Assessing Student Perceptions of Emerging Concepts in Power & Energy Systems via Concept Maps: Rubric Development

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***Abstract*— [Work in Progress] The grid of the (near-) future is envisioned as an intelligent system consisting of millions of smart devices and interconnected decision-makers that can be monitored, supervised, and controlled in real-time. This emerging paradigm calls for a revamping of the power and energy engineering curriculum, with the goal of developing a future workforce with strong foundational skills in not only traditional power systems topics, but also in renewable energy and distributed resources grid integration and in data analytics. This paper presents the vision and the preliminary work of an ongoing engineering education project aimed at improving students' skill sets in renewable energy-integrated power distribution system analysis with data analytics. The project will develop an integrated research-oriented power engineering curriculum that uses active and situated learning pedagogy. This paper presents the preliminary assessment methodology used by the project team to evaluate the current curriculum's effectiveness in developing students' conceptual knowledge of these emerging concepts. Concept maps are used and a scoring rubric is being developed. The data gathered through this graded concept maps will guide the project team in their curriculum redesign.**

Keywords—power engineering education, situative learning, concept maps, electric power and energy systems

I. Background and Motivation

The nature of energy systems has been changing rapidly and there is a fundamental need for professionals that can deal with current and future energy challenges. Power engineers have been a crucial resource in facing past energy crises [1]-[5]. However, today's challenges require professionals who not only understand legacy systems but are also able to analyze the impact of integrating Renewable Energy Sources (RES) into the grid. With the rapid development and deployment of distributed energy resources (DERs), e.g., RES, energy storage systems (ESS), and electric vehicles (EVs), the traditional management of the electric power grid has evolved into a two-way flow, user-interactive, highly automated system forming a smart grid. The grid of the future is envisioned as an intelligent grid that can be monitored, supervised and controlled in real-time, consisting of billions of smart devices and millions of interconnected decision-makers. The realization of the smart grid concept, specifically at the power distribution system level, is a challenging and complicated task as it requires extensive research and development in several key areas, such as advanced Energy Management Systems (EMS), efficient integration of DERs, predictive and prescriptive data analytics, due to (thanks to) the increase in automation, communications, metering, and flexible energy and data sharing.

Thus, today's electric power engineers require multi-disciplinary engineering knowledge to manage the modern power grid consisting of a larger amount of renewable energy resources, digital devices, information technology tools, and sensors. There is a great need for energy professionals that are knowledgeable not only in traditional power systems topics, but also in emerging areas such as renewable energy and data analytics. Most courses in electric power engineering are in need of a revamping to continue to deliver relevant information with respect to current energy needs and industry practice [6]-[13]. Specifically, it is critical to educate a workforce that is well equipped to grasp and leverage the effects of the many exciting changes and emerging technologies in the power and energy field.

This paper presents the vision and the preliminary work of an ongoing engineering education project that addresses the aforementioned need to improve the pedagogical effectiveness of the power engineering curriculum towards a modern power engineering workforce. The work aims at developing an integrated research-oriented power engineering curriculum for active and situated learning, with an emphasis to improve students' skill sets in the area of renewable energy-integrated power distribution system analysis with data analytics, viz: Smart Energy Management Systems. The project's overall goal is to provide students with a series of modules and labs that enhance their situative perspective, by engaging them in an innovative platform that simulates developing changes in the realms of power system analysis with energy data analytics. Integrating RE resources provides interesting

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challenges for system planning and reliable operation. One of the main issues is that such energy resources are intermittent and/or variable; thus, existing power system analysis tools must be modified to incorporate new data analytics tools.

The curriculum redesign employs multidisciplinary (renewable energy system, distribution system, smart grid, intelligent forecasting) situative learning materials to address smart energy management systems and reliable and secure operations of power systems. Enhanced lecture modules and an interactive hybrid emulator-simulator laboratory are being developed and will be integrated in the curriculum redesign. These redesigns will focus on enhancing students' conceptual understanding and engagement with simulated concepts, the basis of situativity. The developed hybrid hardware-software educational and laboratory modules allow for the integration of data analytics with power grid models, addressing the need for effective integrated learning of power system performance with data analytics.

