# Using Threshold Concepts to Restructure an Electrical and Computer Engineering Curriculum: Troublesome Knowledge in Expected Outcomes

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***Abstract*— Virginia Tech is in the process of an intensive restructuring of its Electrical and Computer Engineering (ECE) department, driven by an NSF Revolutionizing Engineering Department (RED) grant. As a natural first step, discussion has centered on how the curriculum can be meaningfully enhanced to go beyond a mere reshuffling of core content without tangible changes in pedagogy. Accordingly, we have adopted the *threshold concept framework*, initially developed by Meyer and Land, as a lens to view elements of the curriculum that are often considered "troublesome" for students to learn and are both transformative and integrative in nature.**

**We opted to frame the discussion of threshold concepts in terms of pedagogical content knowledge (PCK), the knowledge associated with communicating concepts in such a way that others – primarily students – can understand. To capture PCK, we used an instrument called a "content representation" (CoRe).**

**This paper describes one element of our sequential qualitative investigation, which had three primary stages: an individual reflection with CoRe, a series of focus groups discussing and synthesizing the CoRes, and the development of a culminating card sort workshop. The findings from the focus groups will be presented, which include the set of big ideas and the associated threshold concepts within ECE from the literature.**

***Keywords—curriculum; threshold concepts; electrical engineering; computer engineering***

## I. INTRODUCTION

The ECE department at Virginia Tech is a major producer of traditional engineers in a global economy that increasingly demands flexible, interdisciplinary, and creative practitioners. Spurred by industry critiques of the few opportunities allotted for students to practice professional skills and of the lack of diversity in the undergraduate population, the leadership of the department and constituents in the departments of Engineering Education, Science and Technology in Society, and Computer Science drafted a plan for action to address the shortcomings of the department. A highlight of the plan is the prospect of increasing the "fan in, fan out" – the incoming and outgoing students – of the department. Improving the "fan in," the diversity of incoming students, involves K-12 outreach in underrepresented and underserved districts beyond the schools Virginia Tech typically draws from. In addition, since only two majors are offered in the department with little room for flexibility, modifying the "fan out" can be achieved by restructuring the curriculum to support diverse career pathways. The framing of the department's "fan in, fan out" will ideally result in a population of Virginia Tech graduates who are diverse in their backgrounds, identities, and in their technical and professional competencies.

The current curriculum is traditional. Courses typically involve authoritative lectures, closed-ended homework problems, and exams. Due to the inflexibility of the major check sheets, the pathways in and out of the program are formulaic as well. The plan to enact change and revolutionize the ECE department's composition of students and structure began with an in-depth reflection on the department itself and what it values.

## II. BACKGROUND

*"You gotta do that experiment, it's tradition!"* For some instructors, certain elements of a course or curriculum can often seem sinful to remove. In designing a course, one's perceived value of a certain topic or activity may trump other activities that may better poise students to fulfill course and program objectives. A more intentional approach to designing instruction to support the course's learning objectives is the idea of "backwards design" [1]. In backwards design, one begins by (1) outlining the objectives (or outcomes, most use such terms interchangeably) that the instructor would like students to achieve once the module/course/program is complete, then (2) determining acceptable forms of evidence of students meeting the objectives, and finally (3) designing instruction accordingly.

In the development of the new structure for the ECE curriculum, we expect change in the program outcomes and potentially the program educational objectives. Lattuca and Stark [2] proposed the concept of an "academic plan" to support concrete definition of a curriculum and to account for variables in the institutional ecosystem. The "plan" captures the "blueprint for action" [2] that defines the activities, the purpose of those activities, and how the activities will be assessed - as well as the stakeholders. Therefore, a plan could be as small as a unit on DC circuits in an introductory circuits class or as complex as an entire electrical engineering bachelor's degree program.

When designing any academic plan – an entire curriculum in this case – an ideal practice is to adopt a backwards design

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

approach. Instead of defining the content of curriculum first, the designers consider what students are expected to be able to do after completing the academic plan – these are the learning objectives (in this case, the program level objectives). In determining the program outcomes for a new curriculum and beginning to develop material for Fall 2017 using the new curricular model, we sought to identify what the faculty valued in terms of the skills or knowledge *all* graduates need once they leave the program – the "big ideas." This leads to our research question:

RQ: What do faculty in the ECE department believe to be the "big ideas" in the ECE curriculum?

