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Power Engineering Curriculum Update with Situative Pedagogy and Concept Maps as Evaluation Tool

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I. Introduction and Overview

The modern electric power grid is an intelligent and interconnected system, characterized by an increasing amount of renewable and distributed energy sources and storage, and by smart devices and sensors that are remotely monitored and controlled in real-time, leading to smart energy systems / smart grids. This emerging paradigm calls for a revamping of the power engineering curriculum, with the goal of developing a workforce able to grasp and adapt to the evolving conditions and the enabling technologies. The ideal workforce would still have strong foundational skills in traditional power systems topics, with added skills in integration of renewable and distributed resources and in energy data analytics.

In this paper, we present the process and initial outcomes of a collaborative two-institution project aimed at updating the undergraduate (UG) power engineering curriculum at both institutions. The added educational modules focus on electric power distribution systems, renewable energy systems, and energy data analytics. In addition to new lecture modules, the curriculum update revolves around active and situative learning methodologies, in an effort to help students place topics into context and equip them to grasp effects of the emerging changes and technologies.

The paper is organized as follows: the next section presents an overview of the power engineering curriculum redesign and motivations behind it; section III describes the situative pedagogy strategies that have been implemented; section IV presents the evaluation tools used to assess the effectiveness of the curriculum redesign; section V then presents and compares select results from the control and the test groups; finally, the paper concludes in section VI with a summary and a discussion on ongoing work and future plans.

II. Power Engineering Curriculum Redesign

Most courses in electric power engineering have remained unaltered in decades and are failing to deliver relevant information with respect to current energy needs and industry practice [1]-[7]. Traditionally, power engineering education has focused on generation and high voltage transmission systems. Formal education on power distribution systems has essentially been overlooked. **Distribution systems** are inherently very different from transmission systems, which have been and are the focus of traditional power system analysis courses. Properties and components that are unique to distribution include: different voltage and power levels, different network structures, i.e., radial or weakly-meshed vs. highly-meshed transmission networks, level of unbalance across phases, and a high number of distribution-level equipment including distributed energy resources and other emerging technologies. The interest in electric power distribution is resurgent for a number of reasons, including: restructuring of the electricity supply industries bringing new operating and planning pressures for distribution suppliers; the augmented presence of smart monitoring, control and automation devices; and the push for and subsequent increase of distributed and **renewable energy resources**. This last point in particular brings about new and very interesting challenges: uncertainty of loads *and* generation, previous modeling and operating assumptions are now invalid (e.g., unidirectional flow of power). A major barrier in integrating renewables, particularly wind and solar, into the grid is their uncontrollability, since a steady output cannot be guaranteed at any particular time. Developing a reliable forecasting algorithm that can minimize the uncertainty associated with wind/solar power generation can be extremely beneficial for the efficient integration of these resources. Hence, **energy data analytics** techniques, whether on the renewable energy forecasting side, or on the load forecasting side, are of paramount importance.

Thus, the objective of the work presented in this paper is to revamp the UG power engineering curriculum to include new modules on these three main topic areas: 1. Electric power distribution systems, 2. Renewable energy systems, and 3. Energy data analytics. These modules have been developed and added to existing UG courses, as shown in Table 1. The added educational modules are briefly described below.

Table 1. Content added to existing power engineering UG courses

Existing Course	Newly Added Content
Power System Analysis I	Module 1: Electric Power Distribution Systems
Power System Analysis II	Module 2: Renewable Energy Systems
Power Generation, Operation, and Control	Module 3: Energy Data Analytics

Module 1: Electric Power Distribution Systems - Modeling, Operation, and Dist. Automation
The purpose of this lecture module is to expose students to distribution systems. Specific goals are to introduce the following: (1) Similarities and differences between transmission and distribution; (2) Significance of unbalanced system and component models, and unbalanced power flow analysis; (3) Concepts in distribution protection and voltage regulation; and (4) Overview of distribution automation (including service restoration), and select emerging trends (e.g. Advanced Metering Infrastructure).

