"We've Always Done it that Way," An Exploration of Electrical and Computer Engineering Faculty Curricular Decisions

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***Abstract*—Making curricular decisions about critical content is fundamental to the operation of any academic unit in an institution with teaching responsibilities. The literature provides a wealth of information about how instructors plan for instruction and assessment but does not detail how instructors identify core concepts. This work in progress explores curricular decision-making from the instructor's perspective within the context of large-scale programmatic change in an Electrical and Computer Engineering department. We thematically analyzed existing data from a Content Representation (CoRe) instrument used to capture instructor pedagogical content knowledge and teaching strategies for big ideas in a curriculum. The emergent themes for teaching the big ideas concerning the faculty member's perceptions of student attitudes were: instructors valuing systems thinking (but not seeing it in students) and appreciating versatility/adaptability, as well as seeing students struggling with the value of concrete vs. abstract, and having a low tolerance for ambiguity. Teaching strategies were dominantly instructor-centered. This work in progress builds upon what is known about curricular decision-making while offering insights about faculty perceptions of content knowledge and strategies for teaching it.**

***Keywords*— electrical engineering, computer engineering, curriculum, curricular decisions**

I. INTRODUCTION AND RESEARCH AIMS

Significant departmental change is difficult to achieve solely through a curriculum revision [1]. Even before attempting to push for change, the assessment of existing structures can be inhibited by four potential gaps in trust: within the motives, the questions, the methods, or the data [2]. Considering the gaps, small changes can be difficult, as parting with elements of the curriculum can often be emotionally or weakly justified. For example, common roadblocks to change can take the form of rationale for justifying topics like emphasizing graduate-school-readiness, preferred instructional strategies to include in specific courses, or simply modes of thinking such as the traditional approach of "we've always done it that way" [see 3].

This study was conducted in the Department of Electrical and Computer Engineering at Virginia Tech, which is engaged with large-scale programmatic change supported by a Revolutionizing Engineering and Computer Science Departments (RED) grant from the National Science Foundation [4]. In the early stages of the redesign, a fundamental step was establishing a set of essential knowledge and skills expected of all graduates of the program such that learning objectives for new base courses could be created. The base courses are a reimagining of the previous "core courses" into more thoughtful and integrated pieces. To push the creation of the learning objectives for the base courses, the investigators took a more comprehensive approach to the task of eliciting topics from the faculty by probing the instructors about their current instructional practices. This effort sought to address the following research questions using the existing data: RQ1) How do faculty in the ECE department determine essential knowledge (called "big ideas" in the worksheets) for ECE graduates? and RQ2) What strategies do faculty in the ECE department implement in their teaching of essential knowledge (the big ideas)?

II. LITERATURE REVIEW

Historical and current contexts ultimately shape curricular decisions. Seely [5] describes the historical development of engineering education throughout the previous century, highlighting the European influences of mathematical rigor through an intensive battery of theoretical courses. In ECE, the push-and-pull between theory and practice has not stabilized. In 1971, the Electrical Engineering department at Virginia Tech adopted a curriculum undergirded by mathematical and scientific rigor aimed at preparation for graduate school, which has changed little since implementation. In 1989, the first computer engineering degree was conferred at VT, leading to the department renaming itself as the Department of Electrical and Computer Engineering - establishing two distinct paths for students. The split highlights the concept of expansive (dis)integration [6], the emergence of ever more narrow specializations while the field continues to grow in its

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workforce. The (dis)integration and overemphasis on mathematical rigor, at least in part, motivated the RED project design and this examination of the curriculum's implementation.

A standard lens for studying curricula, even in the historical context presented previously, is elucidated in Lattuca and Stark's Model of an Academic Plan in Context [8]. The model frames institutional-level and unit-level factors within an undergraduate curriculum as a function of the plan's purposes, content, sequence, learners, instructional processes, instructional resources, evaluation, and adjustment [8], and involves various actors in the educational system – faculty, students, and administrators [8, 9]. This work would be placed within the content and purposes of the curriculum.

