Stirring up a Special Sauce: Marrying Electrical and Computer Engineering with Threshold Concepts for ECE 101

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***Abstract*—This special session introduces threshold concepts as a framework to design an integrated first-year course that covers a wide range of Electrical and Computer Engineering (ECE) from circuits to software. We discuss an interaction plan to engage participants in distilling fundamental projects for ECE courses into their fundamental components and looking for opportunities to make explicit connections across disciplines. While ECE is used as the guiding example, other disciplines can benefit from a similar approach.**

***Keywords*—electrical engineering, computer engineering, threshold concepts, introductory, course design**

I. Description of Session

In this session, participants will reconceptualize electrical and computer engineering (ECE) curricula at the undergraduate program level by applying threshold concept theory. Through sharing content and experiential knowledge, the groups will produce thematic maps of how threshold concepts are introduced and mastered in undergraduate ECE programs. Threshold concepts are challenging to learn and reorient the way a student thinks about knowledge and the discipline. According to Meyer & Land [1], a "threshold concept is akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress." Common examples of threshold concepts include the ideas of gravity and imaginary numbers. In ECE, Thevenin and Norton equivalent circuits, superposition, voltage, current, pointers, and object-oriented programming are cited as potential threshold concepts [2].

In this session, we will put Meyer and Land's enticing metaphor into practice by using threshold concepts to design an "ECE 101" course meant to introduce students to fundamental concepts in ECE. Starting with backward design [3], we will guide participants in distilling projects into the electrical engineering (EE) and computer engineering (CPE) concepts they embody, ranked by whether the concept is introductory or more advanced. These concepts will then be reconstituted based on complementarity and categorized into larger themes that all students learn in ECE programs. This special session will focus on the themes that are appropriate for an introductory electrical and computer engineering course with an eye toward overall program goals. Drawing from the historical development of the field's landscape, participants will also reconstruct the progression of discovery in the field by pairing threshold concepts with major scientific paradigm shifts. The results of these two activities can then be adapted by participants in multiple offerings in their curricular programs.

II. Session Goal

The primary goal of the session is to engage faculty in using the Integrated Threshold Concept Knowledge framework [4] to identify cross-cutting ideas in ECE to develop a sketch of an "Introduction to ECE" course. While our focus in on ECE, the method we employ applies to other disciplines.

III. Audience

This workshop will be useful and intriguing to ECE instructors teaching lower-division courses in the discipline, to faculty and administrators invested in program evaluation, and to history buffs interested in scientific revolutions. Also, ECE faculty teaching courses later in the curriculum can benefit from exploring ways that fundamental knowledge can be valued and learned by students as they progress toward advanced practice in the discipline. Instructors and researchers exploring first-year courses, conceptual knowledge/change, and threshold concepts - in the discipline or otherwise - can also benefit from the workshop interactions.

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IV. JUSTIFICATION OF SESSION NOVELTY

Electrical engineering historically underwent a sustained period of expansive (dis)integration beginning in the [5], where the field gradually balkanized itself into highly specialized areas with little communication between them, even when in the same department. Subsequently, the task of introducing students to both disciplines in a single course – and faithfully balanced - is challenging. Such a blend is complicated further by different subfields jockeying for priority in such courses. This session will present a thought-provoking opportunity to consider the Integrated Threshold Concept Knowledge framework [4] as a lens to rectify the expansive (dis)integration and find compelling cross-cutting ideas that can form a balanced introduction to the full spectrum of ECE.

V. INTERACTION PLAN

Participants will be engaged in the backward design of a hypothetical "Introduction to ECE" course with consideration to how it fits into the broader curriculum. Attendees will be grouped to brainstorm big ideas in the disciplines, which will involve discussing projects they have done in their courses or projects they would like to implement and have yet to do so. These discussions will be abstracted into the underlying concepts inherent to the projects and the other concepts generated. The concepts will then be sorted to examine them for integrative ideas across the ECE disciplines and provide an opportunity to reflect on major progressions in the discipline over time. We will discuss the implications of the attendees' findings to close the session.

Although we focus on ECE as the primary example because of its considerable disintegration, those from other disciplines will still be able to engage.

VI. AGENDA

This 110-minute session will progress via brief activities for information gathering and sharing, resulting in concept maps of Intro to ECE courses, ECE undergraduate program goals, and historical arcs of the fields' progressions.

