



Designing a Curriculum that Helps Students Create Connected Narratives in Electrical Engineering

Sara Kaye Jones, Iowa State University

Sara Jones recently completed her MS in Electrical Engineering at Iowa State University, where she also completed her BS in Electrical Engineering.

Dr. Mani Mina, Iowa State University

Mani Mina is with the department of Industrial Design and Electrical and Computer Engineering at Iowa State University. He has been working on better understanding of students' learning and aspects of technological and engineering philosophy and literacy. In particular how such literacy and competency are reflected in curricular and student activities. His interests also include Design and Engineering, the human side of engineering, new ways of teaching engineering in particular Electromagnetism and other classes that are mathematically driven. His research and activities also include on avenues to connect Product Design and Engineering Education in a synergetic way.

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Introduction

This paper proposes a framework for helping students construct conceptual narrative arcs throughout a traditional Electrical Engineering curriculum that can be used to practice deep conceptual learning and the higher stages of Bloom's Taxonomy, therefore improving their retention, application, and creative problem solving. A narrative arc is defined here as a student's ability to form a cohesive net of concepts, reasonings, and relationships that can be explained without using formulae as a crutch. While being able to apply and understand mathematical formulae is an invaluable tool for students, too often courses rely solely on the evaluation of the mathematical formulae related to concepts instead of emphasizing the conceptual definitions and relationships. This imbalance results in students being weak in the areas of explaining why and how things happen using words and unable to formulate and solve problems without hard numbers. Designing a curriculum that focuses on connectedness through narrative arcs will help improve retention and ultimately lead to higher achieving students and graduates. The framework, challenges inherent in implementing it, and an example utilizing the delta function will be discussed.

Background

Faculty in engineering departments have long lamented the miniscule amount of retention students seem to have between courses. Students compartmentalize courses [1] and seldom apply new skills to other courses, therefore producing graduates who have segmented and disconnected views of Electrical Engineering. Spurlin and Ozturk found that only 30% of students retain greater than 70% of fundamental information between courses, even when those courses are direct prerequisites [2]. Concepts in one area of Electrical Engineering should reinforce concepts in another area - they are inexorably interconnected [3]. Connections need to be fostered throughout the curriculum by the faculty in order for the engineering student to mature into a functioning engineer [4]. Helping students to create a connected narrative arc of concepts throughout the curriculum facilitates deeper understanding of topics, increased critical thinking, and engineers who can approach problems from multiple angles. These qualities are increasingly important for graduates who will become professional engineers, as the change in technology and mindset move at a much greater pace in industry than academia [5].

Most teaching methods in a traditional Electrical Engineering curriculum have not changed since the 1970s - with a preference for theoretical knowledge rather than practical application [6]. The gatekeeper of knowledge paradigm is upheld, in which the faculty has the knowledge and the students are the empty receptacles into which they can pour their information and expertise [5]. Courses revolve around lectures and lengthy problem sets. The faculty tells the information to the students during lecture, often emphasizing the "correct" equations - flying through a copious number of PowerPoint slides with no time for the students to absorb the material, much less formulate and ask questions. Extensive problem sets are assigned as homework, comprised of complicated scenarios in which the only thing truly being evaluated is how well students can

identify the “correct” equations and do algebra. This often results in students being able to memorize and imitate a large number of equations, but quickly forgetting them once the course is over. This is because they have only entered the first stage of Bloom’s Taxonomy: remembering [7].

In contrast, deep conceptual learning focuses on understanding the underlying meaning of the material, connecting new ideas to previous knowledge, recognizing relationships between parts, and relating concepts to everyday experiences [8]. This is generally more qualitative rather than quantitative knowledge and is associated with the higher stages of Bloom’s Taxonomy. In order for students to engage in deep conceptual learning, they need to address questions such as which concepts apply, why certain equations are used, how and why they were derived, and how these equations and concepts relate to each other. However, significantly less emphasis is placed on these topics throughout a traditional undergraduate Electrical Engineering curriculum. Exploring and reflecting on these questions throughout the curriculum will help students create conceptual narrative arcs that are connected, giving them a more holistic view of Electrical Engineering and creating more capable engineers.

Framework

The framework proposed here contains three parts to help facilitate the development of connected narrative arcs: definition, initial connections, and reflection.

Definition

The definition of the concept should be thorough and provide enough background and justification that the student can anchor the new concept to information previously held. Concepts that cannot be related to previous knowledge held by the student are more tenuous and require more time and effort for the student to comprehend [1]. The definition should include the mathematical formulation if appropriate to the concept, but it should not be the exclusive definition. It has been found that students often have no trouble remembering the quantitative formulae required of them but lack the qualitative knowledge of concepts [9].

