Supporting Convergence Development through Structural Changes to an ECE Program

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Abstract

This NSF Grantees poster discusses an early phase Revolutionizing Engineering Departments (RED) project which is designed to address preparing engineering students to address large scale societal problems, the solutions of which integrate multiple disciplinary perspectives. These types of problems are often termed "convergent problems". The idea of convergence captures how different domains of expertise contribute to solving a problem, but also the value of the network of connections between areas of knowledge that is built in undertaking such activities. While most existing efforts at convergence focus at the graduate and post-graduate levels, this project supports student development of capabilities to address convergent problems in an undergraduate disciplinary-based degree program in electrical and computer engineering. This poster discusses some of the challenges faced in implementing such learning including how to decouple engineering topics from societal concerns in ways that are relevant to undergraduate students yet retain aspects of convergence, negotiations between faculty on ways to balance discipline-specific skills with the breadth required for systemic understanding, and challenges in integrating relevant projects into courses with different faculty and instructional learning goals.

One of the features of the project is that it builds on ideas from Communities of Transformation by basing activities on a coherent philosophical model that guides theories of change. The project has adopted Amartya Sen's *Development as Freedom* or capabilities framework as the organizing philosophy. In this model the freedom for individuals to develop capabilities they value is viewed as both the means and end of development. The overarching goal of the project is then for students to build personalized frameworks based on their value systems which allow them to later address complex, convergent problems. Framework development by individual students is supported in the project through several activities: modifying grading practices to provide detailed feedback on skills that support convergence, eliciting self-narratives from students about their pathways through courses and projects with the goal of developing reflection, and carefully integrating educational software solutions that can reduce some aspects of faculty workload which is hypothesized to enable faculty to focus efforts on integrating convergent projects throughout the curriculum.

The poster will present initial results on the interventions to the program including grading, software integration, projects, and narratives. The work presented will also cover an ethnographic study of faculty practices which serves as an early-stage baseline to calibrate longer-term changes.

Introduction

The National Science Foundation's Revolutionizing Engineering Departments (RED) program [1] asks engineering departments to build on prior investments in understanding engineering learning that significantly changed practices in the first and final years of undergraduate degree programs. Such "bookend" curricula [2] have been shown to lead to less than ideal outcomes since transferrable skills learned in the first year are not reinforced. To catalyze significant

change in engineering education one track of the RED program was designed to support revolutionary change strategies resulting in the transformation of undergraduate engineering education.

This paper reports on a RED project in the Electrical and Computer Engineering (ECE) Department at Bucknell University - a medium-sized, elite, primarily-white liberal arts institution that is located in a rural area in the mid-Atlantic region. The College of Engineering has six departments that offer degree programs that do not differ currently greatly from those at most other universities. The ECE Department is not large, consisting of ten tenure track faculty most of whom teach a five-course annual load including associated labs. Bucknell University has an eight-semester graduation requirement so students who drop or do not pass a course will typically make up the credit at other institutions during the summer because most courses are taught once a year.

Since Bucknell espouses a liberal arts tradition, the theme of the RED project focuses on convergence, an idea emerging from STEM policy [3]–[5] that loosely aligns with engineering design [6] in which initial efforts expand a knowledge space (diverge) then later converge to a solution. As defined in STEM policy, convergence seeks to bring together threads of distinct disciplines in addressing a societally relevant goal. Thus from a policy perspective convergence may be seen to counter the tendency of research to both diverge to new topics but also to become siloed, limiting the approaches the discipline can bring to solving many types of problems. In extreme cases such siloing, which has been called disciplinary capture, means that knowledge outside a discipline may not be valued or even accepted as legitimate [7]. The challenge of convergence is thus not just ontological but rather cultural, how to support, protect, and encourage individuals to work and collaborate outside their discipline.

While most work on convergence is focused on established researchers at the post-graduate and professional levels, the Bucknell RED project seeks to address foundational convergence skill development at the undergraduate level. A central tension of this project is that while a central element of convergence is to enable effective collaboration between experts, undergraduates are not yet expert. This tension impinges upon many of the curricular debates that occur in engineering education and can be (overly) simplistically be framed as: what is the correct balance and timing of developing disciplinary expertise and professional and transferable skills in a degree program? This question was relevant to the transition to new ABET criteria two decades ago in which industry representatives [8], [9] emphasized the importance of transferrable skills for engineering graduates.

In regard to the question of expertise vs. transfer, there is an artificial duality imposed by framing skills as technical or transferrable (or "hard" and "soft" to use outdated language). This project thus assumes that each individual needs a variety of knowledges that align with their own values and hopes for the future. The RED project, which is effectively in the first year due to the pandemic, is simply living with this tension while making several assumptions: 1) disciplinary expertise is essential and the question is one of degree; that is what amount of disciplinary knowledge is most valuable; 2) students will continue to develop expertise throughout their lives, and the willingness and ability to continue development is more important than some defined set expertise at graduation; 3) in a broad, diffuse, and rapidly evolving discipline such as ECE

developing such expertise requires active agency from students. In other words, there is no clearly defined path to become an expert without making choices based on motivation and navigating different curricular/affinity paths. Thus to become an expert one must have some idea of where one wants to go within the discipline.