Another theoretical perspective intimately woven through the larger project is the threshold concepts framework [10]. Threshold concepts are described as "portals" and "a rite of passage" through which students experience an epistemological and ontological transformation. The ideas are often found to be troublesome, irreversible, integrative, bounded, discursive, and reconstitutive. One goal of the curricular re-design is to combat the expansive (dis)integration by intentionally making connections across the big ideas identified by the faculty with associated threshold concepts, thereby bridging the current divide in the ECE curriculum. While identifying thresholds were not a focus of this analysis, they are an important contextual detail since the data used were more intimately associated with threshold concepts. A full review of threshold concepts can be found by Meyer and Land [10] or in the specific context of the authors' work [11,12].

III. RESEARCH DESIGN

Since this qualitative work is situated in a large project with multiple streams of data and faculty engaged in duties beyond their usual workload, the authors opted to examine existing unanalyzed data rather than labor the same population with another round of data collection. This section will describe the methodology and methods employed.

A. *Methodology*

The authors framed the research questions through a pragmatic lens [see 13], evidenced by the choice of methods and data to be described. Pragmatism is concerned with applications and solutions to problems, not necessarily the elegance or complexity of the methods [14; 15]. Since curriculum development was ongoing at the time of the study, this effort sought to understand the rationale behind faculty curricular decisions in choosing and teaching topics with the goal of encouraging better faculty collaboration between the ECE faculty beyond informal interactions.

B. *Methods*

This study utilized existing open-ended qualitative data collected during Spring 2017 [12] using an instrument intended to capture instructor pedagogical content knowledge, the intersection of knowledge about content and the methods to effectively teach it. The data was re-analyzed here using thematic coding concerning the posed research questions.

1) Data Collection

To capture information relevant to the big ideas, faculty in the Department of Electrical and Computer Engineering completed self-reflections about their teaching through an instrument called a Content Representation (CoRe) [16], as recommended by Shinners-Kennedy and Fincher [17], to tie into the threshold concept strand of the project. Industrial advisory board members were also invited to complete the worksheets. The purpose of the CoRe worksheet is to elicit the instructor's pedagogical content knowledge by listing big ideas in the curriculum, ways in which the instructor perceives student understanding of the big ideas, teaching procedures used, and the way students are assessed.

Faculty in the ECE department (n = 15, N = 112) and industrial advisory board members (n = 3, N = 22) completed the worksheet. Participants were asked to list three to five big ideas in the curriculum and respond to prompts about how they teach the big ideas. A blank worksheet can be found in [16] and [17]. With the pragmatic lens of determining what could be learned from the existing data, results from the completed worksheets were used to refine the research questions. The review of the worksheets resulted in a focus on 1) justification of the topics and 2) instructional strategies and challenges.

2) Analysis

Thematic coding [18] was chosen as the approach to the analysis, a common form of qualitative analysis to locate patterns within the data. Two authors maintained an analytic memo journal and coded the worksheets within the journal itself [19]. At the end of each coding session, the coder would write a summary by outlining the salient themes or observations of what was read and coded. The two authors who coded met to discuss codes during their weekly meetings.

Coding was conducted in two cycles [20]. Initial coding [21] was done first to discretize the data into small parts to allow for comparisons, followed by axial coding [22, 23] to uncover the themes in the data by "assembling the pieces" from the fractured initial codes. Both coding strategies are commonly used in grounded theory but are appropriate beyond their usual context [20].

IV. RESULTS

A. *RQ1: Determining and Justifying Essential Knowledge*

Four themes emerged from the analysis of the worksheets for RQ1 (Table I). Faculty provided justifications for topics based on prerequisite topics necessary to know, not explicitly what an engineer would be doing in the workplace; e.g., "most systems have a sensor side (analog) and processing side (digital) and the effects of sampling need to be well understood." Qualifications of ideas as transformative for one's way of viewing and analyzing problems in the discipline, like the Fourier transform and Laplace transform, were also present. Other techniques, like using a variety of algorithms, were described as a means of improving one's practice as an engineer – but not necessarily as essential.

TABLE I. THEMES OF JUSTIFICATION OF BIG IDEAS

Theme	Description	Example
Essential to engineering practice	The idea must be known to practice as an engineer.	"I believe [the ability to debug a complex system] is the most important skill for skills (sic) to learn over their BS study."
Directly related to the "real world."	The idea helps students understand how the world works.	"[Filtering] is what many actual systems do."
Necessary for mastery of other ideas and skills	Without the concept, issues with other big ideas may arise.	"Without proper communication strategies, working in a large team can be a nightmare."
Transformative viewpoint	The idea is a significant shift in how the students see other big ideas or the discipline.	"Understanding how signals are decomposed into some domains (time, frequency, wavelet) provides a new view of the signals and systems."