## III. Research Design

In this sequential qualitative investigation, we used participatory design to explore the faculty's perceptions of the "big ideas" in ECE – the essential knowledge that every graduate from the department should know.

The aim of participatory design is to approach the development of a device, process, or system with the input of potential end users [3]. The three basic stages of participatory design are outlined by Spinuzzi [4] and involve: (1) an initial exploration of work, (2) a discovery process, and (3) prototyping. In the case of the RED grant, the primary end users (or stakeholders) are faculty, students, and industry. Thus, to prepare pilot modules for the Fall 2017 semester, all three groups were involved in the curricular design activities. This paper will focus on the faculty stakeholders.

The first step in the participatory design process is an initial exploration of work – what is being done currently? We explored this question by engaging the faculty in self-reflection on their teaching of "big ideas," using an instrument called a Content Representation (CoRe) [5] (described further in *Data Collection*).

The second step is a discovery process. To cultivate the discussion of "big ideas" in the curriculum, we conducted a series of focus groups with faculty. The participants who completed the CoRes were invited to share their perspectives in person and discuss the kinds of knowledge and skills necessary to become electrical and computer engineers. In this process, participants expanded upon their reflections, generating more big ideas and diverse opinions – providing an opportunity to synthesize the values of the faculty. When interviewing the other stakeholders, like students, we could also begin comparing views across stakeholders. Although only faculty data had been analyzed at the time of writing.

Finally, the culminating step is prototyping. As the goal of the three-step process for the ECE department is to generate a set of focal areas upon which new curricula can be created, we adopted a card sort workshop as the final step [6,7,8]. Card sorts are commonly used to organize website architecture by determining sensible clusters of information via a task to sort cards with brief snippets of content into different piles and form categories. Two pilots of the card sort workshop with graduate students and faculty were conducted, but the full-scale results will be reported in a future publication. To summarize our process, the sequential design is depicted in Table I.

TABLE I. Mapping Data Collection to the Participatory Design Process

| Participatory Design Stage | Method |
|---|---|
| *Initial exploration of work*<br>Engage participants in self-reflection on the curriculum and their contribution to student development. | CoRe |
| *Discovery process*<br>Foster communication between stakeholders (guided by CoRe results) in the department to explore what students must know when they leave the program. | Focus Group |
| *Prototyping*<br>Collaborate through structured conversation to prototype a set of focal areas in the new curriculum based on values identified in the focus groups. (Conducted after the time of writing) | Card Sort Workshop |

### A. Theoretical Framework

An attractive way to frame the examination of the curriculum is through the idea of *threshold concepts,* which serves as a theoretical anchor for the department's restructuring. Threshold concepts are core concepts that, once learned, transform one's perception of a discipline in terms of his/her cognition and identity. The concepts also integrate potentially disparate concepts across the discipline and promote connections in students' mental models, which is why using them to inspire novel curricula was deemed appropriate.

Initially developed by Meyer and Land [9], the threshold concepts framework provides a lens to discuss ideas in the curriculum that are often considered "troublesome" for students to learn. Threshold concepts are not simply "hard" topics; instead, the framework asserts that certain topics, once learned, are transformative in the way students perceive the discipline, and potentially themselves as part of the profession – a shift in cognition and identity. In addition, a concept can earn the qualifier "threshold" if the concept provides a "knotting" effect where other ideas in the discipline are tied together in a way that promotes an integrative understanding of the discipline. Meyer and Land [9] consider transformative and integrative to be essential criteria – primary qualities.

Threshold concepts can also exhibit a variety of other properties, some of which are paradoxical. For instance, one of Meyer and Land's [9] criteria asserts that threshold concepts may be bounded in the sense that the idea may only apply in one discipline. However, different fields draw upon one another superficially and deeply in a variety of ways. In a superficial sense, for example, mathematics has used language from chemistry to liken the elements of a sequence and their structure to periodic elements and compounds [10]. On the other hand, education has used the ideas of developmental psychology more deeply when referencing Vygotsky's sociocultural cognitive theory [11] to design classroom activities. The "bounded" criterion that suggests a threshold concept may be limited to just a single field is a secondary quality and is not necessarily a required criterion; therefore, it can be ignored as appropriate. The other secondary qualities presented by Meyer and Land [9] are “discursive,” “reconstitutive,” and “irreversible” (summarized in Table II).

