Work in Progress: The Electric Circuit Concepts Diagnostic (ECCD)

Dr. Nathaniel Hunsu, University of Georgia

Nathaniel Hunsu is an assistant professor of Engineering Education. He is affiliated with the Engineering Education Transformational Institute and the school of electrical and computer engineering at the university. His interest is at the nexus of the research of epistemologies, learning mechanics and assessment of learning in engineering education. His research focuses on learning for conceptual understanding, and the roles of learning strategies, epistemic cognition and student engagements in fostering conceptual understanding. His research also focuses on understanding how students interact with learning tasks and their learning environment. His expertise also includes systematic reviews and meta-analysis, quantitative research designs, measurement inventories development and validation.

Dr. Kun Yao, University of Georgia

Kun Yao received the B.S. and Ph.D. degrees in physical electronics from Peking University, Beijing, China, in 2002 and 2008, respectively. From 2008 to 2012, He worked at the University of New Orleans and the University of Georgia as a Postdoctoral Researcher. In 2013, he joined the College of Engineering at the University of Georgia as a lecturer, as well as the manager of the cleanroom core facility. He is also affiliated with the Engineering Education Transformational Institute and the New Materials Institute.

Dr. Adel W. Al Weshah, University of Georgia

Dr. Al Weshah is a lecturer in the School of Electrical and Computer Engineering in the College of Engineering at the University of Georgia. He has published in the area of computational electromagnetics. His engineering educational research interests include remote labs and developing innovative instructional materials and techniques.

Mr . Olanrewaju Paul Olaogun, University of Georgia

Olanrewaju Olaogun is currently a PhD candidate of Electrical and Computer Engineering at the University of Georgia. He received a B.Sc. in Electrical/Electronic Engineering from the University of Benin, Nigeria, and a M.Sc. in Electrical Engineering from Florida Institute of Technology, USA. He is interested in the conceptual change research in engineering and STEM. His research emphasis at the time is about formulation and testing of models of conceptual change learning and understanding the processes by which conceptual change occur in engineering. He can be reached at olanrewaju.olaogun@uga.edu.

Work in Progress: The Electric Circuit Concepts Diagnostic (ECCD)

Abstract

Students come to learning in engineering classrooms with misconceptions about the concepts covered in engineering course contents. However, instructional efforts are often do not effectively address misconceptions in students' prior knowledge. Concept inventories (CIs) are often relied upon to identify misconceptions in students' prior knowledge. However, many instructors never benefit much from using CIs because they lack either the know-how, time commitment, or statistical skills required to use them efficiently and effectively. Furthermore, there sometimes are ambiguities about how to interpret students' CI scores. The Electric Circuit Concepts Diagnostic (ECCD) project team will address these limitations of CIs by creating a web-based electric circuit concept inventory that: (i.) provides an immediate and multi-purpose feedback system for reporting about students' circuits and electricity prior knowledge; (ii.) differentiates, with a high probability, between a lack of prior knowledge and misconceptions; and (iii.) uses a scheme of multidimensional knowledge profiles to report on students' prior knowledge and misconceptions. The project will integrate the affordances of cognitive diagnostic modeling (CDM), multi-tier testing frameworks, and computer-assisted testing to realize these project objectives. This work-in-progress report introduces the objectives of ECCD inventory to the ECE research and teaching community.

Keyword: Electric circuit, circuit, misconception, concept inventory, knowledge diagnostic

1.0 Introduction

The quantity and quality of students prior knowledge of basic concepts is pivotal to the ability to learn advanced and complex STEM topics [1, 2]. As such, researchers endeavor to identify and research pedagogies and tools that reveal misconceptions in students' prior knowledge, in order to promote conceptual change learning [3]. Researchers and instructors have employed different techniques to identify students' misconceptions: including methods such as interviews, think-aloud and focus groups. However, these methods are labor-intensive, time-consuming, and require specialized skills to successfully use on a large scale, or in classroom. Alternatively, concept inventories (CIs) have been designed to evaluate students' understanding of basic concepts and to spot knowledge gaps and misconceptions in students' prior knowledge [4, 5]. Because CIs are typically based on Multiple Choice Tests (MCTs), they are relatively easier to administer and scaled to a larger population than interviews or think-aloud methods.

