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BOARD # 249: Infusing System-Level Thinking and Analytics into the Undergraduate Curriculum to Create 21st Century Civil & Environmental Engineers.

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Work in Progress: NSF-IUSE Infusing System-Level Thinking and Analytics into the Undergraduate Curriculum to Create 21st Century Civil and Environmental Engineers

Introduction

Two decades into the 21st century, the CE engineering landscape is at the cusp of a major transformation brought about by the confluence of a number of powerful forces, including (1) an increasingly more complex and interdependent design and construction environment, (2) challenges in climate, environmental, and socio-economic patterns, (3) innovations in materials and construction/design methods, and (4) growing computational capacities paired with the accumulation of large amounts of performance data (with cheaper sensors) coinciding with the revolution of the artificial intelligence (AI), machine learning (ML), internet of things (IoT) and data analytics [1]. We strongly believe that CE engineering education needs a paradigm shift that is commensurate with these rapid transformations.

Traditionally, only a small fraction of CE engineers has been tasked with decision-making that required a multi-dimensional view of how infrastructure components come together to form a functioning system, most of whom acquired the “specialist” system analysis skills through graduate studies. As it is unrealistic to require all CE engineers to acquire these skills through a graduate program, it is our strong belief that students graduating with a bachelor’s degree need to be introduced to these concepts during their undergraduate education. There are two hundred and ninety ABET (Accreditation Board for Engineering and Technology) accredited four-year CE engineering programs in the US producing more than 15,000 graduates each year [2]. Some of our nation’s largest research-focused institutions have the luxury of faculty capital due to the sheer number of faculty members in their department. This gives a select few institutions the flexibility to offer undergraduate classes in these critical areas. However, the reality is that many CE Engineering departments are forced to teach these topics, which are not only important for the development of their students but are also required for program accreditation and professional licensure, in an ad hoc fashion.

Recent advances in analytics have the potential to fundamentally impact CE engineering design, construction, operations, and maintenance processes particularly in complex interdependent infrastructure systems. Advanced analytics can be used to address system identification problems (i.e., input-output) for challenging CE problems [3]. This approach is particularly desirable in the case of complex infrastructure projects with multiple interdependent components. Successful system identification relies on the availability of abundant data for training algorithms such as artificial neural networks. Understanding data structures and the systematic storage and classification of data, particularly in the context of advanced data analytics/science methods are crucial skillsets that will be in high demand for CE professionals in the very near future.

Despite these emerging trends, at present, CE engineering education largely follows a deterministic physics-based approach, often intentionally ignoring variability, uncertainty, system-level thinking, and analytics to limit the scope of courses, thus creating manageable silos that can be taught by instructors with expertise in particular disciplines (structures, geotechnical, water resource, transportation, etc.). A critical examination of the existing curricula at leading higher education institutions has identified the 'siloed monodisciplinary structure' as a major challenge/barrier for innovation and progress in our field [4]. The study highlighted the need for any new curriculum to bring together the themes of cross-disciplinary-mode learning. There are strong calls in our profession for injecting ***analytics and system-level thinking*** into our curricula, arguing that *CE engineers must play the role of master integrators in our society, and undergraduate programs must adapt to meet this challenge* [5]. It is this deficiency in CE engineering education that this project aims to eliminate. We, as CE engineering faculty members, need actions to educate and equip the next generation of CE engineers with these new demands of our rapidly changing world!

Coordinating a national multi-university effort and aligning it with the various academic accreditation agencies, and local, state, and federal professional organizations, to completely revamp CE engineering education across the board is, at best, an aspirational dream. However, *we hypothesize that analytics-based system thinking can be infused into any existing undergraduate CE engineering curricula without requiring complete redesign of these programs.* In this project, we aim to develop a series of system and analytics modules that are not just engaging for undergraduate students, but also easy to implement for course instructors. Each module can be "***plugged-and-played***" into a wide range of undergraduate courses regardless of overall program focus or instructor expertise. Each analytics module (implemented in junior- and senior-level courses) will directly relate back the concepts introduced in the systems module (implemented in a sophomore-level course). This connection will be reinforced by a series of mini projects included in each module thereby developing a coherent theme, linking courses and semesters together, and providing the next generation of CE engineers with a holistic understanding of the profession that will stand them in good stead in their future careers.