TABLE II. Summary of Threshold Concept Qualities [12]

| Quality | Description |
|---|---|
| *Primary* | |
| Transformative | **Must** involve a cognitive shift and **potentially** a shift in identity. |
| Integrative | **Must** “tie” ideas together in students’ mental models (cognitivism). |
| *Secondary* | |
| Discursive | **May** enhance the student’s ability to communicate precise language. |
| Bounded | **May** only apply to one discipline. |
| Reconstitutive | **May** shift connections in the student’s mental models. |
| Irreversible | Highly **unlikely** to be forgotten. |

Determining how the big ideas relate to existing threshold concepts in the discipline will be a crucial part of the restructuring process; therefore, turning to the literature on existing work has proved useful. Our review of the literature [12] revealed that authors in ECE have discussed a variety of ideas as potential threshold concepts (summarized in Table III). To connect [12] to the focus groups results, the concepts are mapped to the big ideas in our analysis.

TABLE III. Potential Threshold Concepts in ECE Explored within the Literature

| Author (Year)<br>*Concept Explored* |
|---|
| Carstensen & Bernhard (2008)<br>*Frequency response (domain), Power & Energy* |
| Carnes & Diefes-Dux (2013)<br>*Voltage & current* |
| Flanagan, Taylor, & Meyer (2010)<br>*Transmission Lines, Fields** |
| González Sampayo (2006)<br>*Circuit as a whole system, LaPlace Transform* |
| Scott & Harlow (2012)<br>*Thevenin's Theorem, Dynamic resistance/linear approximation, Phasors (including reactive power),* $j = \sqrt{-1}$*, Feedback, Dependent Sources* |
| Boustedt (2007)<br>*Pointers, Object Oriented Programming* |

*Note: An asterisk (*) denotes an extension of the author’s argument in terms of a more specific topic identified in Meyer & Land [9].*

## B. Data Collection

We used focus groups to engage faculty in the collaborative generation of big ideas. Focus groups are a useful method of data collection, as one group can generate large amounts of qualitative data [13]. When determining group size, small groups tend to be suited for exploring sensitive topics while larger groups are preferred for maximizing the number of ideas [14]. Some counter-evidence exists about the number of ideas that focus groups can produce; for example, Fern's [15] investigation on the relationship between focus group size and “good” ideas imply that two eight-person focus groups generate as many ideas as about ten one-on-one interviews. In such a scenario, the mode of data collection operates at an efficiency of about 60-70% on average from the perspective of maximizing the number of ideas given the number of participants.

An additional form of data collection helped to increase the efficiency of focus groups. An individual reflection (a “preflection” of sorts) was administered *before* the focus group to encourage participants to have initial ideas to share with the group as an “entry ticket” to join. Even if the amount of ideas did not increase, a potential improvement that the entry ticket idea would provide was a means of improving data quality in general. For instance, a more in-depth discussion on a certain concept or cluster of concepts could be promoted.

Upon obtaining IRB approval, we recruited faculty in the ECE department during a faculty meeting. The composition of each focus group is outlined in Table IV.

TABLE IV: Focus Group Compositions

| Group | Size | Participant Teaching Foci |
|---|---|---|
| 1 | 4 | Power, applied physics – optics and photonics |
| 2 | 5 | Controls, computer vision & machine learning, wireless communications/networking, digital design |
| 3 | 5 | Power, digital signal processing, stochastic signals and systems, electronics, digital logic, computer architecture, engineering professionalism |

As recommended by Shinners-Kennedy and Finch [16], the individual reflection on the identification of “big ideas” was framed in terms of pedagogical content knowledge (PCK), the knowledge of communicating concepts in such a way that others - primarily students - can understand [17]. To externalize PCK, Loughran and his colleagues [5] developed an instrument called a "content representation" (CoRe). In a CoRe, faculty list three to five big ideas in the curriculum and answer questions about how they teach the ideas. The concept of big ideas in the curriculum was then translated into the focus groups.