Framework

These assumptions led the Bucknell RED project to adopt Amartya Sen's *Development as Freedom* [10] framework as central to organizing other project activities. Sen's framework also helps clarify the role of human development and the relation to larger economic functions that drive many STEM policy debates. In the *Development as Freedom* framework, an individual's freedom to pursue a life they value serves both as a means and an end to intellectual and moral development but, as Sen demonstrates, also impinges significantly upon economic and social development. Adapted to a degree program, this framework stipulates that the core value produced by engineering education should be to enhance an individual's capacity for freedom. As freedom is a complex subject, Sen's work frames freedom in terms of two characteristics of the individual: their capabilities and functionings. Although someone may be putatively free to act, they will be unsuccessful leading a life they personally value unless they also have the capability to change their situation for the better. Capability thus includes factors such as relevant knowledge and skills, economic resources, political freedoms, etc. that enable an individual to choose a life they value. Education thus provides new and enhanced capabilities. However an education which assumes a common end for students (as engineering education often does) may not enhance an individual's capabilities unless the student intrinsically values (or comes to value) the assumed end point of that education. Curricular and course design, particularly that driven by outcomes, must assume some ends which are of value to society, the discipline, or the individual [11]. In Sen's framework what a person values being or doing is described by a set of functionings. Each individual has a unique "functionings vector" based on what they personally value. Capabilities in a practical sense are the functionings that are currently achievable based on an individual's unique circumstances. The capacity for an individual to accomplish something they do not value is not considered a capability. As an individual develops they may choose to build capabilities to achieve existing functionings, or they may find new things they value thus adding to their functionings vector. Thus beyond developing capabilities, education opens possibilities of new functionings. In terms of educational change, this framework refocuses the goal of education from economic utility or workforce preparation to maximizing a student's future freedom through increase of their capability (what they can do) in a way that is aligned with their own functionings vector (the things they value, or want to do). As mentioned previously, Sen shows that freedom strongly correlates to multiple societal values. As a framework to refocus institutional assumptions, Sen's work accounts for the diverse capabilities and functions students bring with them into college and seeks to expand their capabilities while providing opportunities to discover and value new functionings.

Convergence and systemic problems and the *Development as Freedom* framework are related since convergent problems need to be addressed by a set of individuals with a broad range of functionings and capabilities. The project thus posits that to develop core capabilities at the undergraduate level to address convergent problems it is necessary for a degree program to: 1)

encourage students to articulate what they value (express existing functionings) and give them some degree of agency to pursue capabilities related to these functionings within an existing curricular structure; 2) provide opportunities for recognizing new functionings by highlighting application of the discipline to a broad set of socially contextualized and convergent problems; 3) develop a set of capabilities what will enable them to address convergent problems that align with their functioning vector should they choose to do so. One of these capabilities is existing disciplinary expertise but workshops, reports, and writings on convergence [3]–[5] highlight other areas as well.

Project Activities

As the author, positivist, and provocateur Paul Gibbons said, "*We have minds that are equipped for certainty, linearity and short-term decisions, that must instead make long-term decisions in a non-linear, probabilistic world.*" Engineering projects exist in larger systems and contexts that graduates should be prepared to navigate in their day-to-day activities, and at times such work includes potentially far-reaching ethical judgements. To shift our undergraduate degree programs from a means-focused technical discipline to one in which students are also equipped to use their technical skills in solving complex, convergent problems in social and human contexts there are four consecutive activities that the project is undertaking.

First is that the department is in the early stages of is introducing convergent projects across the curriculum. A challenge the project is currently facing is determining criteria to classify a project as 'convergent'. At this stage the working criteria are that: 1) problems which are socially relevant and impact society; 2) problems that are not fully bounded and with some level of uncertainty; 3) addressing the problems requires collaboration between individuals with multiple experiences, knowledge, skills, and perspectives; and 4) approaches require ideas from outside traditional disciplinary boundaries. To date an action research approach [12] has been used to trial convergent challenges in the program's four-course design sequence. Preliminary results indicate that students are willing to adopt methods from outside engineering when a course addresses the methods through which these impinge on relevant context and content.

The second activity, changing grading structures, draws on the *Development as Freedom* framework's concept of capabilities. While the reality is far from the ideal, in theory courses develop capabilities while using scores and grades to provide feedback to students about their capacity to enact these capabilities. Scoring mechanisms thus play a role both in establishing student expectations and indicating what knowledge or skills are valued in the context of a course. The Bucknell RED has done preliminary experiments that modify grading structures to provide additional feedback on capabilities that are associated both with student-desired functionings and solving convergent problems. In the trial courses students received separate feedback on how they are progressing on these capabilities as well as grades on exams, homework, etc. The initial indicators are that while this feedback provides valuable feedback to students on capabilities valued by the program, at the current time the method is too faculty time-intensive for wide-spread implementation. We are currently devising a revised method of providing grade feedback based on the baseline set of faculty interview data, discussed subsequently.