Initial connections

Initial connections should be made explicit to the student in order to help them understand the relationships between this concept, previously learned concepts, other subjects, and how this concept relates to the larger picture of Electrical Engineering. One of the most frequently asked questions by students is “Why is learning this topic important?” It is necessary to note here that the motivation behind this question can be hard to discern, especially if the faculty and students do not have a good understanding of each other. There is a balance on both sides that must be struck - the students must remember that the faculty have more experience and should be trusted, but likewise, the faculty should be worthy of that trust and critically evaluate the timing and value of the concept within the curriculum.

Reflection

A period of reflection for every concept should be allocated to the students so they can process information, continue to make connections, and delve deeper into the concept. This period of reflection can be implemented in many ways, whether through in-class discussion, laboratory activities, homework questions, or even an exam question. The student should be asked to explain the concept to the fullest of their ability, its applications and connections, and write down any lingering questions they still have about the concept. In this way, the faculty can both assess what their students have learned and where their instruction may be lacking.

Other connected curriculum models

Several other methods of connected curricula have been proposed. Feldhausen, Babin, and Dringenberg propose a Fundamental Learning Integration Platform (FLIP) which creates a physical connection between the conceptual and practical engineering concepts throughout an entire 4-year Mechanical Engineering curriculum [10]. Students were made explicitly aware of how each concept from their courses fits into the bigger picture through an end of semester project that revolved around a specific aspect of the steam engine. This concept is difficult to apply to Electrical Engineering because of the wide variety of specializations offered within the major. While connections between areas are plentiful, creating a singular project that faculty of all specializations will deem sufficiently applicable would be nigh impossible.

Alnajjar proposes “Integrative Learning Blocks (ILBs)” which connect two courses by accentuating the intersections where common learning outcomes can be enforced [11]. This is accomplished through significant effort on the part of faculty, who need to collaborate on a list of possible shared outcomes and coordinate the timing of their courses. Alnajjar emphasizes that the content of the courses was not altered, but rather the pedagogy. Alnajjar also claims the ILBs were “very successful” with regard to students’ performance, interest, and GPA, but does not offer any evidence, either anecdotal or quantitative. While admirable, a large hurdle to implementing this is faculty commitment. This is discussed more in the challenges section.

Toghiani, Minerick, and Walters [4] offer connection points throughout a Chemical Engineering curriculum in order to assist students in developing an underlying coherent framework. Connection points need to be explicitly made by the faculty, such as between the concepts learned in a calculus course and using calculus to describe physical systems. Toghiani, Minerick, and Walters also emphasize connecting the fundamental courses within Chemical Engineering, such as thermodynamics, heat transfer, separations, and process control. The framework proposed here is most similar to this approach, but adds the component of reflection, which allows time for students to explore and create their own connections outside of those explicitly defined by the faculty.

Challenges of connected curricula and their mitigations

In all of these proposed methods, significant buy-in from the faculty needs to be obtained. However, this proves especially challenging in land-grant universities because as state funding for higher education decreases, faculty’s dependence on research grants increases. Some

universities have transitioned to a model in which raises, promotions, and tenure predominantly rely on research and publications from the faculty and their graduate students. In order for education to become a more prevalent concern for faculty in these situations, teaching will need to be valued by the university, and perhaps even incentivized. It is up to each university, college, and department to discuss and decide how to truly implement this value change rather than pay homage to a pretense of interest in education.

Many universities already offer seminars and trainings in order to improve the effectiveness of current and future faculty's teaching, but in most cases, these are not required. Because of this, there exist faculty who are excellent engineers and truly horrid teachers. Classroom management, curriculum development, exam design, education technology, and instruction methods are all essential to a productive and successful course, yet none or few of these are prerequisite areas of study at most universities for becoming a faculty member. Changing university or department policy to require previous teaching experience or coursework in education would greatly increase the effectiveness of faculty in the classroom and would jumpstart a culture of valuing education. Universities and departments that are worried this will significantly dwindle their faculty applicant pool may consider delaying new faculty's forays into the classroom, ask them to attend a course in effective education methods while continuing their other duties, and start teaching courses in their second semester.

Most classrooms still uphold the traditional lecturing style which provides little room for engagement from the students. This makes learning a passive activity for the students, where they are not participating in learning, but rather being taught at. In order to achieve the higher levels of Bloom's Taxonomy, students need to play with the material and make it their own. The period of reflection allows students this opportunity, especially if done in an in-class or laboratory setting. Laboratory courses give students a more hands-on approach to the concepts and skills they are learning, making it a great time for individual and group reflection. However, if reflection is to be implemented within the laboratory setting, it is critical that the workload of the laboratory is not significantly increased. Adding a reflective portion to laboratory exercises without revising the other activities will most likely contribute to students becoming overworked, which is detrimental to the very thing trying to be accomplished. This is discussed more later.