In theory, knowledge assessment tools (such as CIs) can positively impact science pedagogy by providing instructors with important information about what students know. The significance of CIs spurred several funding initiatives by the National Science Foundation (NSF) to support their development in various discipline-specific STEM fields between 2005 and 2015 [6]. During that era many paper-and-pencil based multiple-choice CIs that instructors could administer to students in the classroom were developed. These CIs were excellent for their simplicity and were deemed invaluable as prior knowledge probes. However, CIs for engineering content from that era were not user-friendly for instructors, and were not particularly designed to inform students.

Although conventional CIs could be useful as prior knowledge probes, instructors might not derive as much benefit from using them as their developers had intended because: (i) there is often sparse education about the various ways in which they can be used to assess students' knowledge; (ii) some instructors struggle with how to handle ambiguities about how CI results should be interpreted; and (iii) they can be inaccessible – either because they are no longer physically accessible, or because many instructors lack the time or skill needed to use them correctly, or to optimize their benefits.

Given current advances in knowledge assessment and computer-assisted testing, CIs can be designed and developed to be more beneficial for instructors *and students* in ways that CIs currently do not. This, we argue, can be done by leveraging the affordances of advanced assessment methodologies and computer-assisted testing. To achieve this goal, our team is developing the Electric Circuit Concepts Diagnostic (ECCD) tool. We hope to integrate components of cognitive science, cognitive diagnostic modeling, conceptual change learning, and computer-assisted testing capabilities to optimize the utility of the CI tool for electrical circuit instructors and students. When completed, students' results from an ECCD test will be presentable in multiple formats that makes it possible for instructors to understand students' prior knowledge and misconceptions about electrical concepts from multiple perspectives.

2.0 Background

2.1 Limitations of Concept Inventories

Students often have misconceptions that hinder their learning of STEM concepts. Such misconceptions are often strongly held, and can be resistant to regular instructional approaches. Unaddressed, students' misconceptions may undermine instructors' efforts to help them accurately learn scientific facts [3]. Misconceptions about scientific or technical concepts can undermine learning and may have negative effects on perceived instructional effectiveness. As such, educational assessments such as CIs can reveal misconceptions in students' prior knowledge and provide baseline data about misconceptions that help instructors identify how to address such misconceptions. Data about students' misconceptions and the depth of their prior knowledge can inform remedial efforts and decisions about instructional adjustments that may improve how content is delivered to help students learn better.

Many instructors use CIs in pre-and post-configurations to evaluate the efficacy of their instructions [4, 7-9]. However, obtaining total scores, or gain scores, only reveal very little about students' misconceptions. Furthermore, CI scores are often not immediately available, nor are they presented in ways that provide instructors and students with meaningful, and actionable, feedback that facilitates strategic instructional decision making. Besides, we identified at least two major drawbacks of CIs from the literature. They include:

2.1.2 Confounding due to false positives: Although MCT CIs can be easily administered, being an MCT type, the interpretation of CI test scores can be obscured by false positives if test takers answers test questions correctly by guessing. Interpretation of test scores may also be obscured by false negatives if a test-taker inadvertently chooses the wrong option [10]. In a four-option multiple-choice test, for example, there is a 25% chance of choosing a correct option by pure luck. Similarly, a test taker has 75% chance of choosing the wrong option inadvertently. The fact that what students really know may be so confounded undermines the objective of administering CIs to probe their prior knowledge. Similarly, it may also be difficult to determine whether a respondent chose a wrong option on the CI test due to a lack of prior knowledge or as the result of having a misconception(s) about the concept the test item assesses. According to extant conceptual change literature, being able to differentiate between misconceptions and a lack of knowledge has considerable implications for effective pedagogy [9, 11, 12]. Thus, an inability to differentiate between students' *misconceptions* and *don't-knows* confounds how CI scores can be interpreted, and may undermine the reason why CIs are administered in the first place.

