# Throwing Away the Course-centric Teaching Model to Enable Change

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# Work In Progress: Throwing Away the Course-Centric Teaching Model to Enable Change

## I. Introduction

The year 2020 is almost here, and there remains an opportunity to innovate in engineering education. Despite tireless efforts and incremental progress to realize "The Engineer of 2020"[1], engineering educators are still working to adapt their practices to the new century. Students continue to leave the discipline at unsatisfactory rates, women and minorities are still vastly underrepresented in the field, and those who ultimately graduate from undergraduate engineering programs may find themselves grappling to fully understand the role of an engineer in a constantly changing world.

Supported by a five-year "RED" (REvolutionizing Engineering and Computer Science Departments) grant from the National Science Foundation[2], a team of educators at Colorado State University (CSU) are working to overcome the failings of the current engineering educational system by reimagining teaching and learning in the Department of Electrical and Computer Engineering (ECE). This paper describes how the department is implementing a new pedagogical and organizational model in which the curriculum is no longer treated as a set of disparate courses taught in unconnected pieces, but as an integrated system that fosters collaboration among faculty and students. Calling for a holistic view of the ECE degree, the team's approach is novel because they are, in effect, throwing away courses, yet their vision can be realized within the structural barriers inherent in higher education.

In a discipline known for being rigorous and inherently abstract, ECE faculty are stepping out of their traditionally autonomous roles to bolster retention by approaching the undergraduate engineering degree as a complex system. As shown in Figure 1, the new model emphasizes knowledge integration and empowers faculty to work in partnership to synthesize and embed technical content throughout the curriculum.

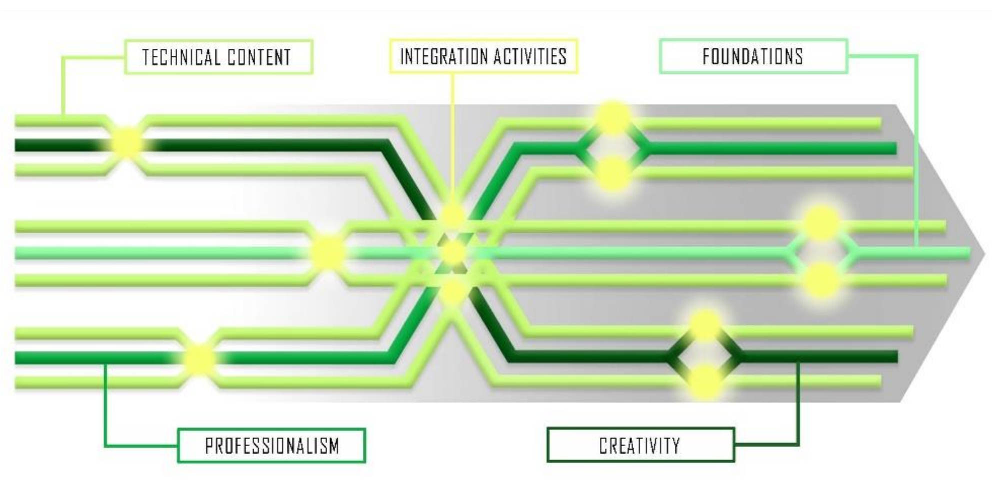


**Figure 1: New pedagogical structure weaves threads throughout the curriculum and provides touchpoints for knowledge integration.**

Many central concepts and skills impact a student's ability to become a well-rounded engineer, and these subjects must permeate the curriculum instead of being taught in individual courses[3] in a linear fashion. In the new model, also shown in Figure 1, faculty members work collaboratively to dynamically interweave the following threads throughout the curriculum:

- **Creativity thread** – integrates research, design, and optimization
- **Foundations thread** – illustrates why math matters in the world of engineering[4]
- **Professional formation thread** – emphasizes professional skills deemed important by industry[5]

In addition to providing an overview of the process the department used to implement its new approach, this paper shares insights to help other institutions adopt the model. Section II gives details about how the department is moving away from traditional courses along with how they are assessing it; section III discusses common barriers educators face when embarking on a significant change; section IV examines how the team framed their work and dives into essential questions that guided the direction of the project; and section V spells out a critical need for a common body of knowledge in ECE and offers future plans for the RED project.