Although a larger group was desired to maximize the number of ideas, a voluntary sample of 14 faculty from the ECE department was tasked to complete a CoRe for the ECE curriculum as an individual reflection and entry ticket to the focus group; then the participants were engaged in a one-hour focus group with three guiding questions:

1) What *are* the big ideas a graduate of the ECE department should master by the time he/she completes his/her degree?

2) What *should* be the big ideas a graduate of the ECE department should master by the time he/she completes his/her degree? (Note that "should" does not necessarily mean the "big idea" is not in the curriculum, it may be underemphasized.)

3) What are the barriers to incorporating the big ideas that should be included in the curriculum? (This question was aimed at determining what incentive structures need to be put into place to motivate faculty to develop new curricula, but is outside the scope of the research question.)

The focus groups were audio recorded. The audio files were transcribed using an external transcription service, then the authors verified the accuracy of the documents by listening to the recordings while reading the transcription and correcting any errors.

### *C. Analysis*

The analysis followed two stages – the focus groups were examined first, followed by an aggregation of the big ideas from the worksheets and the focus groups for the card sort workshop. The most relevant piece from the worksheets was the set of big ideas proposed by each faculty member; the remaining reflections on PCK will be presented in a future publication.

Once the transcription editing process was complete, the text was coded by hand in two cycles as recommended by Saldaña [18,19]. The document was combed through using *in vivo coding* to create a list of big ideas discussed by the participants; then the big ideas were generalized as appropriate (e.g., "model" to "modeling"). In the second cycle, we created a visual representation of the big ideas as a *network* [18] (see Fig. 1). The network consisted of the set of codes (nodes) and relationships between nodes (lines, also called edges). In the network, the nodes corresponded to big ideas or technical/professional concepts mentioned at least once. Broader ideas were clustered closer to the center of the network and were identified through direct language used by the participants; for example:

*Participant i:* "The first one I would think is modeling, the ability to [model]."

To capture linking concepts that evolved in the focus groups, we used lines to connect nodes. For example, consider the following excerpt: "The transmission line is basically a model." In the visual network, "transmission line[s]" and "model[ing]" were designated as nodes and were connected with a line. Lines were also created if another participant remarked on a connection between two concepts – a prime example from the data was as follows:

*Participant i:* "I call it randomness, this concept of randomness…"

[Participant *i* elaborates by naming specific topics under the umbrella of randomness (e.g., stochastic processes)]

*Participant j:* "For photonics, it's essential."

In the final step of analysis after the two-cycle coding, we connected these results to the literature by comparing each element in our network the existing threshold concepts identified in the literature. If the concept was not an exact match, the threshold concept needed to be an integral portion of the "big idea" or concept from the focus group. For example, "sources" are not a threshold concept identified in the literature, but "*dependent* sources" are [20].

## IV. RESULTS

The networks created from the focus groups are displayed in Fig. 1. The focus groups centered around the following big ideas: modeling, randomness, analytical skills / problem solving, systems thinking, change of basis, design, writing ability, programming, part selection, and data analysis. To explain the realization of the "big ideas," an exemplar quote will be provided to contextualize each idea, followed by the details surrounding the discussion in the focus group. To conserve space, big ideas that appeared to be talked about together are described at the same time.