2.2.2 Diminished usability of CI scores due to limited descriptive and interpretive relevance: Traditionally, instructors utilize results of CIs in a couple of ways: (i) as misconception probes, (ii) to assess knowledge gain, (iii) or for making normative comparisons. In many instances where instructors administer CIs, students' scores are presented as single proficiency scores based on item response theory (IRT) or classical test theory (CTT) scoring models. Used this way, CI scores provide a unidimensional indication of the level of students' test performance. However, it fails to highlight how students perform across an array of interconnected bits of concepts or knowledge units that are vital to gaining a better understanding of the multidimensional nature students' prior knowledge. Since student knowledge is an interconnection of small ideas, it is necessary their test scores should be multifaceted.

Alternatively, instead of reporting unidimensional total score on the concepts a CI assesses, we could increase the relevance of CI results if test outcome reporting is based on a multi-dimensional scoring scheme. For example, students' outcome on the test could be reported as multiple scores that indicate how well they have mastered cognitive attributes (or smaller knowledge units) that predict mastery of bigger concepts, or as profiles of concepts or knowledge units that they are yet to master. This objective may be achieved if the reporting of CI scores is based on cognitive diagnostic models (CDM). Unlike models based on classic test theories, CDM-based assessments highlight latent traits or concepts and sub-traits (or sub-processes, etc.) that comprise students' knowledge in ways that allow for reporting multidimensional of students' knowledge. Such multi-facet scores focus more on assessing mastery instead of performance of major concepts.

2.2.3 The cost of facilitating immediate feedback: Educational assessment tools should be capable of providing meaningful and interpretable results that are accessible to instructors with minimal or no psychometrics experience. Since CIs are administered in paper-and-pencil format, collating their results in a way that ensures they can be optimally utilized can require intensive time and skill investments that a typical instructor cannot afford. Most instructors often lack the time and skill to prepare CIs score that are not a unidimensional summary of students' performance.

3.0 Electric Circuit Concepts Diagnostic (ECCD)

To address the limitations of prior concept inventories described above, our research team is developing the ECCD. The ECCD will comprise of a battery of CIs that captures multiple dimensions of foundational knowledge that are essential to acquiring more advanced knowledge in electrical engineering. Table 1 shows the proposed content structure of the battery of tests that will comprise the ECCD test.

Table 1: Proposed ECCD test content focus

ECCD Test Category	Potential ECCD Concepts
Basic Concepts Test	Voltmeter and ammeter
	Branch, loop or mesh, node
	Sequencing reasoning
	Voltage and potential difference
	Short and open circuits
	Resistor, inductor and capacitor
	Voltage and current source
	Energy and power
	Current/charge
	Cell/battery
Current Laws Test	Ohm's law
	Kirchhoff's voltage and current law
	Equivalent resistance (Series and parallel connections)
	Current and voltage division
Circuit Skills Test	Superposition theorem
	Source transformation
	Combining current and voltage sources
	Algebraic manipulations
	Units

3.1 Objective of the ECCD assessment tools: When completed, the ECCD will integrate the affordances of CDM, multi-tier testing frameworks, and computer-assisted testing to realize mitigate these limitations. Functionally, ECCD assessments will endeavor to:

1. Differentiate between what students have mastered, need to know, or might have misconceived.
2. Provide multidimensional feedback about sub-skills and knowledge units that indicates students' *mastery (or non-mastery) of foundational knowledge for electric circuits by*:
   i. Reporting profiles of sub-skills that students have mastered or not mastered to enable instructors to assess students' prior knowledge to determine what needs to be addressed in classrooms.
   ii. Reporting profiles of mastered and unmastered sub-skills may inform students about what they may *need-to-know* to better learn concepts in electric circuit courses.
3. Ensure that multi-faceted, multi-purpose, feedback about students' *prior knowledge* of circuits and electricity can be available to instructors and student promptly.

The ECCD project will be implemented in three overlapping phases that will provide a framework for developing value-added CIs in other STEM domains. The ECCD will improve upon prior electric circuit CIs by offering three features:

The *content feature* of the ECCD tool will comprise a battery of tests that focus on basic knowledge that are essential to mastering concepts that are germane to circuit analysis. Each section of the ECCD test will be designed as stand-alone tests that can be administered separately or together.