## II. Overview of pedagogical approach: Rethinking courses

### A. Shifting the course-centric mindset

Faculty are doing an about-face on courses to change the way students perceive and learn engineering. With transformations occurring in the integration and delivery of content – described in further detail throughout this paper – courses are becoming a mere formality in the ECE department at CSU. Students still register and receive credit for existing classes, and graduation requirements remain the same, but the course-centric mindset is shifting. When professors teach ECE topics in "silos," or disparate courses, students feel like they are learning material in a vacuum, and they struggle to see how their knowledge will allow them to be a successful engineer. The new structure emboldens faculty to work together to synchronize content across the curriculum and provide context to deepen learning. Instead of thinking about individual course outcomes, the faculty have shifted their thought process to: What is the essential knowledge of an ECE education, independent of courses, and how does electrical and computer engineering shape our world?

### B. Change begins with the technical core

While the five-year RED project spans the entire undergraduate ECE experience, the CSU team's proposal called for a phased approach. The first year of the project focused on the technical core of the curriculum, or junior year, where students often find themselves without context to grasp the big picture surrounding technically focused courses that are widely perceived as "real" engineering. It is also a critical transition stage for transfer students and a primary attrition point for ECE majors[2]. In the pre-RED pedagogical structure, technical courses in the middle two years present significant challenges to students because the material is extremely abstract and mathematically intense, and the amount of content covered increases significantly over time.

### C. Learning studio modules blur lines between courses

As described in the *IEEE Access* article, “A Holistic Approach to Transforming Undergraduate Electrical Engineering Education[3],” CSU’s pedagogical model builds on the concept of “nanocourses” [6, 7, 8] to facilitate knowledge integration, a learning model grounded in education pedagogy and supported by research[9-18].The approach blurs the lines between courses because the faculty take a systems – or bird’s eye – view of the curriculum to identify the fundamental technical concepts of an ECE education,. These concepts are then rearranged and organized into cohesive Learning Studio Modules (LSMs). Each LSM is self-contained and addresses one anchoring concept and a set of sub-topics in a given core competency area[19]. While area-specific learning modules have been in existence for years, such modules are usually supplements to the core curriculum and do not typically cover fundamental subjects vital to comprehending abstract topics, nor do they stitch together anchoring concepts to lay the groundwork for real-world applications. Although a departure from the traditional course structure, LSMs still provide a path for students to learn all the intended topics in a rigorous fashion[3, 19]. Much like the badging system[20-22] that has generated interest in recent years, Learning Student Modules enable fine-grained assessments, but do not replace traditional grades with digital badges. Rather, competency-based evaluations are embedded in the LSMs to credential proficiencies and measure student mastery of fundamental concepts[23].

### D. Knowledge integration to understand why

Aiming to connect abstract concepts to the real world of engineering, Knowledge Integration (KI) activities are created to put learning in context and illustrate the societal relevance of engineering knowledge[24]. Serving as a mechanism for helping students grasp the commonality and correlations between core concepts across the curriculum, KI activities bring together in one room all the faculty and students from the technical core to participate in interactive, team-based learning exercises[3]. Using familiar applications such as the smartphone or digital media player, KI activities show students how LSM fundamentals are integrated to form the building blocks of a complex piece of ubiquitous technology.

### E. Threading knowledge throughout the curriculum

In addition to overhauling the technical core, overarching initiatives are designed to weave essential themes, or threads, throughout the undergraduate program that impact a student’s ability to thrive as an engineer. Led by thread champions and integration specialists (described later in Table 1), faculty work together to embed creativity, foundations, and professionalism threads – defined in section I – in the LSMs and KI activities. Besides being tied to deeply technical content in the middle two years, these threads extend beyond the technical core to stitch together and reinforce relevant subjects from the freshman to senior years[3].