Preheat (15 minutes): The start of the session will entail an introduction to the curriculum change efforts in the ECE department at Virginia Tech. The authors will then outline a brief history of ECE to outline how the integration of Computer Engineering into Electrical Engineering has affected the field's disciplinary identity and its reflection in ECE curricula at large. We will highlight the challenge of developing an introduction to engineering course as a common push and pull between faculty for the priority of specific disciplines to ensure those who do not identify with ECE necessarily are engaged.

Ingredients (20 minutes): Participants will brainstorm ECE cornerstone and capstone projects that are either imagined or existing in their program (15 minutes). Next, facilitators will discuss an example project and distill it into ECE concepts that the students must know to work through the project (5 minutes).

Combine (25 minutes): Next, participants will organize these concepts by discipline and then decide whether the concept should be taught in introductory or advanced courses (10 minutes). These concepts will be differentiated using a technique called Disciplinary Concept Graphs (DCGs) [6]. This approach is a type of concept mapping that breaks concepts down into their constituent parts and reveals relationships between "primitives" and subordinate complex concepts. In algebraic terms, a concept X is a combination of a set of n complex concepts C and a set of m primitive concepts P, represented like so in Equations (1) and (2):

$$C = \{c_1, c_2, \dots, c_n\} \quad (1)$$

$$P = \{p_1, p_2, \dots, p_m\} \quad (2)$$

Since complex concepts can be broken down in a similar manner, a hierarchical structure is likely to arise. Eventually, there will be a concept with only primitives, so there is a logical "end" to the hierarchy. By revealing the primitives of a set of complex concepts, it is possible to identify relationships between concepts and determine a continuum of introductory to advanced. *We will focus on the complex concepts and encourage participants to write down primitives separately. This will ideally avoid situations where participants intermix complex concepts and primitives.*

For a set of concepts chosen by the participants, they will identify what they believe to be the most complex concept – we'll call that concept, *X*. The next step is to identify the primitive concepts and the subordinate complex concepts describing *X*. Primitives will likely manifest themselves as properties, physical or mathematical, like mass and charge in Figure 1.

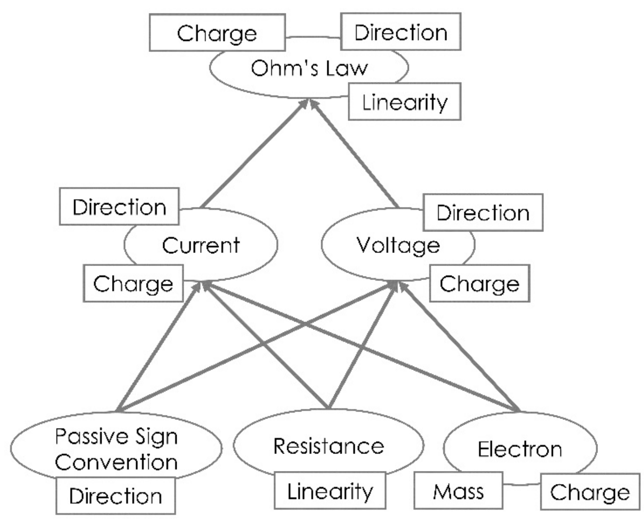

Figure 1. Example DCG for the concept *X* = Ohm's Law, note there are multiple ways to configure DCGs

The participants will continue decomposing the subordinate complex concepts until they are convinced the hierarchy represented enough to engage in discussion across groups. *We are not particularly concerned with, nor are we expecting perfect DCGs during the session*, but the following DCG properties can be used to determine completeness after the session [6]:

(1) Each node names a complex disciplinary concept, and there is a node X, where X is the main complex concept to decompose.

(2) For each node A, there is a path of arrows in the diagram leading from node A to node X.

(3) Each node A has an associated halo of boxes labeled with the names of A's primitive concepts. (This property helps ensure no primitive becomes a complex concept.)

(4) If A is a node and C is the set of all nodes with an arrow to A, then the concept A is the integration of the concepts in C. A is then called an integrating node.

We summarize these properties in Figure 2. This information will be available to participants as a take-home activity if they wish to continue working on their DCG(s).

