

Active Learning Model as a Way to Prepare Students for Knowledge Integration

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Work In Progress: Active Learning Model as a Way to Prepare Students for Knowledge Integration

1. Introduction

The three main courses of an electrical engineering undergraduate program are electronics, linear system analysis, and electromagnetics. Typically, these three courses are taught concurrently in the middle two years of an electrical engineering program without emphasizing the commonality and many interconnections between the content of these courses. In other words, students learn the key concepts in these courses in isolation. This is a critical drawback of the program because in this framework students are led to view the course contents as unconnected pieces. Thus, students lack the understanding of how these unconnected course materials build on each other to form the core knowledge expected of a competent electrical engineer. This lack of understanding manifests itself in low student motivation, interest, and knowledge regarding the discipline. Furthermore, it results in students perceiving a lack of value and career opportunities relative to the amount of effort required to go through the program [1]-[4]. As a result, attrition rates in engineering departments have been higher than expected. For example, the number of American students earning bachelor's degrees increased by 16% over the past 10 years. However, the number of bachelor's degrees earned in engineering decreased by 15% over the same period. Nationally, less than 50% of the students who enroll in engineering courses complete the program [1]. At Colorado State university, we typically lose a third of our electrical and computer engineering students during the first year and another third by the end of their undergraduate program [5]. In order to address this alarming trend of losing student interest in the discipline while simultaneously carrying out the visions of engineering in the 21st century, a radically new approach towards teaching and learning is needed. Toward this end, the authors of this paper, armed with a National Science Foundation Revolutionizing Engineering and Computer Science Departments (NSF RED) grant, are developing a new pedagogical framework where the emphasis is on connecting key concepts across the three main courses using practical real-world applications. This framework is referred to as a knowledge integration (KI) framework [5]-[7]. In this KI framework, the instructors of the three aforementioned courses work together to develop learning activities and cognitive exercises which enable students to recognize the interconnectedness between the concepts of the three courses. Such a framework properly contextualizes the topics in each course to make the student learning deeper and more meaningful.

However, in order to achieve this benefit of the KI framework, students must be able to analyze, synthesize, and evaluate new knowledge – higher level learning skills which are not traditionally emphasized in the undergraduate classroom. Therefore, these higher level learning skills become not just purely aspirational goals but need to be actualized in order to make the KI based pedagogy effective. This is where an active learning model can prove very effective. This paper describes such an active learning model developed and implemented in 2017 for the introductory electronics course in the junior year. This learning model consists of three key components which are described in details - the *concept introduction* or pre-work

component, the *concept exploration* or classwork component, and the *concept reflection* or post-work component. In addition, new assessment techniques tailored to this active learning model has been developed. Finally, this paper concludes with a discussion of the lessons learned when implementing the active learning model in 2017 and future goals of this model.

2. Knowledge Integration and its Relevance to the RED Project

2.1 Motivation for a KI Based Learning Environment

In order to better explain how the proposed active learning classroom model supports a knowledge integration (KI) based learning environment, in this section we explain why such a learning environment is crucial in the first place. We point to Fig. 1 as an illustration of the traditional Electrical Engineering (EE) technical course sequences in the first three years. Students spend the first two years building the foundation in math, physics, and basic circuit theories both in the digital and analog domains. Courses related to EE core competencies starts from the junior year. There are three core competency areas: linear system analysis, electronics, and electromagnetics with two courses in each competency area. These make up the three sets of two-course sequences occupying the entire junior year. In this traditional model, the two-course sequences are taught independently of each other with no effort made to communicate the rich commonality between their concepts. In such a course-oriented curriculum, courses within a core competency are said to be taught in stovepipe-style isolation (see Fig. 1) [5]. In this stovepipe analogy, students do not see the connections between the core sets of courses or understand how the knowledge from these courses fit together in building their mastery over electrical engineering problems. This issue is further compounded by the fact that the conventional lecture-based model uses an instructor-to-student content delivery mechanism that is inflexible and cannot be easily tailored to different learning styles and preferences [8]-[10]. Overall, the stovepipe approach to EE fails students in two critically important ways. First, students with the desire and capacity to become productive engineers are not seeing the relevance of their interests to current curricula, and they are abandoning the discipline. This is especially true for students entering the middle two years of the core undergraduate program where an accelerated amount of new concepts are introduced. Second, students who ultimately graduate from undergraduate engineering programs may not fully understand the role of an engineer and the scope of the field, resulting in high attrition from employment in engineering, particularly among women. In order to address the above problems, knowledge integration (KI) is a very useful approach. The key idea behind KI is that it will weave together anchoring concepts from different courses to make learning more relevant. In effect, we will breakdown the boundaries between the three course sets, thereby emphasizing the latitudinal connections between them as illustrated in Fig. 2. Tying together the key concepts across courses will not only allow students different ways to understand and interpret the same concepts but will also help students to retain their knowledge better. Better retention means that students will be better able to build on the basic knowledge to synthesize newer knowledge to explain new facts and apply to new problems in their professional lives as opposed to merely remembering the concepts themselves.

