Modeling the Perception of Rigor in Large-Scale Curricular Change

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***Abstract*— In response to a call from the National Science Foundation, "Revolutionizing Engineering Departments" (RED), several departments across the United States are engaged with reforming their curricula, program structures, and culture. This work-in-progress paper presents a preliminary causal loop diagram (CLD) drawing from the engineering education literature. A CLD consists of variables and positive and negative relations between them describing the dynamics of a system. One RED team in the Department of Electrical and Computer Engineering at Virginia Tech developed a CLD to conceptually connect project goals and the challenges associated with change. The challenges were hypothesized to be linked to a perception of rigor in the department creating a "culture" that exacerbated difficulties in the change effort, which was supported by the literature. Goals of the grant including broadening participation in Electrical and Computer Engineering and adopting alternative pedagogical strategies were tied to the culture of rigor. Extending the model as a tool for the change effort is discussed.**

Keywords—curriculum design; causal loop diagram; RED; rigor

I. Introduction

The department in this work, the Department of Electrical and Computer Engineering (ECE) at Virginia Tech, is a mid-Atlantic university in the third year of a large-scale change project, called "Revolutionizing Engineering Departments" (RED). The department seeks to expand the pathways in and out of the department by expanding student choice, adopting project-based learning, and shifting departmental attitudes to be more student-centered. Resistance was expected throughout the recruitment and development phases of the project, as with any change effort. However, a theme centered around discussions of rigor emerged, permeating most of the pushback experienced by the team of principal investigators and early-adopters. Rigor generally refers to a standard of quality or performance expected of participants in a discipline, typically mathematical ability in engineering. Blackburn [1] defines rigor as "creating an environment in which each student is expected to learn at high levels, each student is supported so he or she can learn at high levels, and each student demonstrates learning at high levels." (p. 13). However, the definition of rigor has seemingly been perverted to become a broad rejection of shifting the status quo, such as by narrowly defining rigor to be about a subset of easily quantifiable aspects of student performance and ignoring a broader set of skills necessary for students to be successful engineering professionals.

II. Research Aim

To reconcile how the departmental perception of rigor affects the outputs of interest to the RED project, a systems-level perspective was taken using a modeling technique called causal loop diagrams as a reflective exercise. Causal loop diagrams (CLDs) seek to describe the relationships between variables in a system by denoting positive and negative relationships between variables, forming loops of interactions across different processes [2]. The visual modeling in this paper concerns using a CLD to understand how the objectives of the grant interact, connecting how crucial variables increase or decrease with respect to each other.

III. Background

This section will outline the problem situation at Virginia Tech to contextualize how the model was conceptualized. First, the concept of the grant and the proposed interventions will be discussed, then the context and goals, followed by circumstances that complicate the problem.

The immediate population impacted by the problem situation includes the stakeholders of the ECE department, including undergraduate students, faculty, and advisors. The issue concerning this paper is local to Virginia Tech, but the problems of curriculum and culture change are not unique. The issues are attributable a range of forces like financial or staffing demands and shifting accreditation requirements [3]. Other engineering departments have similar grants, so they are engaged in a change process as well [4].

A. The RED Intervention

Efforts to challenge the status quo in higher education, like curriculum revisions, can be fraught with resistance [5]; culture is also a nontrivial element of an organization to alter because an environment welcoming change is needed [6]. Ensuring the alterations are accepted by the population, particularly the faculty because they deliver the curriculum, requires more than a top-down approach. Accordingly, the RED program seeks to aid organizational change in higher education through techniques beginning with stakeholders in a bottom-up fashion.

This work was supported by the National Science Foundation, Grant No. 1623067.

The RED program is an expansion of the previous Department Level Reform (DLR) program in size and duration. In the DLR program, twenty of the awarded institutions were funded within a range of $400,000 to $1.5 million over 3-4 years with remaining awards funded around $100,000 to update their engineering programs [8]. The NSF allowed for a significantly larger budget for the RED proposals, with awards of one to two million dollars over five years [4]. With budgets in the millions of dollars, the NSF is backing "revolutionary" change, not just reshuffling content or small outreach programs.