Module 2: Renewable Energy Systems - Modeling and Integration to the Distribution System
The lecture module exposes students to renewable energy systems, their modeling and integration to the grid. Specific goals are to introduce: (1) Characteristics of renewable energy systems; (2) Modeling of various renewables, and significance of average and detailed models; (3) Control and integrated analysis of power systems with renewables (penetration levels, green energy, renewable portfolio standards, operational efficiency), and (5) Overview of smart and micro grids, challenges with renewables monitoring, optimization and control.

Module 3: Energy Data Analytics - Data Analysis and Power System Forecasting Problems
The purpose of this lecture module is to expose students to data analytics applied to power system operation and planning problems. Specific goals are to provide students with an introduction to: (1) data analytics techniques, starting with statistical analysis (e.g. correlation) and data pre-processing techniques (wavelet transform, self-organizing map, learning vector quantization), and (2) apply the acquired data analytics knowledge to power system forecasting problems (e.g., load demand, wind power, and solar power).

III. Situative Pedagogy Strategies

The curriculum redesign centers not only around the inclusion of the topics of interest described in the previous section, but also on incorporating situative pedagogy strategies in an effort to help students place topics into context and equip them to grasp effects of the emerging technologies. Over the last decade there has been an awareness of the need to incorporate more learning sciences into engineering education as pointed out by [8]. One of the perspectives that the authors suggest is situative learning for its meaningful participatory nature [9]. For this work, we aim to encourage students to engage with the field of power and energy in a way that enables them to make connections beyond theory to practical applications of its utilization and impacts within their communities. Rather than students simply understanding the equations and theories utilized in forecasting of power and energy systems and models they begin to see the impact of their knowledge on real world contexts. "In other words, a central aim of the situated perspective is to understand learning as situated in a complex web of social organization rather than as a shift in mental structures of a learner."

The incorporation of situative perspective in the classroom is by doing, interacting with others and motivated action [10], [11]. Therefore, for this investigation each faculty member incorporated new efforts within their specified modules to encourage the development of a situative perspective in students. In many of these activities there was a strategic effort by faculty to provide students with opportunities to engage with stakeholders in the field (i.e power distribution facilities), investigate natural impacts of their work from literature, or create space for discussion across a class about the relevance of their work. In the table below are examples of assignments that were implemented within a course with a new module on Renewable Energy Systems. In this course, the instructor chose a variety of approaches to engage diverse learners: lectures, student-led presentations, peer evaluations, and field trips. Table 2 provides a detailed overview of what was implemented and how it aligns with situative learning for one of the courses, as an example.

Table 2. Overview of Situative Learning Strategies Implemented in One of the Courses

Course: Power System Analysis II - Module 2 (Renewable Energy Systems)				
Assignment/ Activity	**Description**	**Time**	**Benefit to Student**	**Connection to Situative Learn.**
Lecture: renewable energy systems and integration in the power system	1 lecture - overview of RES and their integration to PS	50 min	Prof. gives theoretical overview of the topic and raises some points of challenges and opportunities	Context of situations and challenges were presented
Students' in-class presentations	Students reviewed and presented a paper (of their choice from IEEE Xplore, approved) on the topic Extra Credit	90 min (across 3 lectures) 3 presentations/ lecture (10-12 min to present + discussion)	Students take ownership of a topic of interest They research it and need to understand it well enough to prepare a presentation on it and present it to the class	Guideline that covered "Effects of Renewable Energy Systems"based on previous lecture.
Student-led discussions	Students' presentations are	60 min (across the same 3	Students (both the presenter and the	

	followed by student-led discussions	lectures)	audience) are asked to think beyond what is being presented and are given the time and opportunity to raise questions and discussion points	
Peer evaluations	Peer evaluations of presentations with raised questions to initiate discussion	15 minutes (within the same 3 lectures)	Students evaluate their peers	Provided a rubric to capture questions
Class visit to Duke Energy Fuel and System Optimization Group + Guest Speakers	They received a presentation on Renewable Energy Systems from the facility & "challenges"	120 min (1 lecture time + extra)		Context & examples
Class visit to Duke Energy Distribution Control Center + Guest Speakers	They received a presentation on Renewable Energy Systems from the facility & "challenges"	120 min (1 lecture time + extra)		Context & examples