B. RQ2: Teaching Strategies for the Big Ideas

Four themes about challenges in teaching and learning big ideas emerged (Table II).

TABLE II. THEMES OF CHALLENGES IN TEACHING BIG IDEAS

Theme	Description	Example
Valuing Systems Thinking (but not seeing it in students)	Instructors want students to think both in terms of parts-to-whole and vice versa	"They are too narrowly focused on solving problems. They are not used to thinking in terms of identifying the most important problems to solve."
Valuing Versatility /Adaptability	Instructors want students to be both rigorous and flexible in their approach to problems.	"The more math-based engineering students are, the more adaptable they will be in their career."
Seeing students struggle with the value of concrete vs. abstract	Instructors want students to be able to understand and apply theory	"I know that they lack intuition about the frequency domain at all and how it relates to the real world."
Noting that students have a low tolerance for ambiguity	Instructors want students to be able to tolerate open-ended problems and embrace ambiguity	"Some engineering students have difficulty dealing with ambiguity -- they want concrete answers."

The primary themes for teaching strategies to address these challenges developed along an axis of active and passive learning. The "teaching procedures" that instructors described in the CoRe were influenced by the instructors' assumptions about their students' thinking and knowledge. Active approaches included in-class problem solving and design. Passive learning strategies filtered into instructor-centered and student-centered categories. Instructor-centered comments did not discuss actively engaging the student, e.g., students could conceivably remain idle through the method and watch passively; for example, "But I tried to use lots of in-class examples (edited and compiled on the fly) to show and explain how things were working." Student-centered comments involved strategies or methods mentioned directly engaging the student in an activity or process, e.g., "Teach a course as "why can't it be like this" (for example, why can't computers be intelligent) and have them identify barriers." Instructor-centered techniques were noticeably more frequent than student-centered techniques. The most common passive technique was showing examples, whether it involved design, analysis, or some combination of the two.

V. DISCUSSION

A. RQ1: Justification of Big Ideas

Instructors described the need for students to understand relationships between big ideas across the curriculum or characterized them simply as important for ECE knowledge, but not necessarily for engineering practice. For instance, one instructor stated that "it is really important that students grasp the connection between circuit models (which are abstract) and physical circuits" but did not explain why making this connection is important for graduates to master.

On the other hand, responses emphasized a specific purpose in learning big mathematical ideas. A big mathematical idea was linear algebra, in which one respondent focused on the mathematics of linear algebra because the topic "come[s] up in circuit design/analysis and [is] essential to understanding much of the math of machine learning." Another machine learning example concerned probability theory: "probability theory is essential to much of machine learning and to analyzing any stochastic event." When referencing engineering practice, respondents tended to hedge their understanding of what students would be doing after graduation. One response claimed "[design, implementation, and testing] are likely what students will be doing once they join industry." Some instructors referenced engineering practice as the rationale for including specific topics, like one faculty member who explained his rationale for positing "prototyping" as a big idea: "engineers [increasingly] prototype and do high-level experiments rather than do complete designs."

Industry partners gravitated toward characterizations of engineering in the "real world." While focusing on a technical or theoretical big idea—such as programming, Fourier Analysis, and Wave and Particle Theory of Light—each board member emphasized the need for students to be able to engage in "professional" or "soft" skills in their careers. They also connected the skills with technical knowledge and practices in engineering jobs. In describing the importance of using robust estimators, one respondent stated: "there are inherent tradeoffs between estimator robustness and computational efficiency that an engineer should be aware of" and invoked sensitivity analysis and boundary conditions as tools because "a key to efficient problem solving is focusing on what is important" and "engineers must understand the impact of their assumptions on the problems."

Industry respondents emphasized *communication* ("The ability to communicate effectively will have as much to do with their career advancement as their technical abilities") and *collaboration* ("It's rare for an engineer to work in isolation. Also rare for a[n] EE to only work with other EEs"). Each characterized a mode of reality that goes beyond mathematics and theory to "systems-level thinking": "Engineers aren't expected to live in the theoretical world—they build and do things. That requires understanding the big picture[…] and how they're supposed to be integrated."