The main change-related goal of the ECE department at Virginia Tech is to broaden participation in their programs in two ways. The department intends to promote a broader range of students coming into the department, but also a wider range of careers out of the department. An associated goal is to unify the electrical and computer poles of the curriculum and better prepare students to embrace non-typical degree and career paths. Such changes are not trivial and involve shifting departmental culture and curriculum simultaneously, which appeared to fit the definition of "revolutionary."

Accordingly, the leaders of the RED grant in the ECE Department at Virginia Tech found the RED call for proposals to be a suitable ignition to shift the existing departmental culture and curriculum to achieve their goals [7]. However, the "revolutionary" aspect of the intervention needed to be clear and unique to secure funding. Therefore, the main interventions being used to engage the faculty in the RED project that is the subject of this paper involve a combination of threshold concepts [9], ideas central to a discipline possessing certain properties, and personas [10,11], research-based profiles of potential users of a certain design, within a participatory design process [7]. Threshold concepts are said to be transformative in how a student conceptualizes their discipline [9] and were presented to the faculty as a way to think differently about central concepts in ECE and how they are presented in the curriculum. Also, the team overseeing the project developed a set of "personas" [see 10,11], which are abstractions of the types of students desired in the program summarized in narrative profiles [12]. "Brad"– a white, upper-middle-class male who excels in math–is the baseline persona adopted by the research team to represent the characteristics of a typical student in Virginia Tech's ECE program. The remaining personas represent atypical students in terms of gender, ethnicity, educational background, and professional goals. Using the two techniques in combination with one another, the project leaders anticipate a shift in department culture and inclusion of a broader range of students.

B. *Context of the Problem Situation*

Although the change goals are shared by a group of the faculty, the severity of the problem is a matter of opinion among other faculty. Functionally the department exhibits little signs of weakness in graduation outcomes. However, the outputs of the curriculum - a curriculum that has not changed since 1989 - are rather homogenous, consisting mostly of students from a specific region of the United States who want to work for a defense contractor despite industry demands not being congruent with the graduating population [13].

The department's internal workings further complicate the recruitment and graduation of a more diverse population. First, the focus on the graduate program and defense industry can push out students with other interests, making major choice a highly constrained decision. Historically, students had the choice between electrical engineering, computer engineering, or double majoring. Students with interests that fall between the two degrees, such as robotics or software-defined radio, or interests that involve other departments were not well-served by the previous EE and CPE curricula. Yet, changing the curriculum is not a priority for a research-intensive department. Research activity is a race to increase the prestige, or what Readings [14] would call "excellence," of the department. The department's focus on "excellence" places research and engineering analysis above all else in pursuit of prestige, serving to isolate the teaching component. An element of prestige, the idea of "rigor," emerged as common theme.

C. *The Perception of Rigor as a Central Variable*

Amy Slaton's [15] seminal work on rigor in engineering positions the field with the concept of meritocracy, where only those who can perform are deemed "rigorous." Slaton's extensive account of rigor in engineering applies well to the department's attitudes, as comments by faculty mirror the labeling of "rigorous" and "non-rigorous" to students. Moreover, Blackburn's [1] text on rigor, while aimed at the K-12 space, applies equally to engineering education contexts and echoes Slaton's [15] work. Blackburn [1] outlines seven common practices or beliefs about rigor: (1) adding substantial amounts of homework is rigorous, (2) adding additional repetitive coursework/activities increases rigor, (3) believing rigor is "not for everyone", (4) providing support implies less rigor, (5) believing specific resources have inherent rigor-enhancing properties, (6) thinking standards alone guarantee rigor, and (7) thinking rigor is a topic itself that must be taught.