The idea of a KI learning environment is not new and is well supported by existing education research. For example, Donlosky et. al. [11] highlighted ten effective learning techniques based on their simplicity and efficacy from the published data. Among these techniques, elaborative interrogation and self-explanation are ranked high. However, in a traditional lecture-based

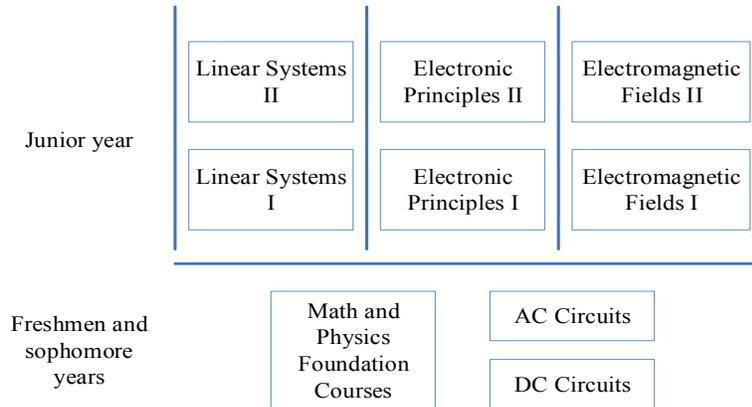


Fig. 1: Technical content of the current EE curriculum in the freshmen, sophomore, and junior years.

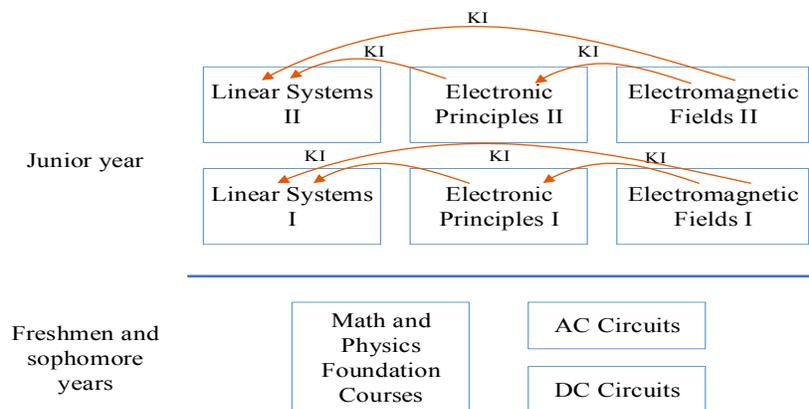


Fig. 2: Breaking the boundaries between the junior year courses with KI activities.

learning model where the instructor is in charge of the knowledge transfer, such self-interrogation is usually not possible. In fact, even when students ask questions in a classroom, it is to clarify their doubts. But once the doubt has been clarified by the instructor, further self-investigation by the student is halted because he/she reverts back to being passively dependent on the instructor to explain the next course topic. On the other hand, a KI-based learning environment requires students to formulate their own answers, to rigorously interrogate their own answers via peer discussions, to synthesize higher knowledge from fundamental concepts in order to tackle new problems, and to prove to themselves and their peers that the synthesized knowledge leads to an acceptable problem solution. Even if a student fails to synthesize higher level knowledge, they have the opportunity to think critically and assess what roadblocks prevent them from synthesizing the new knowledge. An effective KI learning environment has to be able to meet the above objectives by involving the four components underlined by Schwab: learner, teacher, subject matter, and context [12]. Each of these elements is important in their own right to achieve effective teaching and learning, and none can replace others in the process.

