Factors Influence Designing of Sophomore Circuits Courses

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Electrical engineering introductory circuit courses are the first context in which students are exposed to simple, steady-state, or direct current (DC) to complex, transient, or alternating current (AC) circuit theory and concepts. While students are usually taught basic circuit concepts in physics classes, introductory classes tend to go into more depth, as these classes form the basis for a specialization in electrical engineering.

instructional methods | student engagement | curriculum design

1. The Role of Students' Prior Knowledge

Engineering students' ability to learn introductory concepts is very important for their success in becoming experts in their respective disciplines or areas of study. More specifically, "to develop competence in an area of inquiry students must have a deep foundation of factual knowledge, understand facts and ideas in the context of a conceptual framework and organize knowledge in ways that facilitate retrieval and application" ([1], p. 16). According to [2], the process of learning is characterized "in terms of comprehension, skill acquisition, both" (p. 440).

Engineering practice, as categorized by [3], consists of three components:

- Engineering as problem solving, considering the systematic process that engineers use to define and resolve problems.
- Engineering as knowledge, considering the specialized knowledge that enables and fuels the process.
- Engineering as the integration of process and knowledge (p. 429).

In keeping with these three core areas, the root of electrical engineering expertise can be classified as a working knowledge of basic to complex circuit concepts which is transferred from course to course, an advanced mathematical understanding, and the combination of content knowledge and mathematical skills which develops the ability to identify and solve unknown circuit conditions.

At the surface level, the heart of electrical engineering knowledge can be characterized by the ability to identify following conditions:

- The three basic circuit configurations: series, parallel, and series–parallel,
- The four dominant variables: voltage, current, resistance, and power,
- The four main components of electric circuits: source, control, load, and conductors, and
- An understanding of how all these factors interact to create the desired circuit operation.

Research, however, has indicated that students tend to have difficulty understanding these very basic concepts, which then becomes problematic when more complex concepts are introduced [4][5][6][7]. The work of Shaffer and McDonald [8] has been cited as one of the hallmarks of the research conducted on investigating the difficulties students experience when learning direct current (DC) circuit concepts. Ref. [9] used various studies expanded on the categories and sub-categories summarized in the table above to include:

- An inability to handle simultaneous change of variable (p. 37).
- An inadequate use and misuse of analogies (p. 47).
- A fear of qualitative reasoning—the mechanical use of formulas (p. 49).

Similarly, Bernhard and Carstensen [10] and Streveler et al. [11] reported that a basic understating of the relationship among various electrical quantities is an important area of difficulty for students. Students tend to have difficulty envisioning quantities such as voltage, current, and resistance acting interchangeably in a circuit, yet still performing their own circuit task toward the holistic operation of the circuit [12][13]. In each case, a recommendation has been made for the use of specific instructional strategies possessing the ability to help students to overcome these difficulties. This is based on the premise that students not only learn these basic introductory concepts, but are able to apply them to more complex contexts such as other courses and the world of engineering practice. This involves the ability to transfer knowledge. However, it has been discussed that “one’s existing knowledge can also make it difficult to learn new information” ([14], p. 70). The transfer of knowledge is highly dependent on mastery of the initial information, which involves a deep conceptual understanding rather than the memorization of facts. To achieve this deep conceptual understanding and the ability to apply what is being taught, sufficient time to process and explore related connections to other concepts as exposure to various means of representation is a necessity [14][15].

2. The Nature of Introductory Courses

The primary goal of introductory courses is to ensure that students develop a foundational knowledge that can be transferred to more complex concepts as they progress toward degree completion and beyond [16][17]. Thus, researchers recommend that learning environments should support active engagement and guide students towards the acquisition of self-regulated processes [16][18]. In such a setting, students are encouraged to construct their own knowledge and skills in learning these concepts through actively navigating their role as learners [19][20].

Any investigation of students' ability to reflect on their prior knowledge and how it impacts their explanation of concepts long after they have exited the learning environment highlights the decisions made by instructors about which concepts to reinforce as significant.

Since knowledge acquisition is a key role in introductory courses, one of the main pedagogical principles often employed is problem solving through repeated practice [21]. Problem solving in introductory circuits courses emphasizes the acquisition of the fundamental theories and mathematical techniques required to analyze and design circuits [22][23]. The role of problem solving should not be understated, as this provides a means by which students can solve problems in a controlled, yet repeated way that further influences their long-term understanding of the concepts being taught. According to [21], deliberate repeated practice has significant benefits for learning fundamental concepts that can then be transferred to future and more advanced courses.

3. The Role of Mathematical Thinking

Mathematical thinking and being able to apply theoretical mathematical principles are critical to learning and analyzing circuit concepts due to the high level of abstraction that is associated with this aspect of electrical engineering. According to Schoenfeld [24], an advanced level of mathematical understanding is paramount to learning complex concepts as "the tools of mathematics are abstraction, symbolic representation and symbolic manipulation" (p. 3). These are the principles upon which circuit analysis and understanding are built. The role of advanced mathematical thinking is evident in the level of math that is required in most cases before students can enroll in circuit analysis courses [25]. For example, the work of Faulkner et al. [26] espoused that pursuing an engineering degree entails enrolling in and successfully completing a series of mathematics courses. Typically, this sequence includes multiple semesters covering topics such as calculus, linear algebra, and differential equations. More specifically, readiness for and successful progression through calculus are often identified as strong indicators of one's likelihood to graduate with an engineering degree [27][28]. Consequently, in the realm of learning circuits, advanced mathematical thinking can aid how students engage in problem solving, critical thinking, abstraction, logical reasoning, and pattern recognition, which are necessary skills for circuit analysis [26][29].

4. Guiding Framework—Pedagogical Content Knowledge (PCK)

Pedagogical content knowledge (PCK) as a framework is used in research to highlight how the knowledge and beliefs held by instructors influence their classroom practice. This framework posits that, as instructors blend their own knowledge about specific content and their experiences, they tend to present content to their students in the form they believe best enables learning [30]. In addition, instructors use their PCK to determine: (1) what concepts are important for emphasis, (2) the teaching strategies that are most effective for teaching specific topics and, (3) the learning activities necessary to foster conceptual understanding [31]. Though PCK has its roots in scientific education and is often used as a construct for measuring a science teacher's use of their own knowledge to become effective in teaching, PCK can also be used as a guiding principle for data collection and analysis in studies aimed at investigating the nature of scientific content and student learning. The five components of PCK, as discussed by Magnusson, Krajcik, and Borko ([29], p. 97), were used to guide the collection of data. These are:

- Orientations toward science learning: this involves daily instructional decisions regarding class objectives and content, student engagement, and the use of curricular materials (p. 97).

- Knowledge and beliefs about science curriculum: this involves how information about the goals of the class is communicated to the students over the duration of the course, as well as the activities and materials used in achieving these goals (p. 104).

- Knowledge and beliefs about students' understanding of specific science topics: this involves the prerequisite knowledge and skills students are required to have, how teachers incorporate individual student ability in the dissemination of class activities, and what concepts students find difficult to understand (p. 105).

- Knowledge and beliefs about assessment in science: this involves the decisions made about the appropriate means for assessing student learning, such as approaches, activities, or specific procedures (p. 109).

- Knowledge and beliefs about instructional strategies for teaching science: this involves the various approaches used to represent scientific concepts and principles in a manner that best facilitates student learning.

This framework was used as it provides the opportunity to examine the decisions made by professors relating to how the content of a course is taught to the students, the strategies used for student engagement, and how students perceive difficulty in understanding is addressed.

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