IV. Evaluation Plan and Concept Maps

The educational research presented in this paper aims at addressing the need to improve the pedagogical effectiveness of the power engineering curriculum for the modern power engineering workforce. Specifically, it is critical to educate a workforce that is better equipped to grasp and leverage the effects of the many exciting changes and emerging technologies in the power and energy field. With this goal in mind, our evaluation plan was designed to explore the following questions: 1) Do students exposed to situative learning develop a more complex understanding of energy management, integrated power system analysis, and data analytics? and in turn 2) Do they take greater account of context and community? In an effort to understand how the use of situative pedagogy can enhance the curriculum, concept maps have been selected and utilized as a tool to assess students' depth of understanding and ability to connect and contextualize important topics.

Concept Maps are graphical tools for organizing and representing knowledge [12] and have been recognized as appropriate for assessing knowledge integration, particularly in multi-disciplinary fields [13]. Since the knowledge required by a modern power engineering workforce is substantially multi-disciplinary in nature, with a high degree of interconnectedness and a wide range of sub-topics, we hypothesized that concept maps can be useful in assessing students' base knowledge and subsequent gains in knowledge. Concept maps allow students to create a graphical representation of their perception of the subject and interconnections between all relevant concepts. Through concept maps developed by the students, students' understanding can be evaluated and gaps in knowledge can be identified. The insights gained by analyzing students' concept maps can then guide needed curriculum modifications.

In the effort to create a control group, students enrolled in the existing, unaltered courses, were asked to develop concept maps of their current understanding of the three main topics: Concept Map (CM) 1. electric power distribution systems, CM 2. renewable energy systems, and CM 3. data analytics for power systems operation. In subsequent offerings of the courses, students in the modified courses were also asked to develop concept maps on a central concept, as shown in Table 3 below, at the beginning of the course (pre-assessment) as well as at the end (post-assessment). Each student was shown a 6 minute video that explained the key components necessary in developing a concept map (central concept, linking terms, etc.) and how to develop a concept map in the free online cmap.hmc.us software. A few diverse examples of concept maps on unrelated concepts were also shown in the video. Students were then given 15 to 20 minutes of in-class time to complete the assignment.

Table 3. Concept Map Central Topic by Course

Central Concept	Course Investigated
CM 1. Power Distribution Systems	Power System Analysis I
CM 2. Renewable Energy Systems	Power System Analysis II
CM 3. Forecasting in Power Systems	Power Generation, Operation, and Control

One of the challenges with using Concept Maps as an assessment tool was the need to develop an effective grading methodology, which would be robust and consistent across graders. The rubric used in this work was developed iteratively using preliminary grading exercises. The modified rubric is an extension of the holistic approach introduced in [14], which relies on three categories: comprehensiveness, organization, and correctness. In the process of updating and finalizing the rubric, three power engineering faculty serving as subject-matter experts graded all of the concept maps, an outside expert (faculty researcher with a background in engineering education and electrical engineering, but not teaching any of the affected courses) then served as a guide and mediator in the analysis process. For additional information on the rubrics we developed to score the concept maps, please refer to the authors' prior work presented in [7].