### F. Pedagogical and organizational assessments

Prior to the launch of the RED initiative, the department collected baseline data at pre-determined points in the program to serve as a yardstick for measuring success. A mixed method, longitudinal study has been developed to test the efficacy of the new teaching and learning model. With ABET’s accreditation criteria in mind[3] the two-pronged plan utilizes granular assessments to measure the impact of the pedagogical and organizational changes. Pedagogical measures range from evaluating students' perceptions and competencies[25-30] to assessing their grasp of technical content through standardized concept inventories[23]. The change assessments are designed to develop a solid perception of the department and gauge impact of the new approach on organizational norms. To gain a well-rounded picture of the organizational culture and how it is anticipated to change over time, a multiphase analysis of faculty and staff is being conducted, as well as a series of surveys and observations of the student population to understand the impacts from the learners' perspective[3].

## III. Common barriers to change

Creating and nurturing change in an academic organization can be challenging[31]. Even when educators strive to be revolutionary in their approaches to teaching and learning, they are nevertheless bound by institutional constraints and must adhere to rigid policies and procedures[32]. Barriers exist at multiple levels, ranging from the requirements of the departmental code to the university registrar to ABET. Beyond administrative obstacles, individual faculty can represent the greatest path of resistance[33-34]. Academic departments such as ECE are known for encouraging independence and rewarding entrepreneurialism. To advance their careers, faculty members are motivated by the criteria of the Promotion and Tenure (P&T) review process, which emphasizes individual achievements and contributions regardless of team performance[35]. Faculty face further constraints working within a deeply embedded assessment structure of the university, which measures individual course outcomes and instructors' performance in those courses, rather than the efficacy of the system as a whole. Such individualized reward models do not incentivize faculty to work collaboratively and think beyond the walls of their own classrooms[36]. While these barriers are unavoidable, it does not mean educators are stuck with the status quo. With teamwork, careful project management, and creativity, revolutionary approaches are possible within higher education structures without getting bogged down in paperwork, scheduling, and layers of approvals. Furthermore, faculty can, and will, change with the right incentives and support from department administration.

## IV. Framework for revolutionizing an ECE department

### A. Identifying the core implementation team

Winning a big proposal and having the opportunity to carry out a novel idea can be equally exciting and intimidating, especially when a dramatically new approach is being introduced. As with any successful endeavor, it is all about the people. Because the department's new pedagogical and organizational structure is built around collaboration, it was essential to identify the right players with relevant expertise to embrace the reimagined roles that are central to propelling the project forward, as outlined in Table 1.

**Table 1: Reimagined roles to propel project forward**

| Key Roles in New Structure | Reimagined Responsibilities |
|---|---|
| Project Lead/Principal Investigator | Department head and visionary |
| Co-Principal Investigator, Social Scientist | Assesses organizational climate and directs change research |

| | |
|---|---|
| Co-Principal Investigator, Engineering Education | Provides insights into pedagogical approaches and orchestrates educational research to measure efficacy |
| Project Manager | Leads the direction and execution of project |
| Technical Core Content Experts | Determine fundamental technical concepts that define an electrical and computer engineer |
| Technical Core Team Members | Help define core content across the curriculum, instead of individual courses |
| Integration Specialists | Synthesize content and identify touch points for knowledge integration |
| Math Foundations Champion | Leads the partnership with the Math Department to help students understand, and make linkages between, ECE topics and foundational content |
| Professional Formation Thread Champion | Spearheads the team's interactions with industry to ensure graduates are better prepared to work in a constantly changing global economy |
| Creativity Thread Champion | Plays a pivotal role in bringing creativity, research, and design into all levels of the program |
| Project Communications Specialist | Communicates vision internally and externally |

### Importance of naming a project manager

A key strategic move is to name a project manager to work in concert with the department head. Creating a collaborative environment among mostly tenure-track faculty might seem like a basic objective, but it is not the norm in ECE education, where faculty are accustomed to working in silos. The project manager plays an indispensable role in facilitating collaboration among traditionally autonomous faculty.

### Leveraging existing strengths to form core implementation team

To ensure success, the department head and project manager worked together to determine ideally-suited faculty and staff to expand the implementation team beyond the architects of the proposal. Leveraging the department's existing strengths, they solicited participation from people with skills and interests that align with the reimagined roles of the new structure, and from faculty who possessed an altruistic motivation to improve the student experience.