2.2 Implementing a KI Based Learning Environment

In this paper, the focus is kept on the junior level courses because the students are exposed to the core departmental coursework starting from the junior year. In the fall semester of the junior

year, students take the introductory level courses: Electronic Principles I, Linear System Analysis I, and Electromagnetic Fields I. In the spring semester, they are required to take the follow-on courses: Electronic Principles II, Linear System Analysis II, and Electromagnetic Fields II. In each of these courses, the syllabus was broken down into the basic concepts by the very instructors who have been teaching these courses for many years. In so doing, concepts that may be important but not fundamental to a course was packaged into other appropriate courses. The concepts that remained behind were considered to be the very fundamental concepts, also referred to as the anchoring concepts. Typically, each course has five designated anchoring concepts. The content material relevant to each anchoring concept was cast into a learning studio module (LSM). Thus, there are five LSM for each course. This entire process of converting each course to its LSMs required weekly meetings between the instructors over the entire spring semester of 2016. Semesters are of the traditional 15-week duration. Currently, the schedule for each semester is organized so that the content of each LSM takes roughly 2 weeks to cover. Moreover, the pace for all LSMs are synchronized such that at the end of the first two LSMs, all the students from the three courses are ready to start the first KI module. Each KI module consists of a week of activities. Thereafter, students move onto the next two LSMs followed by the second KI module. Finally, the semester concludes with coverage of LSM 5 followed by the third KI module. This pattern is repeated in the spring semester as well.

In order to lend context to the KI activities and relate them to contemporary electrical systems that students are most familiar with, a cellphone based radio system platform is chosen as the vehicle through which the KI learning is done [7]. A cellphone platform covers a variety of complex and coupled functional blocks such as the power management system, baseband subsystem for voice and signal conditioning, processing, and storage; the signal up-conversion and down-conversion at the RF level; as well as the radio transmission and receiving components, i.e., antennas. These functional blocks are shown in Fig. 3. Each KI module focusses on one of these functional blocks and by analyzing the operation of these functional

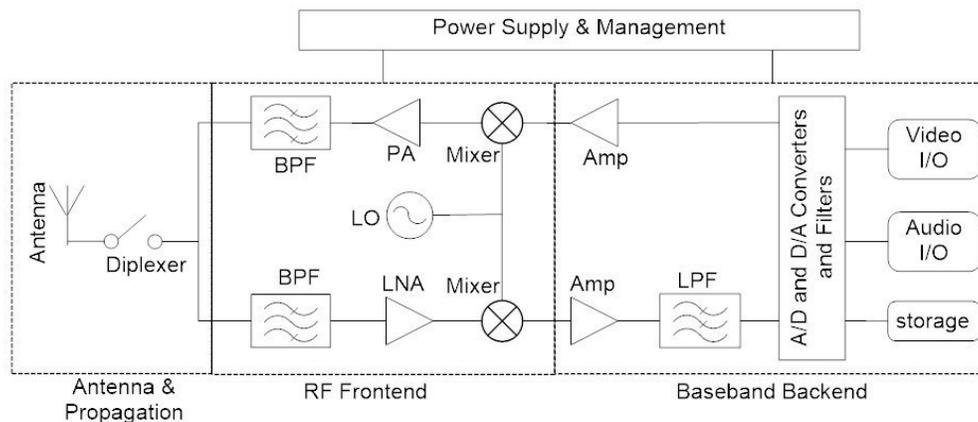


Fig. 3: The block diagram showing the different functional blocks of the cellphone based radio system platform.

blocks, the interconnections between the relevant LSM topics of the three courses is emphasized.