B. RQ2: Teaching Strategies for the Big Ideas

Response data from faculty regarding RQ2 resulted in a near dichotomous view of teaching strategies with a collection of assumptions about how students think and learn. Most of the procedures for teaching could be discretely categorized as either active or passive with a skew toward instructor-centered comments. Moreover, the four emergent themes of challenges in teaching the big ideas interrelate and were difficult to separate. For example, from the perspective of the instructors, ECE students should be able to think in terms of systems, and to do so it is necessary to be versatile and adaptable. However, being too versatile can also be an indication of a lack of rigor. As one instructor commented, "Students don't know when the differences are significant and when not, they too easily accept a wide definition of 'approximate.'" Instructors also valued the related ability to be both concrete and abstract in the realm of these big ideas. As seen in threshold concept theory [10], the challenge of much essential knowledge is not only technical difficulty but also being able to "think like an engineer." In this case, thinking like an engineer involves having mastery of content as well as the ability to shift between theoretical and concrete instantiations of factors within a system. Ultimately, the data reveal instructors recognizing the need for students able to tolerate ambiguity/uncertainty while also, in some cases, admitting to their struggles in identifying precise and constant solutions.

Industry responses also noted abilities that are difficult to teach and/or learn while balancing technical coursework, e.g., *project management* ("I took a 'management science' class. I've used that knowledge more than everything I learned from the EE courses I took to get that degree"); and *cognitive flexibility* ("Students have difficulty in explaining several possible ways of solving a problem before committing to detailed analysis"). Industry respondents suggested that faculty not focus only on math and technical analysis, but to "focus on requirements first and test solutions qualitatively. Don't immediately dive into crunching numbers." The board member continues with: "perhaps provide a non-optimal solution and ask students to improve upon the solution by going back to the problem to be solved." One industry respondent wrote that teaching communication "may have to be done by outside faculty, as Dept faculty may see it as beneath them." The idea of professional skills being beneath engineering faculty is troubling, but not unexpected. The focus on technical skills over more workplace-oriented skills will be a major hurdle in changing the department's culture. Finally, writing as a former student, an industry respondent described potentially transformative effects of communication instruction: "They'll likely hate having to take the class as students but be thankful they did as alumni."

C. Limitations

The instrument used in this work elicited a range of effort in the responses, so the researchers inferred the intended context of the responses provided by the faculty. Although faculty were not time-constrained it may be possible that effort was affected by the length of the CoRe worksheet. One desirable outcome of the CoRe worksheets was comparing the faculty and industry advisory board responses. The faculty voices outnumbered those of the industry advisory board, so only provisional analyses address the differences in what faculty and industry value as big ideas. Finally, this qualitative exploratory study does not purport to be representative of all ECE faculty either at Virginia Tech or broadly.

D. Lessons learned and suggestions for future work

The CoRe worksheets were chosen for their connection to pedagogical content knowledge and as a means of identifying threshold concepts [17], two key objectives in the context of the larger project and jump-starting curriculum development. While our re-analysis of the worksheets provided insight into the methods and rationale of faculty on the big ideas all ECE graduates should know, more themes may have been uncovered if the instrument were streamlined to differentiate between the ideas of learning for the sake of understanding the physical world, learning to understand the intricate mathematics in the next course, and learning specifically for the workplace.

VI. CONCLUSION

This paper explored the rationale ECE faculty provide for asserting specific topics as big ideas and the teaching strategies used to convey them. Leveraging existing data, four themes emerged to capture the reasons why faculty affirm topics as big ideas: essential to engineering practice, directly related to the "real world", necessary for mastery of other concepts and skills, or leading to a transformative viewpoint. Comparisons with industrial advisory board responses found alignment. Also, teaching strategies were explored concerning the faculty's perspective on students' thought processes which resulted in a divide between instructor-centered and student-centered techniques, with a bias toward instructor-centered techniques.

Conducting this small effort provided valuable insight for the larger project in the authors' context, as interactions with faculty developing courses are now approached with the emergent themes in mind. It is possible the themes can extend outside of the ECE context, and future work can explore how the themes transfer across departments and institutions.

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