Overall, this evolution towards making connections and reflective learning necessitates a shift in the mindset of the faculty, where they are no longer the gatekeepers of knowledge, but rather experiencing the journey of learning with their students. Transitioning from a passive learning environment to an active learning environment can be expected to catalyze several large changes. Freeman et. al. [12] showed in their meta-analysis of 225 studies comparing traditional lecture style environments and active learning environments that students in traditional lectures were 1.5 times more likely to fail than students in active learning environments. Students in active learning environments performed better on traditional exams and even better on concept inventories than their counterparts in traditional lecture environments. Active learning environments are sometimes considered a spatial change, where the amphitheatre lecture hall is replaced with a smaller classroom with tables which facilitates group work. While changing the physical space may be helpful, Stover and Ziswiler showed that it is the instructional style of an active learning environment that matters the most [13]. They also warn of several common pitfalls of transitioning to active learning environments. Faculty who wish to implement an active

learning environment or the framework presented here may simply revise their own pedagogical methods in the classroom. It is suggested that faculty research several active learning methods and evaluate which methods may be adapted to best fit their strengths, the content of the class, and the format of the class (whether there is a laboratory component or not).

Extensive problem sets are the enemy of reflection. Overworked students do not have time to reflect and make connections [1]. If faculty do not facilitate this period of reflection, it is much more likely that students will not engage with the material as deeply and will remain in surface learning. Students instead learn lessons on how to do extensive tradeoff analysis between their grades, effort and time commitment, and their actual learning. For those students to whom poor grades are unacceptable, this often results in copious amounts of time spent on work, with little regard to their mental and physical health. In addition, extensive problem sets rarely help students explore and understand concepts. They are comprised of closed problems - ones that are amenable to a single correct solution - and do not test the relevant problem-solving skills [14]. Some faculty shy away from asking questions to which there is no “right answer” and the student responses have to be individually assessed. The time commitment required for grading these types of problems can be daunting. John Heywood addresses the complex subject of designing assessment questions at length in several of his publications [1]. Reducing the length of problem sets and asking more conceptual questions is one of the first steps towards helping students create connected narrative arcs.

Connected narrative arc example

The delta function, commonly represented as δ , is found in abundance throughout the Electrical Engineering curriculum. Because of this, the delta function makes an excellent example for a narrative arc. The following section outlines the concepts and connections that can be made throughout a curriculum using the delta function as a common narrative arc.

Definition

The delta function is generally introduced through discrete time signal analysis as the Kronecker delta function or unit impulse $\delta[n]$, a piecewise function which has a value of 1 at $n = 0$ and 0 everywhere else. This is an approachable and practical definition, as all discretely sampled signals can be thought of as a summation of time-shifted and scaled unit impulses. This piecewise function is oftentimes intuitive for students to understand and makes a solid introduction to the topic of utilizing delta functions in Electrical Engineering.

The delta function in continuous time systems is referred to as the Dirac delta function $\delta(t)$, which is not a function at all, but a distribution. The most intuitive way to explain the Dirac delta is as the derivative of the unit step function. For this reason, the Dirac delta function is taught directly after or in conjunction with the unit step function. Like the Kronecker delta, the Dirac delta is 0 at every point except $t = 0$. However, it does not have a finite value at $t = 0$, instead the integral of the Dirac delta over all time is equal to 1. Students will likely be puzzled by the fact that there is not a precise, functional definition for the Dirac delta. Faculty should provide a thorough explanation and answer any student questions about this with patience.

Initial connections

From this rudimentary introduction, connections can start to be made in other areas of the curriculum. Faculty should highlight the numerous connections and applications and may choose to go in depth for a few. Most connections revolve around the delta function being used as a signal and this may become a common touchpoint for students. Some of the connections that may be emphasized are listed below (but this is by no means a comprehensive list).

- Signals and Systems
 - Convolution
 - Fourier and Laplace Transforms
 - Impulse response for characterizing a system
- Electromagnetics
 - Localized charge modeling
 - Diagnostics, scattering, and transmission of waves (band-limited)
- Probability
 - Discrete probability density distributions

Reflection

The reflection period is a time to ask students to explain what they know about the delta function. They should provide a definition in their own words (and may provide a mathematical definition if they like as well), connections, and applications. Students should be allowed to explain in their own manner, provided that it can be easily understood by others. For example, one student may decide to write everything they know out longhand, while another provides a concept map and a short blurb about the definition.

Conclusion

The current structure of Electrical Engineering classrooms in university is not working. A lot needs to change in order to help students focus on conceptual learning instead of regurgitating formulae. By using the framework presented in this paper of definition, initial connections, and reflection, faculty can help facilitate students' creation of conceptual narrative arcs. There are many challenges to overcome, such as faculty buy-in, the use of extensive problem sets, and framing assessment questions correctly.

In regards to future work, implementation in the Electrical Engineering classroom is a must. It would require cooperation between faculty and a critical evaluation of which concepts are most important in the Electrical Engineering curriculum. It would need long term monitoring and a follow up survey of students to see if it has made a significant impact on their critical thinking, problem solving, and retention of concepts.

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