V. Select Results

In this paper, we review the current results from the Spring 21 and Spring 22 semesters around Module 2: Renewable Energy Systems. The data from Spring 21 serves as a baseline dataset, gathered before any modifications were made to any courses. For another level of validation, a pre-assessment was done in Spring 22 at the beginning of the term, to serve as a similar baseline in that semester before the new material was presented to students. Finally, a post-assessment was completed at the end of the course, after the newly developed activities were integrated into the course, as shown in Table 2. In Spring 21 there were six students who participated in the concept map collection. The average score across these students was 5.5 (std.dev. of 0.7) out of a max score of 9. In Spring 22 where four students participated in the concept map pre-assessment, the average score was a 5.4 (std.dev. of 0.8), which is very similar to the average score seen in the control group, as expected. Unfortunately, only two of the initial four students opted to participate in the concept map post-assessment that semester and were found to have an average score of 8. While the numbers show definite improvement in students' depth and breadth of understanding in the area of Renewable Energy Systems we are aware of the limitations of basing our results on a limited population of students. This was the first data collection in a three year project and efforts are being made to increase participation in future assessments. Below is a pair of concept maps pre- and post- from the same student in Spring 22. Based on the developed rubric, presented in detail in [7], there are clear visual clues of the expansion in the areas of comprehension and organization of concepts across the two maps.

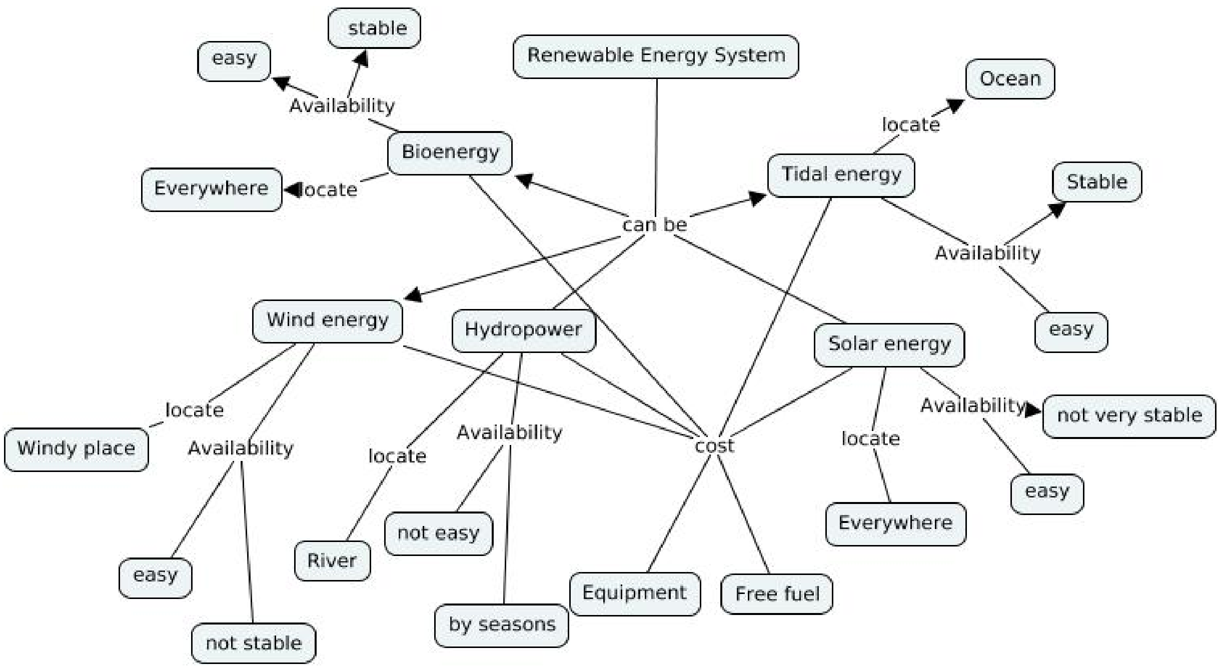

Figure 1. Concept Map Pre-Assessment of Renewable Energy Systems (Spring 22)