A set of Blackburn's [1] myths, as she calls them, can be seen in the RED project. For example, throughout the grant work to this point, the concept of moving toward a student-centered curriculum and away from the instructor-centered traditional curriculum garnered some comments from faculty members about lessening rigor, hinting at myth #4 because being student-centered implies more curricular supports. Students too far outside the norm of the department were deemed to "not be serious about the program" [16] (myth #3) and the new curriculum was not "rigorous" because of the departure from "engineering science." The idea of rigor from the perspective of the research team became fuzzier as it was embedded in resistance to the change effort across the goals of the project. Accordingly, the concept of rigor, particularly its perception and value in the department, was positioned as a central variable in the causal loop diagram the team constructed to understand challenges encountered in the change process.

D. *Exacerbating Circumstances*

Rigor in its varied perceptions across the department is reinforced through additional exacerbating circumstances, such as the lack of synergy between electrical engineering and computer engineering in the department's operations. Electrical engineering has undergone expansive (dis)integration through its history, meaning the field has subset itself into smaller and smaller subfields [17]. The department, while technically a single unit on paper, is segregated between electrical engineering and computer engineering. Faculty across the disciplinary lines rarely communicate and curricula have evolved dichotomously [13]. Furthermore, within each program are several different research specialties. Thus, repositioning a large department housing several specialty areas is a communication and collaboration issue.

Like other fields, engineering has its own disciplinary culture and set of norms [see 18,19]. Accordingly, the analysis-driven pedagogy and curriculum design have led to a mindset in the faculty in which a standard of "rigor" must be upheld [see 20]. The department, like others, offers a curriculum highlighting engineering science, a feature whose influence dates back to European perspectives on engineering education [see 21]. Changing priorities from engineering science to engineering design is not a trivial task as a result. Resistance can take three common forms: (1) resisting the idea itself, (2) resisting the change based on emotional issues (being unvalued or used), and (3) resisting due to deep-set distrust or a contrasting worldview [22]. Here, the worldview of upholding the rigor of engineering science is the most apparent barrier.

Issues particularly lie within the middle years for the department. The middle years of engineering are a relatively unappealing mix of technical content and "rigorous" mathematical analyses flanked by relatively more palatable design experiences at the beginning and the tail-end of the degree programs [23], both at Virginia Tech and broadly. Therefore, the middle years are a focus of the NSF RED program. Although the call to change in the department seeks to integrate more formative experiences in the middle years to cater to a more diverse student body, the faculty cite time as a constraint, a common barrier [24] - particularly at Virginia Tech where the department has an undergraduate enrollment of over a thousand students.

A goal of the RED project at Virginia Tech is to diversify the incoming class, but some difficulties exist. STEM knowledge holds an elevated status in society due to its rational, objective, "rigorous" perspective and the people who possess it, experts [25]. While diversifying the profile of the profession is of interest, the field has barricaded itself from those "not serious" about engineering through gatekeeper courses (e.g., Electrical Circuits) and competitive learning environments like those found in the middle years in the department at Virginia Tech, which has a documented effect on underrepresented students [26,27]. A phrase commonly associated with inhospitable environments as described is "chilly climate" [28], which is reinforced by the culture of rigor in the department. The wealth of literature on the hostile, even discriminating, nature of STEM is disturbing [see 29,30,31,32,33], as the choice of majoring in one of the disciplines under the STEM umbrella appears to be more about what keeps students out than in. The "not serious" and exclusionary attitudes in STEM speaks to Blackburn's myth #3 once again [1], serving to reproduce a homogeneous set of students.

IV. Methods

Considering the review of the context and the associated literature, the approach taken in this paper synthesized the themes of rigor in the face of attracting a diverse group of students with respect to the departments research and teaching missions. The diagramming method chosen to create the model was CLDs because many of the quantities of interest that would communicate the system dynamics have no intrinsic physical measures. Moreover, Sterman [2] recommends CLDs as a technique for problem finding as the procedure allows the modeler to illustrate the dynamics of interest then find influential loops driving the problem. Readers are encouraged to consult Chapter 5 of [2] for a walkthrough to create a CLD in their own context.