The KI activities are created by the three course instructors in collaboration and consultation with each other so as to best spark the intellectual curiosity among the students as well as to best reveal the interconnections among the LSM concepts of the different courses. For this purpose, each KI module consists of a pre-work assignment. This pre-work assignment consists of multiple questions that are rooted in the relevant LSM materials while being directly related to a

functional block of the cellphone system of Fig. 3. Importantly, the questions are kept as open-ended as possible to promote elaborative self-interrogation and self-explanation among students. In particular, when answering the pre-work questions, it is not enough for the students to know the LSM materials. Rather, they must demonstrate deep understanding of the LSM concepts, tie concepts from the LSMs of different courses together to synthesize new knowledge, and use this new knowledge to explain the operation of each functional block in question whether at the physics level (or device level), the circuit level, or the systems level. Next, in the class sessions, the students are encouraged to share with the class how they engaged with the pre-work questions. All three instructors are present during the KI sessions and they collaboratively probe the students understanding of how different concepts across the three courses are stitched together in analyzing the particular cellphone functional block. Wherever possible, the critical thinking process during the KI sessions are further aided with hands-on lab exercises to be performed before the KI sessions, MATLAB-based simulation assignments packaged into the pre-work, and in-class live demonstrations during the KI sessions. In the next subsection, we provide more details by taking the reader through the implementation of the first KI module.

2.3 Example of a KI Module: KI 1 (Power Management System)

The first KI module focusses on the AC-to-DC power conversion unit, also referred to as the ‘Power Supply and Management System’ in Fig. 3. In Figure 4, the key component for the power conversion unit – the full-wave rectifier bridge is shown. In order to understand how the rectifier bridge works, the KI exercise integrates the following concepts listed in Table I from the first two LSMs of the three courses. It is observed from Table I that diodes and PN junctions are major topics in the first two LSMs of Electronics Principles I. However, their treatment in the LSMs is restricted to time-domain analysis. On the other hand, the concept of periodic signals, the impact of linearity and time invariance on circuit behavior and signal output is the focus of the first two LSMs of Linear System Analysis I. Note that traditionally, these concepts from the two courses are taught without any discussion on how they are interconnected. However, in the KI exercise, these concepts are combined together to obtain a frequency domain understanding of the spectrum of the input AC signal (say V_{in}) and the output periodic signal across the load in Fig. 4 (say V_{out}). It can be shown that the spectrum of the signal V_{out} has a DC signal component present that was absent in the spectrum of the input signal V_{in} – a key manifestation of the nonlinear operation of diodes. The spectrum of V_{out} is established both through rigorous mathematics and commercial circuit simulators in the KI. Thus, students are able to comprehend at a deeper level what linearity (or nonlinearity) actually means in terms of operation of real life devices that was not possible in Linear Systems Analysis I, how nonlinearity of device characteristics manifests themselves in measured data, and how signal periodicity, linear and non-linear transformation, and signal energy and power are all interrelated.

Similarly, another key element in Fig. 4 that naturally lends itself to KI activities is the capacitor present in the RC circuit. From a fundamental electromagnetics perspective using concepts of static electric and polarization field vectors, the operation of linear capacitors are discussed in LSM 2 of Electromagnetic Fields I. Similarly, the contribution of capacitors to the RC time constant in unit step response of linear time invariant circuits is discussed in LSM 1 and 2 of Linear System Analysis I. However, the interconnections between these two concepts have never been explicitly explained to the students. In the KI exercise, by tying these two concepts together, students are shown how the polarization vector affects the dielectric constants, and

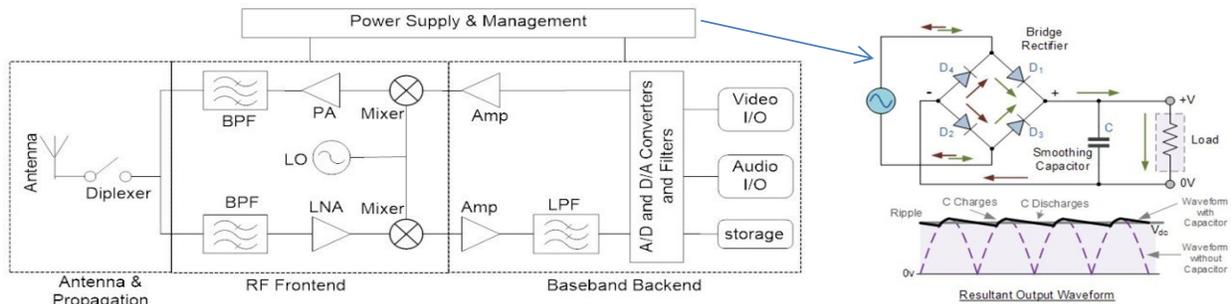


Fig. 4: The AC-to-DC power conversion unit ('power supply and management system' of Fig. 3) using for the KI activities.