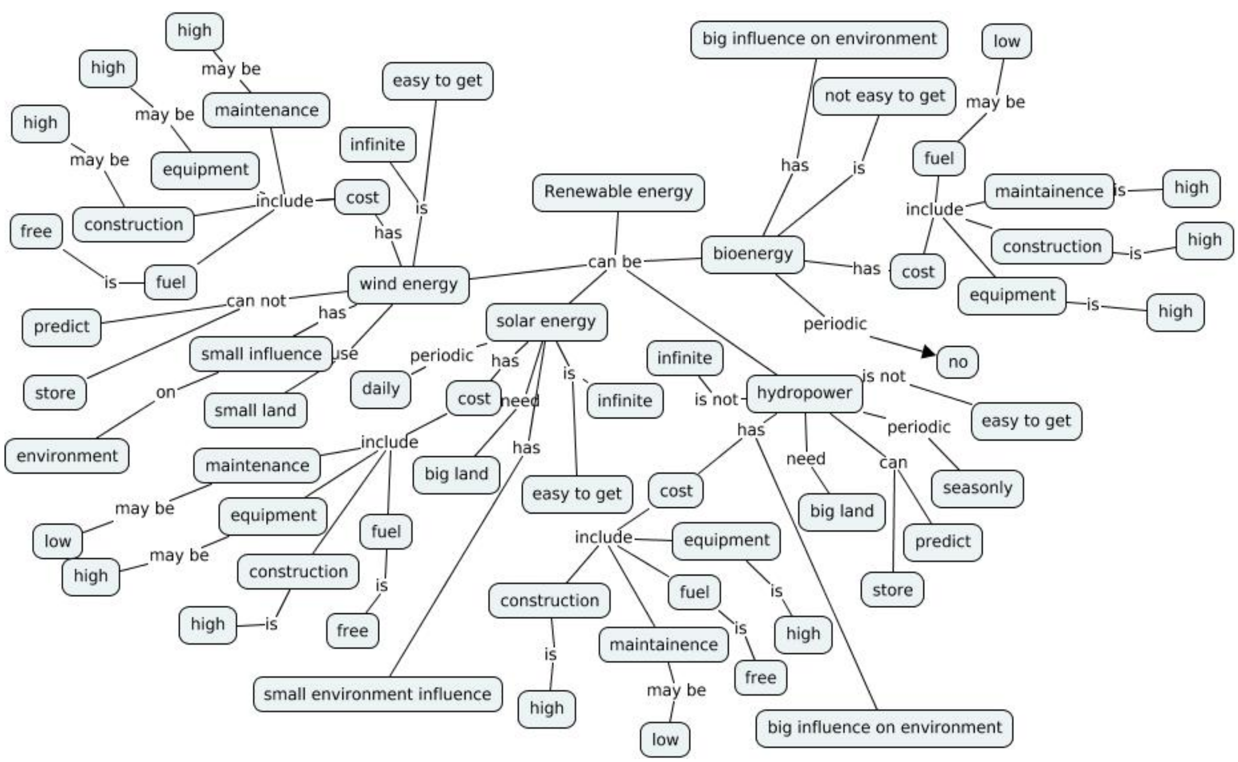

Figure 2. Concept Map Post-Assessment of Renewable Energy Systems (Spring 22)

VI. Conclusion

This paper presents the process of updating UG power engineering curriculum by adapting existing courses in two collaborating institutions with new modules on distribution systems, renewable energy systems, and data analytics. The curriculum redesign is not only focused on including instruction of these topics of interest, but it also employs situative pedagogy strategies aimed at helping students contextualizing topics and fully grasping the effects of emerging technologies in the energy field. Concept maps have been selected and utilized as a tool to assess students' depth of understanding and ability to connect and place into context important topics. Across three courses, new educational modules and approaches centered around situative pedagogy were adopted. Concept maps obtained from the students in the control group (in the courses pre-modifications), and those from students in the modified courses, were graded using a purposely developed rubric. The preliminary data analysis shows very promising results, indicating a consistent improvement in students' concept map grade for the modified courses, across the three rubric categories of comprehensiveness, organization, and correctness. Ongoing efforts include continuing to collect and analyze concept map data, as well as looking at additional metrics of evaluation, such as number of key words included, number of connection links, and number of levels in each concept map. Moreover, the team is currently working on doing a detailed analysis of the gathered concept maps to identify recurring gaps of knowledge or missing connections, which will guide further curriculum updates. Detailed assessment through the concept maps and feedback/observations in response of the utilized situative learning strategies will not only guide our curriculum redesign moving further, but will also be insightful in the application and adaptations of these tools, both situative pedagogy and concept maps, in disciplines beyond power engineering.