A CLD consists of a set of variables and directed links between the variables. Positive links indicate the variables move in the same direction and negative links indicate the variables move in opposite directions. Loops are appended by an R or B for "reinforcing" and "balancing" respectively. A loop is said to be "reinforcing" if the variables within the loop influence growth or decline in the outcome variable. A common example of a reinforcing loop is how a savings account grows with interest. Given an initial balance, each timestep adds another percentage of the current balance to itself, growing without bound. Alternatively, a loop is said to be "balancing" if the loop seeks to alter the status quo by moving the current state of the system to a new state. An example of a balancing loop can be seen in how a thermostat seeks to change the current temperature to a new value and *maintain it*.

The PI team on the grant first created the diagram by drawing from the literature relevant to the issues targeted by the RED proposal including 1) attracting a broader range of students into the program, 2) fostering a wider range of careers, and 3) expanding student choice. The three goals were then broken down into relevant variables, connected using arrows, and appended by a + or – if the relationship was positive or negative. The literature was then backdropped with Riley [18] and Slaton's [31] work on rigor in engineering education.

V. Results

The diagram of "rigor" and its influence on issues in the curriculum development process is shown in Figure 1 and Table 1. Faculty conceptions of rigor are used to initialize the model via historical influences of the discipline [see 15,19].

A. *Future Work*

The model has enabled the team to think through questions or actions that can lead to adjustments throughout the change process. For example, the model has generated the ideas of (1) inviting the curriculum designers to the research meetings to collaborate on the change process and not just the curriculum, (2) efforts to increase belonging through department-based social activities, and (3) embracing a mix of tenure-track faculty and other promotional ranks such as Instructors and Professors of Practice in the change activities. Surveying the interests of the atypical populations to the department has also been suggested to occur in the new

Introduction to ECE Concepts course and later in the curriculum, such as in Senior Design, based on the *B: Static Culture* loop. The intent of the survey is to ensure the student needs can be addressed early to instill a feeling of belonging and monitor student career interests. Further work involves the team engaging in additional interventions to achieve the goals of the RED project and tie assessments of the intervention to loops in the model and monitor progress over time. For other updates on this project, please consult [7,12,13,16,40].

VI. Concluding Thoughts

This paper presented a preliminary model to monitor the problem situation that the efforts under the RED award are attempting to address. The CLD provides a conceptual model of how the different elements of the system, the department's dynamics, connect and reinforce one another. Causal loop diagramming was used as a problem finding technique, so the causal loop diagram served as a way to connect the issues faced in the department to the broader literature. Because the model was created with a specific department in mind, it is contextually bound to a department at a large research-intensive institution undergoing a substantial transformation. However, the diagramming method can be applied across a wide range of socio-technical problems including curricular and cultural change. We encourage RED teams and others engaged in large scale change to explore systems-level techniques like CLDs to find latent connections in their projects' objectives.