The *assessment features* of the ECCD will comprise both three-tier and cognitive diagnostic modeling assessment components. A three-tier testing approach will enable the ECCD tool to differentiate, to a higher degree, whether students *have misconceptions, or lack prior knowledge* of basic electric circuit concepts other than conventional CIs. The three-tiers of the test will comprise (i) items and distractors on knowledge content being tested (ii) options that probe students' rationale for their response to items, and (iii) and an assessment of students the confidence in the option they chose. In addition, the ECCD tool will employ cognitive diagnostic modeling to facilitate a *multidimensional* score reporting scheme. Test scores will be reported as *profiles* of cognitive attributes (smaller knowledge units) that students have either mastered or need to master correctly.

The *access feature* of the test will be facilitated by employing computer-assisted testing via a web-based application that allows test scores to be computerized and accessible to instructors and students. This will enable test results to be available and presentable in multiple formats *immediately* after a test is conducted. It also will also make the test more available and accessible to instructors who intend to use the tool to assess their students' prior knowledge.

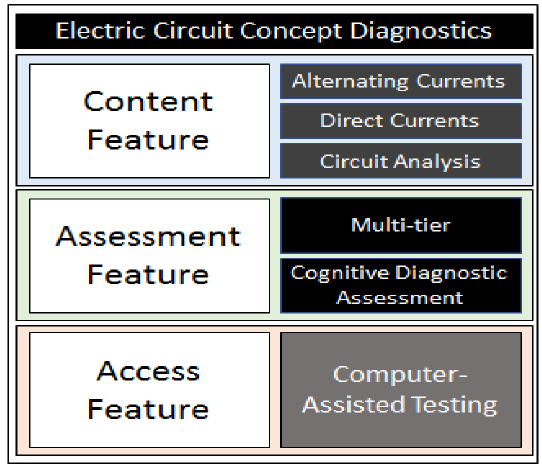

Fig. 1. Conceptual Layout of the ECCD

Each component of the ECCD project will require extensive cross-disciplinary knowledge and expertise. As such, we propose to distribute the tasks associated with the ECCD project into three manageable phases that enables us to: (i) simplify project goals and activities in order to achieve our objectives realistically; (ii) manage the complexities and multidisciplinary skills and resource needed to successfully deliver the project objectives, and to carefully work on its eventual roll-out incrementally, as well as to create a mechanism that ensures project sustainability beyond the life of the funding

4.0 Development phases

The ECCD project will be achieved in the following phases:

4.1 Defining Test Content: Project activities in this phase focused on identifying concepts that we deemed are critical to students' success in electric circuit analysis. At this stage, we identified basic concepts that instructors think are most critical for students to master AC, DC, and circuit analysis concepts. We relied on the contributions of instructors and content knowledge experts. At the conclusion of this stage, ECCD was narrowed to focus on the most important concepts, and identify and associate specific items to selected concepts.

4.2 Identify alternative conceptions: The major deliverables at this stage of the project are to develop the reason-tier of the ECCD, and to develop a preliminary Q-Matrix for the test. We will identify students' misconceptions about target concepts by administering open-ended formats of the ECCD to a wide pool of circuit students in college [13]. The open-ended format of the test will include question stems with no answer options provided. Q-Matrix will be developed to map every item on the ECCD with all sub-skills and cognitive attributes that respondents need to answer items correctly [14]. The Q-Matrix is needed to develop a multi-dimensional reporting scheme at the second phase of the ECCD project.

4.3 Test Compilation and administration: When the content and reason tiers of the ECCD are completed, we will compile the test and append a confidence-rating tier. The full test will be piloted on electric circuit students to conduct initial validation studies.

4.4 Validation and Evaluation: Preliminary validation studies will be conducted to examine the psychometric properties of the instrument, and to validate the Q-Matrix based on a CDM model. We plan to conduct cognitively diagnostic analyses using a CDM model to validate the diagnostic properties of the test [14 - 16].