Table I. Key Concepts in the First Two LSMs of the Three Junior Year Courses

Course	Linear Systems Analysis I	Electronic Principles I	Electromagnetic Fields I
LSM 1	<u>Transient and Complex Exponential Signals</u> <ul style="list-style-type: none"> Continuous & discrete-time signals Signal energy and power Periodic, even, and odd signals Continuous & discrete complex exp. & sinusoidal signals Continuous & discrete unit impulse & unit step functions and sequences 	<u>Semiconductor Physics</u> <ul style="list-style-type: none"> Intrinsic and extrinsic semiconductors Transport of charge carrier – drift and diffusion PN junctions and their operations in equilibrium, forward bias and reverse bias. 	<u>Electrostatic Field in Free Space</u> <ul style="list-style-type: none"> Electric field due to charge distributions Electric scalar potential, gradient Gauss' Law, integral form Gauss' Law, differential form, divergence Conductors in the electrostatic field
LSM 2	<u>Linear Time-Invariant Systems</u> <ul style="list-style-type: none"> Linearity Time-invariance Impulse response Discrete-time LTI systems: Convolution sum Continuous-time LTI systems: Convolution integral Properties of LTI systems: Memory, causality, invertibility, stability, and unit step response Causal LTI systems described by differential and difference equations 	<u>Diodes, Diode Models and Applications</u> <ul style="list-style-type: none"> I-V characteristics of diodes – also referred to as the nonlinear diode model Approximating the I-V characteristics using different diode models Large & small signal diode model Circuit application of diodes – rectifiers, voltage regulators, limiting circuits, voltage doublers 	<u>Electrostatic Field in Material Media</u> <ul style="list-style-type: none"> Polarization of dielectrics, bound volume and surface charge densities Generalized Gauss' Law, dielectric-dielectric boundary conditions Analysis of capacitors with homogeneous and inhomogeneous dielectrics Electric energy & energy density

consequently, the value of the capacitor for different dielectric mediums. Students can thereby infer how the polarization vector affects the system-level quantities such as the RC time constant of the circuit. Of course, by changing the RC time constant, different magnitudes of ripple voltage in V_{out} (i.e., different low-pass filter characteristics of the RC circuit) can be achieved. This illustrates how integrating the concepts across all three courses enables students to start from the most fundamental physics-based concepts and be able to predict and analyze system level behavior.

2.4 Formative Assessment Techniques and Data Collected

In order to assess the impact of the KI activities, the authors have developed two distinct assessment techniques. One technique tests the student's mastery over KI skills and the other,

his/her mastery over the core EE competency areas. In the first technique, students who have graduated from their junior year are presented with a design tear-down problem at the beginning of their senior year. This design tear-down problem is carefully selected by the instructors of the junior year courses. Typically, the selected problem includes a sophisticated electronic equipment (e.g., the transceiver chain in an optical mouse) where there is rich integration of concepts from electronics, linear systems, and electromagnetics. In this exercise, students are asked to identify the different functional blocks of the system, identify the different concepts learned that are key to the operation of each block, and provide detailed analyses of how the concepts across the junior year course sequences interact with each other to inform their understanding of the operation of each block. The student responses are graded and the statistics of the data (e.g., mean, median, standard deviation) is collected by the RED team. The authors have already collected the data for the students entering the senior year in 2017. In addition, the authors have also collected the same data (for the same design tear-down problem) for students entering the senior year in 2016 who were not part of the KI learning environment. A thorough comparison of the data between 2016 and 2017 is currently being conducted by one of the authors who is the educational assessment professional on the RED project. It is expected that the comparison will help quantify the difference a KI-based learning model has on the student's ability to fit together knowledge from different courses to better understand how complex electrical systems work. Moreover, the authors will continue to gather the same data for future years. Comparing the data across future years will reveal how the fine-grained year-to-year adjustments to the KI learning environment is enhancing the value of this practice.

For the second assessment technique, the very same set of students are also required to take a concept inventory test at the beginning of their senior year. The test consists of 25 multiple choice conceptual questions spanning each of the three competency areas carefully selected by the instructors. These questions are designed to test the proficiency of the students regarding the core competencies of an EE program. Similar to the design tear-down problem, for the concept inventory test, data has been collected from the set of students who entered the senior year in 2016 and 2017. We have noticed a distinct improvement in the scores from 2016 to 2017: from 29% to 43% in the electronics area, from 17% to 58% in the linear systems area, and from 15% to 37% in the electromagnetics area – all pointing to a deeper and richer learning experience provided via the KI learning environment.