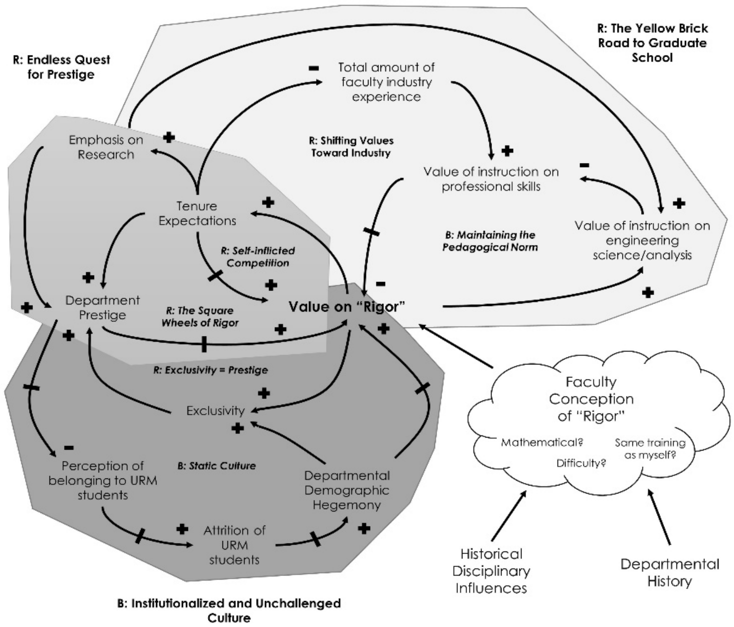

Fig 1. "Rigor" as a Generative Force in the Resistance to Curricular and Cultural Change at the Virginia Tech RED Site. The relations X → Y with "+" indicates an increase in Y by X and "-" indicates a decrease in Y by X. A dash on → represents a delay in X's impact. Each main loop is highlighted by a shade of gray in the background. The names of the main loops appear outside the gray backgrounds while names of minor loops appear within the set of arrows comprising the loop. Note that the "Value of Rigor" is initialized by a seemingly confounding factor of how faculty conceptualize rigor. The varying conceptions aggregate to the variable "Value of Rigor."

TABLE I. Description of Relationships in the Main Loops of the Causal Loop Diagram

<u>*Reinforcing Loop: Endless Quest for Prestige*</u>: The main reinforcing loop is the cycle of increased tenure expectations and departmental competition through the reinforcing subloop of tenure expectations and the value on rigor, *R: Self-inflicted Competition*. Edwards and Roy [34] outline the concept of perverse incentives and hypercompetition in academia, which can be applied in part here in the sense of the tradeoff between the research and teaching mission of the department in the face of increased expectations regarding research productivity. The ECE department is research-intensive, so tenure expectations increase research activity due to the "emphasis on research," which is seen as the primary method of increasing the department's prestige [see 35]. The value on "rigor" is increased, but slowly, hence the delay and the sub-reinforcing loop *R: The Square Wheels of Rigor*.

<u>*Balancing Loop: Institutionalized and Unchallenged Culture:*</u> The prestige of the department influences the perception of belonging for non-typical students, including underrepresented minority (URM) students, students with professional interests outside the norm who want to combine ECE with another discipline (e.g., wearable technology and fashion), and non-traditional students like transfer students. A subset of the 234 incoming students to the department this year, for example, may elect to not attend or leave once enrolled depending on the perception of their fit in the department. The perception of belonging decreasing from consequences of the department's prestige then increases attrition of the URM students. As attrition of URM students increases, the departmental demographic hegemony also increases. As the students become more alike, the exclusivity of the department augmented by the value on rigor, also increases. This process causes the loop *B: Static Culture.* Exclusivity then becomes an indicator of prestige, hence the loop *R: Exclusivity = Prestige* [see 15]. Finally, the lack of diversity reinforces the value on "rigor." Those who could challenge the status quo by being in the program are no longer there, if they ever were. Note the balancing loop is heavily delayed across the succeeding variables because demographics do not shift rapidly. The new courses are being piloted in Fall 2019 and Spring 2020, so we will have baseline data in Summer 2020.

<u>*Reinforcing Loop: The Yellow Brick Road to Graduate School*</u>: This loop begins with the emphasis on research exacerbated by the increase in promotion and tenure expectations [see 36]. Because of the value placed on research, the focus on instruction on engineering science is palpable. Further, the value of instruction on engineering science leaves less room for instruction on other topics, including professional skills. Active learning methods are also resisted in engineering, according to faculty, because of time constraints and large course enrollments [37]. The perception of rigor places a high value on analysis, so shifting values toward equal treatment of professional skills would stabilize the value on rigor, shown in the loop *B: Maintaining the Pedagogic Norm*. However, the last loop that could shift values in pedagogy would be the amount of industry experience held by the collective faculty. Because the total number of those with industry experience is currently low, the balancing loop *B: Maintaining the Pedagogic Norm* upholds the value system. If more faculty obtain industry experience in some fashion, the effect of the value on "rigor" regarding the focus on engineering science could be lessened [see 38], which could serve to decrease the disproportionate value on engineering science and analysis through the *R: Shifting Values Toward Industry* loop. The "tenure expectations" connection to "total amount of faculty industry experience" is made to signify that faculty looking to join the department or participate in industry outreach are impacted by the tenure expectations. The promotion and tenure system do not explicitly value connections to industry in undergraduate education [see 36, 39], which creates faculty with undoubtedly successful research careers but who likely have not worked in industry.

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