## B. Gaining buy-in

The success of any large-scale change requires teamwork, buy-in, and collaboration. CSU's project is framed within complexity theory[37], an idea that suggests the world is more complex than a simple cause-and-effect paradigm and organizations must adapt by embracing diversity and interactions. Within the complexity theory framework, existing patterns are disrupted and emergent self-organizing structures are encouraged. The combination of disrupting entrenched patterns with promoting interdependence and autonomy encourages novelty and a culture for new ideas[38-39].

While there is no doubt that faculty and staff have experienced role strains as a result of the change, a few strategies allowed the department to elicit buy-in and overcome potential resistance to embrace collaboration.

### Communicating the vision

It is important to commit to regular and consistent communication to garner support and help others understand the goals and objectives of the project. As shown in Table 1, the implementation team includes a communications specialist who is responsible for communicating the vision to all stakeholders, both internally and externally. In addition, the department head and project manager frequently revisit the project goals and objectives with the core implementation team to ensure everyone is on board and on track with realizing the vision.

### Creating incentives to overcome barriers

The ECE department was in a fortunate position because it was poised and ready for change. For years, the department had been working toward revamping its approaches to teaching and learning, but it did not have the right incentives in place to inspire a major cultural shift. Serving as a catalyst for change, the RED funding allowed the department to build on its previous successes to create a path forward.

With support from the college and university administrations, the department developed an incentive plan that addresses the common barriers outlined in section II. Namely, the Promotion and Tenure process changed to accommodate the new approach. The general breakdown of faculty responsibilities did not change (50% research, 40% teaching, 10% outreach), but the components within the 40% teaching allocation were modified to motivate and reward faculty. They are no longer evaluated solely on the number of courses taught and new courses developed. Instead, faculty are evaluated and receive raises based on their ability to work collaboratively to weave coherent threads throughout the curriculum, continuously integrate disparate concepts, show the utility of knowledge, and demonstrate connections to the real-world. To further encourage faculty to deliver content as a multifaceted team, they received support from dedicated graduate teaching assistants whose roles also changed to mirror to the new teaching and learning model. In addition, the criteria for internal undergraduate teaching awards changed to include assessment of threads and knowledge integration.

## C. Defining the project

After gaining commitment from the appropriate faculty and staff, it is time to put the vision into action. Often the hardest step, it is important to return to the original idea itself, not only to determine *how* to make the vision a reality, but to clarify the goals, objectives, and timeline with those who were not involved in the initial idea generation.

As shown earlier in Figure 1, the heart of the new model relies on the team's ability to think holistically to weave threads and facilitate knowledge integration. Much like the process used for an engineering design problem, a significant amount of time was dedicated to understanding this unique model, identifying the constraints, imagining how the team would work together, and brainstorming solutions to overcome the perceived challenges.

While the proposal provided a vision and strategy for implementing the LSMs, KIs, and threads, the team quickly realized they had a lot of questions. In fact, the early meetings were marked by a series of questions that surfaced again and again about how to best organize and teach ECE topics and move away from the course silos.

## D. Using questions to develop the implementation plan

Answering the following recurring questions allowed the team to develop an effective implementation plan to carry out the vision of the project. Regardless of the institution – big or small, public or private – engineering and computer science educators can draw on these questions to develop their own goals, timeline, and strategy to fit within their unique organizational culture and structure.

**Logistics of throwing away the course-centric mindset**

- How can we shift the department mindset to a holistic view given the course-centric nature of higher education, specifically in terms of registration, grading and transcription, billing, transfer credit, room scheduling, teaching loads, promotion and tenure, etc.?
- So as not to impact the current total number of credits in the degree, how can the current total semester contact hours for affected courses be reallocated to LSMs, KIs, and thread content?
- Do courses need to be co-located and sequenced on the schedule to make delivery more effective?
- Should we offer all content in true “studio” format, i.e., one long session twice a week, incorporating all connected material for that day? Would this present too significant a cognitive load for students to manage? Is it better to retain more space and time between learning sessions?