3. Proposed Active Learning Classroom Model

3.1 Need for an Active Learning Model and Literature Review

The discussion of the previous section suggests that for the KI modules to be most effective, students must be able to do the following:

- 1) Appreciate how different engineering and scientific concepts can be viewed from different perspectives, e.g., how can the concept of linearity (or lack thereof) be understood from both a time and frequency domain system analysis?
- 2) Be able to stitch together concepts from the Electronic Principles, Linear System Analysis, and Electromagnetic Fields courses to analyze and predict how complex systems operate.

In order for the students to acquire the above skills, they must be trained in the higher level

learning skills of being able to analyze, synthesize, and evaluate new knowledge [13]. Unfortunately, the standard lecture-based instruction method that is commonly practiced when covering the LSM topics puts greater emphasis on content coverage than inculcating the above skills in students [10]. This means that despite our best intentions, there is a misalignment between the way LSM topics are covered and how KI modules are planned, resulting in students not being adequately prepared to make the most of the KI activities. Thus, there is a need to tailor the way in which the LSM content is delivered to ensure that not only is the content coverage adequate and timely but also that the students are being better trained in the higher level skills of learning. For this purpose, the authors of this paper have developed a new active learning model to be used for content delivery during the LSMs.

Active learning is defined to be an instructional method that requires students to be cognitively engaged in their own learning process. In the works of de Winstanley et. al. [14] and Clarke and Mayer [15], it has been shown that meaningful learning exercises and appropriate cognitive activities embedded in the instructional method can be very useful for students to mentally process what they have learned and appreciate how they have learned it. Other research works such as [16], [17] have consistently found that active learning practices are associated with higher student achievement and engagement. In fact, comparative studies show that students employing active learning strategies in the planning, monitoring, and evaluation of their learning progress have been found to outperform peers lacking these skills [18]. The authors of this paper have based their own active learning model on the following foundational principles found in the literature. An example has been provided in Section 3.3 to explain how these foundational principles help us achieve our unique goal of preparing students for KI-based learning.

- 1) Active learning activities should push students to generate connections, questions, and solutions, leading to greater recall and comprehension [19].
- 2) Active learning activities should help students integrate or fit in new knowledge to the pre-existing knowledge bank. This directly trains students in the skills of knowledge integration [20].
- 3) Repeated and temporally spaced retrieval of knowledge is essential for long-term retention [21].

3.2 Implementation of the Active Learning Classroom Model

A pilot program of this learning model was devised and tested in the 2017 fall semester for the Electronic Principles I course. The class size for this course was 74. The lecture component of this course does have a laboratory component attached. The laboratory component requires three hours a week while the lecture component requires two and a half hour a week. We point out that in developing this active learning model, the laboratory component was not touched.

The active learning classroom model consists of three stages. In the *concept introduction* stage, students are introduced to the relevant LSM concepts outside of the classroom. For this purpose, a variety of learning tools such as relevant textbook passages, articles from the internet, lecture videos, and Powerpoint presentations with voice-over are provided through the online learning management system. These different tools support the varied learning styles of the students. The purpose of this concept introduction stage is to allow the students to gain a preliminary understanding of the basic facts related to the LSM topics. This preliminary understanding prepares them for the deeper dive they will face during the class sessions. Moreover, the

instructor is freed from delving into the fundamentals of each LSM topic, thereby allowing him to devote more of the class time towards analysis and application of the LSM topics to problem solving. In order to ensure that students are adequately prepared prior to class, they are divided in groups and each group is required to post the biggest questions that they had about the material and also correctly answer the questions posed by at least three other groups. Students receive a penalty if these basic activities are not completed prior to class. The teaching assistant (TA) for this course makes a list of the most common and well-thought out questions.