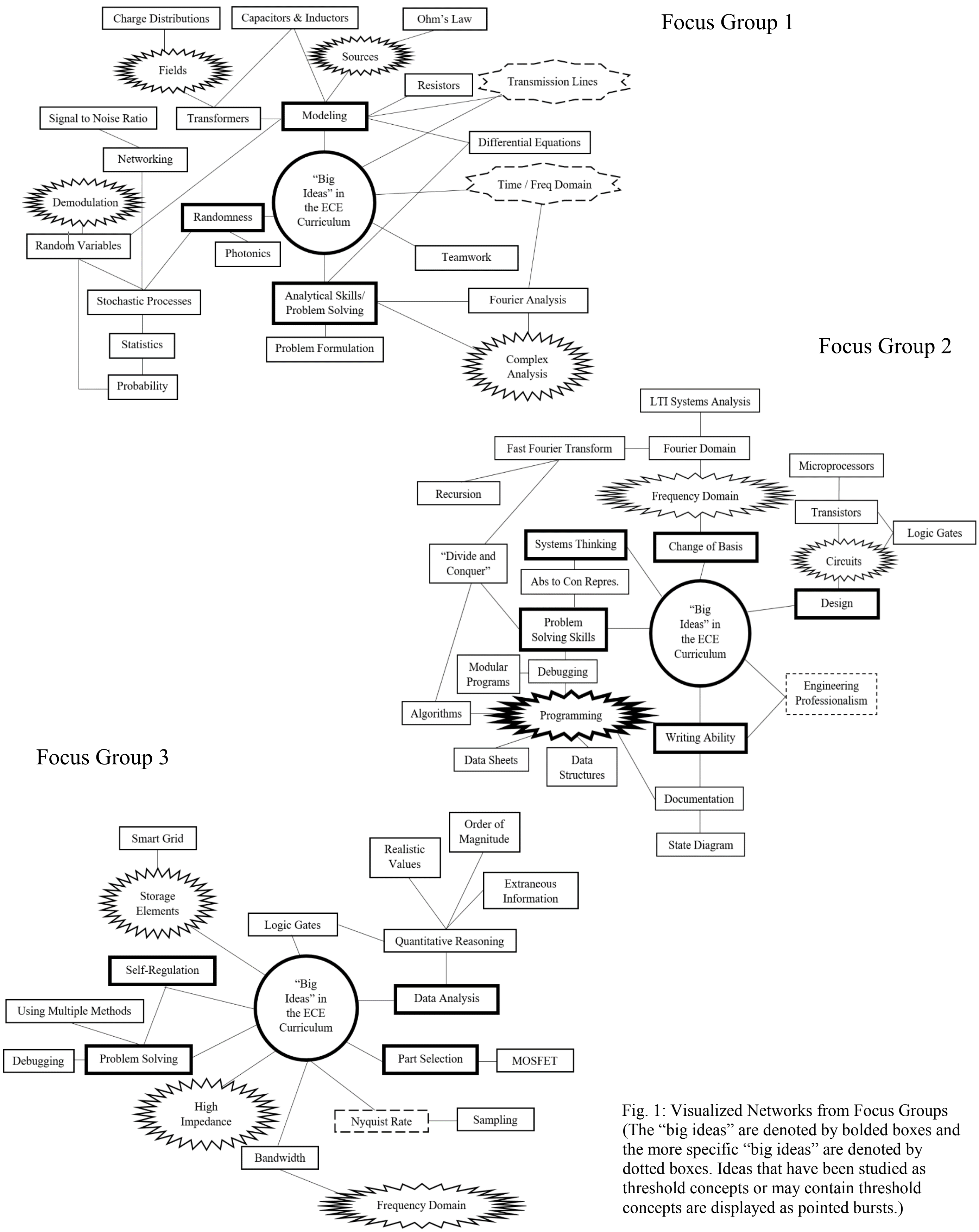


Fig. 1: Visualized Networks from Focus Groups (The "big ideas" are denoted by bolded boxes and the more specific "big ideas" are denoted by dotted boxes. Ideas that have been studied as threshold concepts or may contain threshold concepts are displayed as pointed bursts.)

### 1) Modeling, Design, & Systems Thinking

*"I think the modeling here includes a lot of things… I think it's the ability to extract the fundamental elements from a problem you're facing."*

Of the three big ideas discussed, modeling prevailed as the idea that promoted the most variety in related concepts in the network. The faculty referenced a variety of concepts as "models," even simple circuit components like a resistor – at least in terms of a schematic diagram. From an abstract understanding, resistors are simply pieces of a puzzle – much like capacitors, inductors, and switches. The group agreed that each piece plays a certain part in achieving a goal in a system. For example, one participant described his experience teaching students about transformers and how the device in the real world can be augmented to reduce losses from voltage drops by simply "[putting] resistors and inductors in the right place." Yet, the faculty claimed the students still struggle. Another example was "transmission line modeling, when it comes up," which according to the instructor, "is really a modeling issue." Transmission lines were also explained from a "fields" point of view, but amounted to little additional understanding – according to the instructor.