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References

[1] A. Pahwa, W.B. Kuhn, R. D. Miller, and A. Rys, "Educational and research challenges and opportunities related to renewable energy," IEEE Power and Energy Society General Meeting, 2011.

[2] NSF-Sponsored Workshop on Reforming Electric Energy systems Curriculum, University of Minnesota Campus, Minneapolis, MN, October 4-5, 2014.

[3] N. Mohan, W.P. Robbins, and B.F. Wollenberg, "Power systems education based on CUSPTM-Curriculum," IEEE Transactions on Power Systems, Vol. 29, No. 4, July 2014.

[4] W. Redar, A. Bose, A. Flueck, M. Lauby, D. Niebur, A. Randazzo, D. Ray, G. Reed, P. Sauer, and F. Wayno, "Engineering the future, a collaborative effort to strengthen the U.S. power and energy workforce," IEEE Power & Energy Magazine, July/August 2010.

[5] H. Chai, J. Ravishankar, S. Krishnan and M. Priestley, "Work-in-Progress: A Holistic Approach to Bridging the Gap between Power Engineering Education and Electric Power Industry," 2022 IEEE Global Engineering Education Conference (EDUCON), Tunis, Tunisia, 2022, pp. 2044-2048.

[6] H. Hussin, H.Z. Abidin, Y. Husaini, M. Muhamad and M.I.M. Ali, "Students' perception on teaching and learning activities and their understanding in power engineering course," 2017 IEEE 6th International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Hong Kong, China, 2017, pp. 333-338.

[7] V. Cecchi, C. Smith-Orr, F. Atchison, S. Kamalasadan, P. Mandal and I. Lopez, "Assessing Student Perceptions of Emerging Concepts in Power & Energy Systems via Concept Maps: Rubric Development," 2021 IEEE Frontiers in Education Conference (FIE), Lincoln, NE, USA, 2021, pp. 1-4.

[8] A. Johri, B.M. Olds, "Situated engineering learning: Bridging engineering education research and the learning sciences". Journal of Engineering Education, 2011. 100(1), 151-185.

[9] J. Greeno, A. Collins, L. Resnick, "Cognition and learning". In R. Calfee & D. Berliner (Eds.), Handbook of educational psychology, 1996. pp. 15–46. New York, NY: MacMillan.

[10] J. Greeno, "Learning in activity". In R. K. Sawyer (Ed.). Cambridge handbook of learning sciences, 2005. pp. 79–96. New York, NY: Cambridge University Press.

[11] C. Goodwin, "Action and embodiment within situated human interaction". Journal of Pragmatics, 2000. 32(10), 1489–1522

[12] J.D. Novak, A.J. Cañas, "The Theory Underlying Concept Maps and How to Construct Them". In Technical Report IHMC CmapTools 2006-01: Florida Institute for Human and Machine Cognition, 2006.

[13] M. Borrego, C.B. Newswander, L.D. McNair, S. McGinnis, M.C. Paretti, M.C. "Using Concept Maps to Assess Inter-disciplinary Integration of Green Engineering Knowledge". Advances in Engineering Education, 2009. 1(3),1–26.

[14] M. Besterfield-Sacre, J. Gerchak, M. Lyons, L.J. Shuman, and H. Wolfe. "Scoring Concept Maps: An Integrated Rubric for Assessing Engineering Education". Journal of Engineering Education, 2004. 93 (2):105–115.