time and workload in the courses is to employ a greater use of digital tools, such as ITS (Intelligent Tutoring Systems) where students may submit solutions and receive immediate constructive feedback at any time. There are a number of existing tools already available as well as more tools being piloted in the university engineering classrooms.

A structured process needs to be implemented for curriculum management that mirrors the educational directive of "life-long learner." This would involve a regularly scheduled review and adjustment of content and delivery methodology to incorporate pedagogy evolutions and changing industry needs.

Summarizing and expanding, “many initiatives are still in development or being investigated relative to the college of engineering vision for the future:

- Create a pre-college online course to better prepare incoming first-year engineering students for the rigor of the coursework and challenges of collegiate life.
- Move much of the first-year success seminar information to a pre-college engagement.
- Create industry-focused information modules to introduce first-year engineering students to the career environments ahead.
- Incorporate more industry guidance and engagement into early college career programs for students, and adjust/enhance curriculum accordingly.
- Create a more robust feedback program from industry and former students to drive enhancements to the first-year programs and curriculum.
- Develop a strong mentoring network to ensure that each student receives solid personal guidance in both academic and career matters.
- Create a deliberate professional development program for the first-year engineering professors to better connect them with industry needs and curriculum adjustment opportunities. This may include summer industry work/research, or shadowing industry advisors.
- Include a required student course exploring the science of teaching and learning to set a foundation for the expectation that each student can effectively share their knowledge. This will help drive more students to STEM teaching roles” [2].

In a re-building strategy steady state, “reflections and feedback are built into the students’ learning loops and the role of the academics have changed from presenting content and assessing how well students perform to facilitating the students’ learning. The curriculum in this case is regarded as a learning process where students have to identify problems and devise possible technical solutions to these problems while explicitly developing employability skills” [1]. Courses may be adjusted “on the fly” such that the learning process sees the students becoming collaborators on course enhancements and adjustments.

The inquiry leading to the redesign was rooted in performance in a support course, yet the full new deployment addressed challenges across the program. “A realization from refreshing the curriculum is that regular course updates and enhancements keep the course content relevant, and industry advising in the area of new hire expectations and the market vision should be the true drivers of design. Often a dive into a symptom leads to the larger issue which needs to be addressed which, in this case, was a more relevant first-year curriculum structure” [2].

Critical to ongoing success is addressing the myriad enhancements identified in coordination with adjustment guidance gathered from the delivering professors as well as student and industry feedback following each semester. Continued refreshing of the materials and exercises to more closely match what is occurring in industry is an action that must be maintained.

References

[1] A. Kolmos, R.G. Hadgraft, and J.E. Holgaard, "Response strategies for curriculum change in engineering," *International Journal of Technology and Design Education*, vol. 26, pp. 391-411, 2016. [Online]. Available: https://doi.org/10.1007/s10798-015-9319-y.

[2] R. Brooks, "First-year Engineering Curriculum Program Redesign," in *ASEE-GSW 2021 Virtual Conference,* March 2021.

[3] N. A. Pendergrass, R.E. Kowalczyk, J.P. Dowd, R.N. Laoulache, W. Nelles, J.A. Golen, and E. Fowler, "Improving first-year engineering education," *Journal of Engineering Education*, vol. 90, pp. 33-41, 2001. [Online]. Available:10.1002/j.2168-9830.2001.tb00564.x.

[4] A. Cahill, A. Ogilvie, and M. Weichold, "Work in progress: First-year curricular change in engineering at a [large southwestern university] through partnering with physics," in *2020 ASEE Virtual Annual Conference Content Access,* June 2020. [Online]. Available: https://doi.org/10.18260/1-2--35636.

[5] Emails to author, July 2020.

[6] Emails to author, March 2020.