The third activity is to use Bucknell university's e-portfolio system to enable students to construct narratives related to convergent projects. The purpose of narrative in this project is that in order to develop skills in addressing convergent problems students must intentionally bring together experiences from the wide range of courses and activities accessible to them at a liberal arts university. Portfolio development assignments are currently being integrated into several courses, particularly in the design thread of the ECE curriculum. Initial results are positive, and the project is currently experimenting with different e-portfolio formats that can elicit how students are developing both functionings and capabilities. One major issue that is still being worked out is how to have a single portfolio that covers all four years of the program. The initial experiments are thus focused on having students address different prompts each year. In the first year students explore various functionings in the major and identify personally relevant functionings. In the second year the focus is on potential careers, extending the functionings view beyond the undergraduate program. In the third year students focus on processes of personal transformation by using a Hero's Journey framework, reflecting college as a time of personal change. Finally, in the fourth year, students reflect on their developing identity as an engineer and how their functionings have and may continue to change.

Finally, the Bucknell RED project seeks to support the faculty time required to implement projects, change grading structures, and adopt narratives by reducing the amount of time faculty spend on routine activities through wise adoption of educational software. This has not been started yet, but early work has been to take a broad survey of existing software, presented in a separate paper at this conference. In future years the project will seek to bring a set of software products together into a suite that integrates with campus learning management system and supports the alternate convergence-focused grading structure. While the goal for faculty is to reduce repetitive effort by approximately five hours per week, the goal for students is to develop a readily accessible "dashboard" of their progress they can use in developing self-narratives of their academic journey.

Current Status

Currently the project is in the "initial attempts" and "gathering baseline data" stage. The RED PIs are concluding a nine-month ethnographic analysis of the program conducted by a postdoctoral research fellow attached to the project which is capturing the instructional strategies used in classrooms that gives insight into enacted practices in Bucknell University's ECE Department. This analysis looks both at student perspectives through the researcher embedding herself in student groups and the classroom environment, as well as faculty perspectives obtained through interviewing each faculty member and making observations in most classes. This analysis is designed to determine the predominant pedagogical methods currently in place, how these differ across the curriculum by year and topic, and give insights into student experiences. While too long to include in full, some of the elements that emerge from the baseline study include:

- A surprising degree of agreement among program faculty that convergence skills and understanding of social context is needed for engineers.
- While lecture is still the predominant pedagogy, particularly in theory-based classes, faculty show considerable interest in expanding the range of teaching methods used.

- Often attempts to incorporate social context or integrate projects into courses feel contrived and superficial, and this is particularly true for courses early in the curriculum.
- Faculty group around the importance of prioritizing theoretical or professional skills with relatively few prioritizing more holistic student development.
- Faculty listed many ways positive change could occur with the most desired change figuring out how to work more one-on-one with students. This was more valued by faculty with a theoretical focus.
- Structural aspects of the university such as credit systems and how grades were assigned constrained innovation and there was a common desire to create low stakes "sandbox" courses.
- Faculty perceived a wide range of barriers to change with many responses centering around resource availability (particularly time), fear (of failure, change, career prospects), the changing characteristics of students, and structural/institutional challenges.

The results of this baseline study are currently being developed into a taxonomy to let the project look across existing activities in the program and judge whether there are areas of development that are over- or under-emphasized. The insights into faculty aspirations for the degree program are also being used to develop a department-wide rubric to streamline the effort to change grading practices. These baseline findings indicate there is wide faculty acceptance of developing methods to promote more individualized student trajectories, but time, relevance, and perception of student acceptance/ability are barriers to larger scale implementation.

Summary / Next Steps

In summary the baseline interviews and ethnographic observations showed that there is broad support for more individualized student trajectories and focus but resources and structural limitations provide barriers. A somewhat surprising result was the number of faculty who believe that one of the most significant limitations to more personalized instruction arises from students themselves. While it is too early in the RED project to determine the efficacy of the four project efforts to provide functionings and capabilities related to convergence, early-stage data does not indicate any of these efforts are ineffective. However, the constraints on faculty time has confirmed as an important factor for the success of long-term implementation.

Several immediate next steps are suggested. Faculty professional development is a key need as are examples of ways to provide relevant and meaningful convergent projects/content in courses, particularly those early in the curriculum. Thus short-term efforts of the RED project will be to establish communities of transformation for faculty, students, and staff. While this was initially intended to be one of the logistically simple aspects of the project, the global pandemic, need to teach in hybrid modes, and Bucknell University's policy mandates have severely depleted faculty motivation and engagement [13]. Additionally, there is considerable work needed to develop operational and informative definitions of convergence at the undergraduate level and translate these into content and pedagogy that can be implemented in courses that have either a theoretical or professional focus. Similarly understanding how to better articulate and align faculty beliefs around the importance of theoretical preparation, professional skills, and student development will be needed to avoid rather than exacerbate tensions as the project moves forward.

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