In fact, the effect of abstraction in modeling may be even more severe. For example, an introductory Circuits course examines the various network theorems such as Kirchhoff's Voltage and Current laws, Thevenin's Theorem, and so on for circuits with a direct current supply and alternating current supply; but, as one of the participants observed: "by the end of day, all the problems [look] similar to each other."

The second focus group also brought up the concept of modeling within systems thinking and design, especially the ability to move between abstract thinking and reality. One participant remarked: "What I think is needed is, for lack of a better term, intellectual agility. I think about the problem abstractly and, at the same time, I am able to think about it very concretely with software, hardware implementation and maybe keep going back and forth between the two. "

Upon comparing the concepts to the threshold concepts identified in the literature, fields, sources (voltage and current), storage elements, and transmission lines emerged as troublesome knowledge.

### 2) Randomness

*"I call it randomness, this concept of randomness. It can be the context of probability, random variables, or it can be stochastic processes. So, this really goes into almost every corner of ECE..."*

The participant who offered the concept of randomness made a compelling amount of connections to different areas of the department courses. For example, "for a lot of the network people who study [stochastic processes], network traffic, they need to do this modeling, and there's a lot of statistics stuff in there, and also signal to noise ratio, and the concept of randomness."

He further explained randomness in the context of signal modulation, which underpins much of communication in electrical engineering. He claimed that, "if you study wireless signal propagation problem for signal demodulation," you need "some sort of model," which in the case of modulation, is a random variable. More specifically, the model is a stochastic process, which is a collection of random variables. From the participant's discussion of randomness and the comments from other faculty, an entire branch of the network was quickly born.

Despite the number of concepts articulated by the members of the focus group, only one threshold concept appeared in this branch based on the reviewed literature, demodulation. While demodulation is not a threshold concept, it does require the frequency domain – which is a threshold concept [21].

### 3) Analytical Skills / Problem Solving, Change of Basis Part Selection, and Data Analysis

*"For the definition of Fourier analysis, I think it belongs to a large set, a concept that we can call analytical skills, or basically math…complex analysis, Fourier analysis, that's really fundamental for ECE."*

The collective idea of analytical skills and problem solving was somewhat overshadowed in the discussions by modeling and randomness, and implicitly entered the conversations periodically. For instance, when discussing the issues of modeling and students' difficulty in conceptualizing abstractions, such as a lumped element model for a transmission line, one participant discussed how she handled the idea of *problem formulation* (or *definition*) in her teaching: "And I think [problem formulation is] a very important part of the problem-solving procedures. In the beginning, we really need to define the problem from the real world. You identify these elements and realize that these can be abstract[ed] to (what is this) [the] ideal models that we'll learn later on."

The third focus group discussed specific areas of problem solving, such as part selection: "another problem I saw frequently was that they really don't have a whole lot of practical understanding of how to choose devices and how to choose components for a given circuit. They look at the capacitors and they had no idea what kind of capacitor to pick, and you go to digi-key and there's hundreds of thousands of different capacitors and it's like, 'What kind of capacitor do I pick for this switch and circuit?'" The faculty clearly valued problem solving in all of its forms, both mathematical and practical.

The concept of frequency domain was repeated in every focus group, but focus group two generalized the concept to the idea of changing bases: "Basically, the concept of [a] signal could be represented in different basis. That's kind of the bigger concept, the Fourier domain wants specialization and you could have different things.... but just signal decomposition in [a] different basis... that give[s] you different abilities to look at things, [that] is the broader idea." Although variants of Fourier appeared to be "go-to" big ideas, the more general idea of changing domains captures a broader and perhaps more compelling big idea.

Specific ideas from data analysis were also presented, such as "answer reasonableness:" "well, say you're looking at a circuit or you need to measure the length of table, and you design a computer program to measure the length of your table, and the computer program works for an hour and a half and it tells you it's -4.5 inches long. Some students will [say], 'This took an hour and a half, this must be right'." We categorized these types of comments as the big idea "realistic values."