Project Approach

The goal of this project is to ensure the next generation of CE engineers are prepared to design, build, operate, monitor, and maintain the vast and complex civil infrastructure systems required for a sustainable and resilient society in the decades to come. To accomplish this goal, we propose to develop a series of educational modules implemented across the undergraduate CE curriculum. Our innovative modules will change how undergraduate students think about CE engineering, shifting their focus from a siloed understanding of the traditional CE domains, towards a holistic and advanced Civil Infrastructure Systems and Analytics mindset and skillset. The resulting research products will not only provide the next generation of infrastructure designers/builders/operators with the system-level thinking and analytics skills they will need to thrive in the 21st century, but also help attract students with diverse backgrounds into this critical STEM field. Specifically, the two objectives of this project are:

- Objective 1: Develop a series of educational modules that first introduces CE engineering students to system-level thinking and then provides the foundation for the requisite analytics skillsets. These modules will be integrated into existing classes across a student's undergraduate CE engineering curricula by providing flexibility to the department while linking coursework together across the semesters.

- Objective 2: Implement these modules and evaluate their effectiveness. Implementation of these modules would enhance a student's CE engineering undergraduate education without putting additional pressure on instructors/department to develop the new contexts or revamp the course offering structures. Our research team have implemented these modules in a variety of undergraduate CE engineering courses providing a test bed to evaluate the effectiveness of the developed modules. Implementation and subsequent refinement of these modules across the curricula would allow the program to stand on the cutting edge of CE engineering education showcasing a cohesive theme across traditionally disparate undergraduate courses. Also, our team have endeavored to highlight critical topics such as ethics, sustainability, and resilience, all of which should increase the attractiveness of a CE engineering education to a broader spectrum of high-school students.

This project is in progress and partial results are presented in this work-in-progress paper. The project aimed to evaluate the effectiveness of an educational video on multi-objective optimization. Junior civil engineering students (n=38 students) at the second semester level participated in this study, which involved a control group (n=24) and an experimental group (n=14). Participants were surveyed twice over a three-week period using multiple-choice and short-answer questions to assess their understanding of multi-objective optimization in civil engineering. Specifically, the survey included technical questions to gauge students' baseline knowledge and a short-answer question asking students to define multi-objective optimization and its relevance in civil engineering. Students also self-assessed their knowledge, and an instructor provided additional ratings based on the short answers. The experimental group viewed the educational video via EdPuzzle, which ensured engagement by tracking video completion. The control group did not access the video or receive additional instructional material.

Results and Discussion

Our preliminary results showed the experimental group had a baseline knowledge score of 64.5%, while the control group scored 60%. After the intervention, the experimental group improved to 74.5%, a 10.2% increase, whereas the control group only increased by 2.9% to 62.9%. This suggests that the video significantly enhanced the experimental group's understanding. Individual question analysis revealed a 5.2% to 15.7% improvement in correct responses by the experimental group, contrasting with the control group's inconsistent changes (-7.1% to 7.2%). Before the video, 47.4% of the experimental group rated their knowledge at the lowest level (1), similar to 42.9% in the control group. Post-video, no experimental group students rated their knowledge at the lowest level, with 100% rating between levels 2 and 4, indicating increased confidence and knowledge. Surprisingly, the control group's self-rating declined, with an increased percentage rating their knowledge at the lowest level, from 42.9% to 57.1%.

Our preliminary results showed that the educational video improved knowledge and self-assessed confidence among students regarding multi-objective optimization in civil engineering.

The control group's results suggest a realization of their limited understanding of the topic, highlighting the video's educational impact. More rigorous statistical analysis as well as diverse systems/analytics assessments are underway and will be reported in the next reporting period.

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