Classroom time is devoted to the *concept exploration* stage. In this stage, 15 minute mini lectures are interspersed with 5 minute group activities. By structuring the lecture sessions into small segments, the instructor is able to deliver the LSM content in small chunks without overwhelming the students or losing their attention. The main goal during the mini-lecture sessions is to provide a more thorough theoretical and detailed examination of the LSM topics that the students have encountered in the concept introduction stage. In particular, the first mini-lecture opens with the instructor randomly calling on students and asking them to provide the class with their brief understanding and interpretation of the concepts covered in the concept introduction stage. In addition, the first mini-lecture session is also dedicated to answering the most common and well-thought-out questions and clearing up any doubts/misunderstandings noticed in the student posts in the concept introduction stage.

During the group activities, students get a chance to first discuss their understanding of the theory covered in the mini-lecture session among their peers and secondly, apply that knowledge to solve engineering problems. In effect, during the group work stage, the classroom is repurposed into a 'knowledge workshop' where students can inquire about the material, test their application and cognitive skills, and interact with one another through hands-on activities. This provides students with a valuable opportunity for self-interrogation, to think about what they have learned, and eventually to internalize the information covered in class – something that is not possible in the traditional lecture model. In addition, one group activity session is dedicated to peer instruction where a particular group shares their way of thinking about the LSM concepts and how they fashioned their understating of the concepts into problem solving tools with the whole class.

The above group discussion sessions offer multiple learning benefits. First, within a group, the students take on the responsibility of clarifying the doubts and questions of their peers. This allows for dissemination of knowledge not just from instructor to students but between students as well, leading to fewer gaps in understanding within a class. Second, by engaging within their groups, individual students are exposed to different lines of thinking and understanding of the same concepts. Thirdly, the peer instruction exercise forces students to abandon their passive learning roles and encourages them to think deeply, better engage with the course material, and come up with innovative ways to communicate their knowledge to their peers. Moreover, if the group's knowledge is proven to be flawed, this peer instruction exercise provides a platform where the common misconceptions and misunderstanding are identified, talked about, and clarified by the instructor.

Finally, in the *concept reflection* stage, each group of students provide a brief online reflection statement at the end of every class describing in their own words whether the questions they

posted in the concept introduction stage had been answered in class, what learning tools best helped them to grasp these answers, and what doubts still remained. These statements serve as daily micro-feedback to the instructor regarding this pedagogical model. Due to the regular nature of this feedback, the instructor has the opportunity to continuously refine the active learning model throughout the entire semester to better meet student needs rather than waiting for the formal end-of-term course surveys. Moreover, each group is again required to correctly answer the doubts/queries that at least three other groups post in the reflection statement.

3.3 Illustrating How the Active Learning Model Prepares Students for KI

In this subsection, we describe how the aforementioned active learning model is implemented using an illustrative example. In this example, we assume that we are covering the operation of diodes (LSM 2). In the pre-class reading/video/presentations, the operation of diodes in forward bias, reverse bias, and the unbiased condition will be explained. Next, in the first mini-lecture session, the instructor will discuss how the operation in these three regimes can be understood based on the concepts of static charge density and electric field/potential in the depletion layer of the diodes. It is pointed out that students already know the concepts of static charge density and electric field/potential from LSM 1 of Electromagnetic Fields I although not in the context of diodes. By requiring students to recall that piece of knowledge and leverage that knowledge to grasp the ‘how’ and ‘why’ of diode operation, the instructor will explicitly lean on the three foundational principles described in Section 3.1 to promote knowledge integration.

Next, during the group work sessions, the student groups will be asked to reason whether diodes are linear or nonlinear circuit elements and provide validations for their reasoning. This exercise will push students to do three things – (i) recall from the LSM 2 of Linear System Analysis I what the conditions of linearity are (foundational principle 3), (ii) relate that knowledge to the characteristics of diode operation to understand that diodes are nonlinear elements (foundational principle 1), and (iii) be able to put back the new knowledge (‘diodes are nonlinear circuit elements’) into their knowledge bank of linear and nonlinear systems (foundational principle 2). Thus, by going through these three steps, the students will have gained an unshakeable understanding of why diodes are nonlinear circuit elements. It is clear from this example, how the active learning model helps the students draw meaningful connections between what they have learned across all three courses, thereby laying the very seeds of KI in the student’s minds. As a result, the active learning model is made to fit our goal of preparing the students for KI.