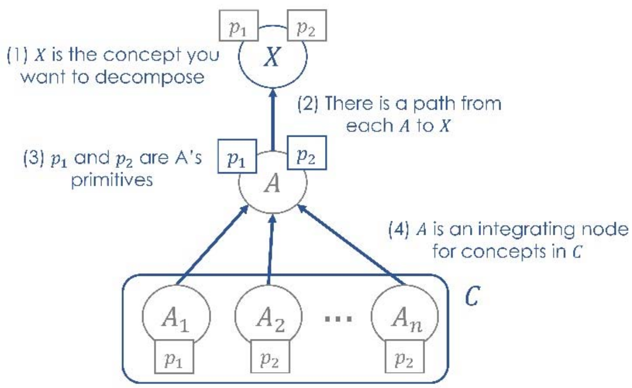

Figure 2. Demonstration of DCG properties

From here, the participants will cluster the concepts based on complementarity while keeping track of disciplinary identity (ranging from EE to CPE) and difficulty level (5 minutes). These clusters will yield broader themes, which we will use to introduce the threshold concepts framework (10 minutes).

Heat (10 minutes): In the discussion of threshold concepts, we will provide a brief overview of the literature on ECE threshold concepts to scaffold what was developed in the *combine* step.

Whisk (20 minutes): Next, we will use the participant-identified threshold concepts to build an introductory ECE course that reflects EE, CPE, and the integration of the two (20 minutes). We will use the narrative thread approach to threshold concepts to encourage parsimony in their formulation [7]. The narrative thread approach is a tactic to avoid a growing laundry list of threshold concepts as the discipline evolves.

The participants will use their draft DCGs to promote finding connections among the concepts that form a broader 'narrative' that extends beyond loaded analytical strategies such as Fourier Analysis. For example, instead of the source transformations, Thévenin equivalents, and Norton equivalents all being threshold concepts, we can combine them into the following narrative thread: 'We can exchange components locally to an equivalent form without changing a linear circuit's output.'

Participants will be prompted to think integratively by framing their courses around the narrative threads. The deliverable of the *whisk* stage will be at least one narrative thread to share and a set of experiences to support the narrative.

Thicken (10 minutes): We will use the last 10 minutes for lightning talks by groups presenting their results and questions.

VII. Facilitator Bios

David Reeping: Dr. David Reeping is a Postdoctoral Associate in the Department of Electrical and Computer Engineering at Virginia Tech. He earned his Ph.D. in Engineering Education from Virginia Tech and was a National Science Foundation Graduate Research Fellow. He received his B.S. in Engineering Education with a Mathematics minor from Ohio Northern University. David has primarily studied signal processing and machine learning techniques in the context of ECE, translating these techniques to educational research.

David has worked with Virginia Tech's Revolutionizing Engineering Departments project in the Department of Electrical and Computer Engineering for four years. He has led research on threshold concepts as a means of developing integrated curricula. He is currently teaching the first course in the department's new curriculum called "Introduction to ECE Concepts," which intends to introduce students to the breadth of ECE.

Desen Ozkan: Desen is a Ph.D. candidate in Engineering Education at Virginia Tech. Her research focuses on interdisciplinary curriculum development in the context of cultural, technical, and societal constraints and influences. She has worked as a graduate research assistant on the NSF RED project in the ECE department since the Fall of 2018.

Lisa McNair: Dr. McNair is a Professor of Engineering Education at Virginia Tech and Director of the Center for Educational Networks and Impacts (CENI) at the Institute for Creativity, Arts and Technology (ICAT). Her research and practice focus on developing integrative education projects that transverse perspectives within and beyond the university. She is a co-PI on the NSF RED project in the ECE department at Virginia Tech, with responsibilities including curricular design and evaluation.

Tom Martin: Dr. Tom Martin is a Professor in the Department of Electrical and Computer Engineering at Virginia Tech, with courtesy appointments in the Department of Engineering Education and the School of Architecture + Design. He is the Deputy Executive Director of ICAT, where he oversees several interdisciplinary initiatives. He is a co-PI of VT ECE's RED grant, where his responsibilities include overall project management, transition planning for community college transfer students, faculty/advising staff working group leadership, and departmental undergraduate program design. He has facilitated numerous design and brainstorming workshops such as the one proposed here, for both industry and academia, with group sizes ranging from about 5 to about 60 people.

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