5.0 Potential significance to the ECCD Project to Engineering Education

Conceptual change pedagogies require that we identify students' misconceptions in order to help them overcome such misconceptions. Hence, efforts to identify misconceptions are pivotal to implementing effective conceptual-change-focused pedagogy. To serve this objective, CIs have been recommended to, and used by, instructors in foundational engineering courses [7, 8]. Because misconceptions can be particularly problematic in learning engineering concepts, being able to effectively and efficiently identify them becomes pivotal to building solid engineering education "houses" brick-upon-brick on sound foundations.

Despite their limitations, CIs are still more effective and efficient for probing students' misconceptions than interviews. However, rethinking and redesigning CIs can be helpful for both instructors and students. For example, if designed to provide meaningful, multi-dimensional, and readily accessible knowledge scores, more instructors may find them as helpful prior knowledge diagnostics that help them rethink and direct their instructional efforts toward pedagogies that are effective to foster conceptual change learning. In the same vein, CIs may be designed to provide multi-dimensional scores that help students to better recognize gaps and misconceptions in their prior knowledge. The ECCD will build on current thinking in the development CIs and help instructors gauge students' prior knowledge and identify misconceptions crucial to learning electric circuit concepts. The diagnostic tool will build on current framework for CI design in engineering assessment by incorporating multi-tier MCT, cognitive diagnostic models (CDM) and computer-assisted testing capabilities to enhance the knowledge diagnosis capabilities of the ECCD. When fully completed the ECCD project will be unique in its integration of the three features mentioned above, and exemplary for future CI projects for different STEM areas.

Reference

1. Kang, H., et al. Cognitive conflict and situational interest as factors influencing conceptual change. 2010. 5(4): pp. 383-405.
2. Otero, V.K. and M.J. Nathan, Preservice elementary teachers' views of their students' prior knowledge of science. 2008. 45(4): p. 497-523.
3. Limón, M.J. and instruction, On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. 2001. 11(4-5): p. 357-380.
4. Libarkin, J. Concept inventories in higher education science. BOSE Conf. 2008.
5. Smith, J.I. and K.J.C.L.S.E. Tanner, The problem of revealing how students think: concept inventories and beyond. 2010. 9(1): pp. 1-5.
6. Roman, A.S., et al. The development of a Q-matrix for the concept assessment tool for statics. American Society for Engineering Education. 2010.
7. Steif, P.S. and M.A. Hansen. New practices for administering and analyzing the results of concept inventories. 2007. 96(3): pp. 205-212.
8. Streveler, R.A., et al. Learning conceptual knowledge in the engineering sciences: Overview and future research directions. 2008. 97(3): pp. 279-294.
9. Madsen, A., S.B. McKagan, and E.C. Sayre. Best practices for administering concept inventories. 2017. 55(9): pp. 530-536.
10. Arslan, H.O., C. Cigdemoglu, and C.J. Moseley. A three-tier diagnostic test to assess pre-service teachers' misconceptions about global warming, greenhouse effect, ozone layer depletion, and acid rain. 2012. 34(11): pp. 1667-1686.
11. Chi, M.T. and R.D. Roscoe, The processes and challenges of conceptual change, in Reconsidering conceptual change: Issues in theory and practice. 2002, Springer. p. 3-27.
12. Chi, M.T. Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. International handbook of research on conceptual change. 2009, Routledge. pp. 89-110.
13 Treagust, D.F, *Development and use of diagnostic tests to evaluate students' misconceptions in science.* 1988. 10(2): p. 159-169.
14. Torre, J. and N.J. Minchen. *Cognitively diagnostic assessments and the cognitive diagnosis model framework.* 2014. 20(2): pp. 89-97.
15. Ravand, H.J., *Application of a cognitive diagnostic model to a high-stakes reading comprehension test.* 2016. 34(8): pp. 782-799.
16. Santiago-Román, A.I., R.A. Streveler, and L. DiBello. *The development of estimated cognitive attribute profiles for the Concept Assessment Tool for Static*. in *2010 IEEE Frontiers in Education Conference (FIE)*. 2010. IEEE.