In this work in progress paper, we discuss the value that our work will add to the field by increasing students' situative awareness in the power and energy field. The paper's focus is to report on the work performed to evaluate our current curriculum's effectiveness in developing students' conceptual knowledge through concept maps. The choice of using concept maps in our work is discussed in Section II. We then present the methodology used as well as the challenges encountered to develop the scoring rubric for the concept maps (Section III).

II. Concept Maps in Engineering Education

Concept maps, as graphical tools for organizing and representing knowledge [14], have been recognized in the literature as appropriate tools for assessing knowledge integration, particularly in multi-disciplinary fields [15]. Power engineering is increasingly evolving to address the needs of the modern power grid and in response to modern problems and concerns. The future state of the power engineering discipline can be said to require aspects of data analytics, engineering sustainability, and areas of computer and systems engineering, among other fields. This fundamentally multi-disciplinary nature implies high degrees of interconnectedness with a wide range of sub-topics, and the authors postulate that concept maps can be of particular use in assessing students' base knowledge and subsequent gains in knowledge.

Using concept maps as an assessment strategy by which to judge both a pre- and post-instruction understanding of a topic allows a student to create a graphical representation of their personal perception of the subject, with the connections between ideas they believe are relevant, ideally without the influence of another party [16]. The gaps in knowledge, and importantly, the way in which the knowledge has been structured, can be identified and addressed by modifying the curriculum accordingly. Crucially, however, concept maps as an assessment tool require a robust and effective grading methodology that is standardized across graders [15]. A holistic approach to scoring concept maps has been introduced in [17] which relies on three categories: comprehensiveness, organization, and correctness. The rubric introduced in [17] has been modified iteratively for this work during preliminary grading exercises, as discussed below. The authors believe this modified rubric to be effective and capable of producing repeatable scoring results across different graders.

In our investigation concept maps allow us to gauge not only what aspects of the topics students perceive as relevant, but also how they situate these concepts into real world contexts. It is the overall goal of this project to see a growth in the depth of concept students identify with power engineering as well as a more complex understanding of the situative nature of power engineering as they move beyond the classroom.

III. Methodology

This investigation is focused around a series of power systems courses at both the University of North Carolina at Charlotte (UNCC) and The University of Texas at El Paso (UTEP). At each campus, students within Electrical Engineering departments will be engaged in courses that will be modified to enhance students' understanding of these emerging concepts in power and energy systems. Within each course, concept maps will be developed by students around the central concepts identified in Table I.

TABLE I. Investigated Courses & Central Concepts

Central Concepts	Course Investigated
Power Distribution Systems	Power Systems Analysis 1 (UNCC)
Renewable Energy Systems	Power Systems Analysis 2 (UNCC)
Forecasting with respect to Power Systems Operation	Power Systems Operations (UTEP)

Rubric Development

The research team consisted of three faculty experts, who are well versed in the topics of electrical engineering and power and energy systems, and each teaches at least one of the courses investigated in this study. Additionally, an outside expert (faculty researcher with a background in engineering education and electrical engineering not teaching any of the courses), served as a guide in the analysis process, with the assistance of two graduate students, one from each institution.

Before researchers could evaluate student concept maps, an agreed upon rubric needed to be established by which to score each map. Using the rubric established in [17] as a blueprint, the experts evaluated the existing rubrics alignment with their own beliefs about what the student concept maps should include. Initial modifications to the rubric removed qualifications of spelling within correctness and a requirement for feedback loops at the median level of organization. The team also realized some challenges in building consensus around comprehensiveness. The work in progress rubric is presented in Table II below.