A narrower area of the analytical skills / problem solving branch, specifically the foundation of complex analysis (the square root of minus one) emerged as a threshold concept in the literature [9] and in the network. Programming also emerged in the network as a threshold concept due to object oriented programming [12].

#### 4) Writing Ability

*"I think [writing is] ... one of the top skills that if you cannot express your idea clearly, then no matter how great [the] things you're doing are - it doesn't matter."*

Writing skills appeared in the second focus group in terms of how students should consider presenting their documentation: The faculty remarked that "with all forms of documentation, you have to put yourself in the place of the reader, who may know nothing about what you're doing... it's important to get out of yourself and think, "Okay, what should I tell someone, a stranger, about this." Although the majority of the second focus group was concerned with the writing ability of students, one participant provided a different perspective: "I'll offer a slightly dissenting point of view, so I'm often an instructor in a senior design course, heck of a lot of writing, various documents, it's kind of a structure of design methodology and not too bad. Provided you tell them what is needed and not … It's not Shakespeare but it's …"

Faculty in the early years of the curriculum asserted that students' writing skills were lackluster while the instructor at the senior level was more impressed with the quality of the project reports. Writing strategies began to somewhat blend back into coding, as structure in both media are important for readability. Nevertheless, writing was agreed upon as a fundamental skill that ECE graduates should have.

## V. Discussion

### A. Lack of professional skills

Despite encouragement through initial prompting at the beginning of the focus groups, the participants focused almost exclusively on technical skills. Much of the conversation was dominated by various implications of modeling and problem-solving skills, with a slight detour in the discussion to touch on randomness in ECE. In the first focus group, for example, although one participant mentioned teaming near the start of the hour, professional skills were not mentioned thereafter.

Although the lack of detailed discussion of professional skills like teamwork and communication was disheartening, it was not surprising. The literature in ECE threshold concepts makes little to no mention of professional skills [12], meaning authors appear to be prioritizing technical threshold concepts above all else. In a future focus group, perhaps more prompting toward professional skill big ideas is necessary.

### B. Lack of lab skills and practical experiences, but a high concentration of analysis and problem solving

Another surprising absence was practical lab skills, except for big ideas that hinted at implementation beyond the design phase. The theory and practice balance is an old issue with deep historical roots [23], but still has a profound effect on the big ideas that the faculty value. Although the faculty emphasized modeling in various forms, there appeared to be a disconnect with engineering practice. In fact, the large category of analysis and problem solving contained skills that were largely tacit, knowledge that is difficult to transfer to another individual through language [24]. Debugging was a prominent example of one skill that the faculty deemed awkward to teach - the focus of programming is on the product, what does the script accomplish?

While, in fact, the journey to reach from point A to B - even when armed with the necessary functions - can become bogged down in correcting syntax and figuring out how the jagged pieces of the puzzle fit together. One piece of advice a faculty member gave was the use of modular programs; to illustrate, given a sequential program with a progression $A \rightarrow B \rightarrow C$, if the output is incorrect, then assume $A \rightarrow B$ produces a correct result and test C independently. If C yields the desired result, assume $A$ yields the result the user wants and test $B \rightarrow C$ to see if it produces the correct output. This troubleshooting technique generalizes to any progression of n steps, $S_1 \rightarrow S_2 \rightarrow \ldots \rightarrow S_n$ and attempts to isolate pieces of the program and locate the issue; however, *resolving* the issue can be an entirely different story.

### C. Integration of threshold concepts in big ideas

The mention of certain threshold concepts was not surprising in the focus groups and worksheets, particularly time/frequency domain and transmission lines. The time and frequency domain was expected to arise considering the methods of analysis in ECE will often leave the domain that is most familiar to students, the time domain, in favor of a new frontier, the frequency domain. From the perspective of the threshold concepts framework, the transformative criterion from Meyer and Land [9] is easily understood in the context of the shift to the frequency domain since the "transformation" is so literal.