**Technical content: Learning studio modules and knowledge integration activities**

- What does it mean to be an engineer? What is common to all engineering disciplines? What makes electrical engineering different from any other degree? How do you prepare students for that commonality while also preparing them for the specialization of the discipline?
- What are the fundamental/core technical concepts of an electrical and computer engineering education?
- What are the anchoring concepts for each existing course? What are the components of that anchoring concept?
- What process should be used to determine the content of LSM and KI modules? What is the state-of-the-art in defining the content of the core courses of the signals, electromagnetics, and electronics sequences?
- What is the optimal sequencing of LSMs to provide opportunities to make the most meaningful connections in LSM content during the KIs?
- Where are the intersections in course material, which could possibly serve as knowledge integration points?
- What should be the classroom activity for each fundamental concept, and what should it look like? What about for each KI?
- What pre-work will be required, and how will it be used to reinforce the content taught in LSMs and prepare students for effective participation in KIs?

**Professionalism, creativity, and foundations threads**

- What is the appropriate thread content?
- How can the thread content be integrated into the LSMs and KIs to make the best connections to the technical content? Where are the best opportunities for integration?
- *Professional Formation:* What is state-of-the-art in defining the critical skills engineers need in order to be effective engineers?
- *Creativity:* How does one teach creativity, innovation, design, and optimization? And how do we integrate research into the LSMs to allow students to see real-world applications of anchoring concepts?
- *Foundations:* What is the value of a mathematical perspective within an engineering curriculum? How do engineers use math?

**Data collection and assessments**

- What will be the assessment method for each LSM? What will be the assessment method for each KI? How will pre-work be assessed?
- What baseline data should be collected in year one to assess the change effort - what methods will be used and for what purpose?
- How do we assess the effectiveness of each intervention?

**Support, partnership, and resources**

- How can we use the services offered by the University to support the project? How can flipped classrooms, active learning, and other instructional innovations be used to facilitate instruction and understanding of LSM content?
- What faculty development will be required to support and reinforce the change?
- How will TAs support the goals of the program, and what kind of training will they need?
- What tools can be used to most effectively support the goals of the program?
- Who can the team partner with internally and externally to increase the likelihood of success?
- How can we better integrate with the Colorado Community College system to provide a clear pathway for students seeking engineering degrees?

## V. Summary, conclusions, and future work

This paper introduced a new organizational and pedagogical model that is changing the way students learn electrical and computer engineering. Included was the process the department used to implement the first phase of the project in the technical core of the curriculum, with proven strategies that enabled collaboration among faculty and staff to transform their approach to teaching and learning. In addition to identifying the right people to lead the project and gaining their buy-in, this paper highlighted important questions that can be used as a guide for other departments wishing to adopt the model.

While still too soon to form hard and fast conclusions, early results show that the RED project is making a positive impact. In addition to fostering a more collaborative environment among faculty and students alike, on the whole student performance has improved since the intervention. Findings show that the number of students receiving Ds, Fs, and withdrawals in the junior year has been slashed, and concept inventory scores point to a deeper understanding of technical content. But just like any engineering design problem, the RED project is an iterative process. Now in phase two of the project, which tackles the sophomore year of the program, the department continues to analyze and improve its approaches to ensure a transformational learning experience for ECE students.

Whether looking in the rearview mirror or into the future, the RED team recognizes the power of asking smart questions to solve complex problems. Thoughtful questions framed their project and allowed them to make progress toward realizing their vision. Notably, the project underscores the importance of the question, “What does it mean to be an electrical and computer engineer?” This underlying question brings to light a critical need for universally defined technical concepts in ECE education. For the RED project, core material encompasses signals and systems, electromagnetics, and electronics, but ECE is a broad discipline with numerous specializations, and other institutions may hold a different view of the fundamentals. The ECE department invites the community to join them in determining what it means to be an electrical and computer engineer through the development of a common body of knowledge. Such a compilation would serve as an invaluable resource for educators in defining the core concepts, skills, and essential knowledge of an ECE education, as well as the role of electrical and computer engineering in a constantly changing world.

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