TABLE II. MODIFIED CONCEPT MAP SCORING RUBRIC – BASED ON [17]

	1	1.5	2	2.5	3
Comprehensiveness covering completely/broadly Use the below terms to help determine comprehensiveness	The map lacks subject definition; the knowledge is very simple and/or limited. Limited breadth of concepts (i.e. minimal coverage of the topic). The map barely covers some of the qualities of the subject area.	The map has a combination of the features outlined in 1 and 2. Does not fit well into either category.	The map has adequate subject definition but knowledge is limited in some areas. Map suggests a somewhat narrow understanding of the subject matter.	The map has a combination of the features outlined in 2 and 3. Does not fit well into either category.	The map completely defines the subject area. The content lacks no more than one extension area.
Organization to arrange by systematic planning and united effort	The map is arranged with concepts only linearly connected. There are few (or no) connections within/between the branches. Concepts are not well integrated.	The map has a combination of the features outlined in 1 and 2. Does not fit well into either category.	The map has adequate organization with some within/between branch connections. Some, but not complete, integration of branches is apparent. Feedback loops *may* exist, if applicable.	The map has a combination of the features outlined in 2 and 3. Does not fit well into either category.	The map is well organized with concept integration and the possible use of feedback loops, if applicable. Sophisticated branch structure and connectivity.
Correctness conforming to or agreeing with fact, logic or known truth	The map is naïve and contains misconceptions about the subject area; inappropriate words or terms are used. The map documents an inaccurate understanding of certain subject matter.	The map has a combination of the features outlined in 1 and 2. Does not fit well into either category.	The map has few subject matter inaccuracies; most links are correct.	The map has a combination of the features outlined in 2 and 3. Does not fit well into either category.	The concepts that are present are integrated properly and reflect an accurate understanding of subject matter, meaning little or no misconceptions.

In an attempt to provide a more uniform scoring, the experts were each assigned to their respective central concept and asked to provide a list of sub-concepts that could be associated with their central concept. These sub-concepts were derived from key terms found in their textbooks, class resources and lecture notes as to parallel language that they might expect students to use in developing their concept maps. A sample list for the central concept of Renewable Energy Systems is shown in Table III. Additional discussion arose amongst the experts as challenges were identified about what quantity of sub-concepts had to be included for a score of 3 in comprehensiveness. To aid each of the experts in scoring, each was also asked to update their list of sub-concepts developed in an earlier iteration into 3 tiers, with tier 1 being the most essential sub-concepts and 3 the most obscure, to represent the level of depth associated with each sub-concept in respect to the central concept. The ranking also aided scorers in evaluating the organization, as higher-level concepts may have more connections within the concept map. The tiered sub-concepts are also presented in Table III. The use of a mathematical formula to determine the score in comprehensiveness is currently being investigated. The formula would account for percentage of topics/sub-concepts out of each tier present in the student's concept map, weighing each tier differently, with the lowest weight for sub-concepts in tier 1 and highest weight for sub-concepts in tier 3.

TABLE III. RENEWABLE ENERGY SYSTEMS TIERED SUB-CONCEPTS

Tier 1	Tier 2	Tier 3
Sources of renewable energy • Solar • Hydro • Tidal • Nuclear • Geothermal • Biomass *Energy storage* • Need and types • Connections • Support	*Characteristics of renewable energy* • Intermittent • Variable • Sustainable • Can be replenished • Non-dispatchable *Connection method of renewable energy to the grid* • With power electronic devices • Switches • Transformer	*Power Electronic Devices* • Inverter • Converter • Connection and control methods *Grid impact of renewables* • Stability • Reliability • Resilience • Grid ancillary services • Coordination • Active and reactive power balance

IV. Discussion and Future Work

The work done to establish a scoring rubric based on a collaborative consensus will aid in the future assessment of student concept maps. This developmental work will not only support assessment in this particular project but all projects that use concept maps as assessment tools. Some concept maps have been developed in the existing courses, but need IRB approval before collaborative analysis can occur. From what each expert has observed in their own courses, the team plans to allow students approximately 30 minutes to develop their concept maps. Additionally, a six-minute tutorial video has been developed to provide consistent instruction and explanation of concept maps and how to create them across both campuses.

The research team plans to collect pre and post concept maps from students across all of the courses of interest in the Fall 2021 and Spring 2022 semesters. The pre concept map will serve as a control for students' base knowledge before new modules are incorporated into the courses to enhance current power systems curriculum. The post concept maps will serve as formative feedback for the team as the newly developed modules will be re-evaluated based on the results of the concept maps.

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