However, alignment between the literature and networks was challenging since the larger concepts that emerged from the discussion needed to be broken down further into more fundamental parts. Threshold concepts were often embedded within the big ideas or concepts; perhaps the only exception was transmission lines. For example, the participants mentioned complex analysis, a considerably dense area of mathematics, in a passing comment. At the heart of complex analysis is the threshold concept, the square root of minus root [9], which is present in all complex arithmetic in ECE. In addition, a previous study on transmission lines as a threshold concept [25] suggested that electrical and magnetic fields were the troublesome knowledge, but deeper insights into the analysis reveals more fundamental issues.

The discussion of transmission lines can quickly become abstract, as mentioned in the focus groups. The analysis often pushes onward from the lumped element model in terms of the typical types of passive components like resistors and capacitors to the derivation of the Telegrapher's equations – a pair of coupled partial differential equations that can be decoupled by transforming them using phasors – another threshold concept [20]. Frankly, transmission lines are replete with threshold concepts, and the proliferation only appears to spread the more one examines the way transmission lines are taught.

### *D. Future Work*

A clear next step in the research design is to analyze the larger scale card sort workshop recently conducted with faculty. The pilots provided some initial insight into how such an activity could be run and provided some external evaluation on previous conclusions, but a more detailed analysis should follow. Other future subprojects include completing a deeper analysis of the worksheets, as there is a large amount of unrelated qualitative data related to teaching practices in the ECE department that can inform next steps.

In addition, focus groups conducted with undergraduate students and industrial advisory board members will be analyzed to compare perspectives of different stakeholders.

Another avenue for future work is to look closely at others in ECE and CS who have done work in threshold concepts and see how well the work transfers to the current context beyond superficial curricular connections. For example, Parker and McGill [27] reported on restructuring an entire engineering curriculum based on threshold concept centered modules. Modules are an attractive option to move forward, but whether it is compatible with the institutional context is an open question.

### *E. Limitations*

A weakness of the network analysis is the requirement to create a line between two concepts. If concepts A and B need to be in direct reference to one another, then another concept, C, that may be intimately connected to A, may not have a line since it was not referenced in conversation – B may not even be a strong connection. An example of a gap in the results was the author's inference to draw out the frequency domain in the demodulation concept, a connection not explicitly mentioned in the focus group. Part of the issue may be the level at which the big ideas and topics were discussed.

At a high level, it can be difficult to pull out specific ideas that are vital to the conversation. Moreover, if the goal of the network was to demonstrate all latent and prominent connections between the big ideas in ECE, the presented network is also a clear failure. Such a realization is not necessarily a loss from a "rigor" perspective, as the construction of a complete network on which everyone agrees is highly improbable.

Finally, since the focus groups were conducted with faculty, only their values are represented. Although this was the population chosen in the research question, more comprehensive networks to inform the full-scale reform would involve the students and industry – as planned.

### *G. Author Reflexivity Statement*

The authors approached this study from a pragmatic perspective. The work began as a study to identify threshold concepts using a Delphi Study, but the results from this investigation were intended to inform curriculum development for the Fall of 2017; therefore, a Delphi study to rate threshold concepts against Meyer and Land's criteria [9] was deemed to be infeasible due to the time constraint and general practicality of the results for the project. Instead, the study aimed to understand what the department valued and situate known threshold concepts in their values.

Moving forward, a more in-depth analysis will be done on the CoRe worksheets. Discussing the worksheets in depth would serve to answer a different research question related to how threshold concepts might inform processes of renewing curriculum in terms of implementation - teaching. The work of the participants would not have been done justice if the results were only allocated to a short section in this paper.

## VI. CONCLUSION

This paper presented the onset of an investigation that examined faculty perceptions of big ideas in their teaching to inform a large-scale restructuring of an ECE academic plan. Our analysis revealed several focal areas the faculty value, including modeling, design, writing, analytical skills, and a grasp on randomness in ECE. Known threshold concepts emerged as focus group topics while others were engrained in the subject matter.

Although more work must be done before Fall 2017 to prepare for new pilot curricula, the probing of faculty values through the focus groups was vital to understanding the next steps to curriculum renewal in the context of promoting a cultural shift in the department. The lack of professional and lab skills prompted concern, so the absence must be addressed as the program objectives take shape and change to meet the new aims of the department.

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