3.4 Formative Assessment Techniques and Data Collected

As part of the assessment techniques, the lead author along with the educational assessment professional on the RED project, are currently extracting the DFW (Drop-Fail-Withdraw) rates, the mean and median scores, and the percentage of students obtaining A- or higher grade from the student records of 2016 (when a traditional lecture model was used) and 2017 (when an active learning model was used). The comparative analysis of the scores from these two years across the above metrics is expected to reveal the impact the active learning model had on student performance. As part of this comparative analysis, the lead author has tried to keep the complexity of the midterm and final examinations, the raw score required to achieve an A-grade, and the number of assignments as similar as possible between 2016 and 2017. This data

represents the longitudinal or temporal data collected. The authors envision that such data will continue to be collected every year. Comparing the data across future years will reveal how the fine-grained year-to-year refinements made to the active learning activities positively impact student learning.

Besides a longitudinal data analysis, from 2018 onwards, the authors plan to develop a ‘posttest’ for all the three two-course sequences of the junior year. The questions of this posttest will be created and moderated by the instructors with the goal that all the posttests pose similar levels of intellectual challenge. These posttest will be administered a week before the final exam and will encompass the materials from all five LSMs of the courses. The idea is that the posttest will compare the performance of the same set of students across six different courses of which only the Electronics Principles I course is currently being taught using the active learning model of this paper. The scores of the posttest will be the lateral data collected. Comparison of the posttest scores from Electronics Principles I with that collected from the remaining five courses will directly inform us how well the active learning model enriches the learning experience over traditional lecture-based learning for the same cohort of student. As before, the educational assessment professional on the RED project will be in charge of the data analysis.

As a final assessment technique, one of the co-PIs of the RED project is currently pilot testing a new student survey named Learning ENvironment Survey (LENS). The LENS survey moves away from evaluating the instructor and rather requires students to identify what instructional practices best supported/hindered their learning. The LENS survey can provide student-centric feedback on the perceived value of the active learning model. Additionally, this feedback can be used to fine tune the active learning activities from year to year. The combination of longitudinal, lateral, and student feedback data will together form multi-modal data revealing the effectiveness of the active learning classroom model.

4. Lessons Learned and Future Directions

As explained in Section 3.1, one of the attractive features of our active learning model is that it solicits daily feedback from the students through the concept reflection stage. From this feedback, the authors have learned the following lessons and plan on these future directions:

- i) Based on the outcomes of the active learning classroom model, the authors believe that this model has the potential to provide students with the necessary training in the higher level learning skills. Concrete evidence to this effect will be obtained using the assessment techniques listed in Section 3.4. The authors envision a similar active learning model being developed for the Linear System Analysis and Electromagnetic Fields courses from 2019 onwards. With all three courses being taught using a similar classrooms model, students will be better able to appreciate the coherence between the LSM topics covered in these courses.
- ii) Students have been very enthusiastic about the active learning classroom model and truly appreciate how this model has enhanced their learning and understanding of very complex topics. This increased appreciation of the value of their education is critical to ensuring students are committed to their degree program and graduate on time.
- iii) In order to conclusively establish the link between the learning model and increased student retention and program completion rates, the authors are currently gathering relevant data as

described in Sections 2.4 and 3.4. A better picture of the impact that this active learning model has on student retention and program completion will be available after 2018 once all three courses use this model.

iv) One possible drawback of this learning model is that the time available to the instructors for content delivery is reduced. However, the authors argue that covering greater volume of content does not directly translate to deeper learning. In fact, one of the very reasons for the RED project is to prioritize the inculcation of higher level learning skills over content volume. That is why, in designing the learning model, the syllabus of the electronics course has been stripped to the very essential and fundamental anchoring concepts that are covered in the LSMs. In other words, content that may not be as fundamental to the course but part of the earlier versions of the syllabus has either been given lower priority or if possible, completely removed. In addition, in this learning model, there is a markedly greater emphasis on pre-work where students are introduced to the new concepts. This ensures that students coming into class have the basic facts related to the concepts and can better utilize the class time in delving deeper into the ‘why’ and ‘how’ of the concepts rather than the ‘what’.

v) It is not uncommon for students to display increased levels of anxiety due to the change in the classroom learning model. On the other hand, it has been observed that students are more welcoming of the change if the rationale and motivation for this change is cogently explained to them. As a result, the instructors utilize the first day of class to explain both the details and the motivation for this change in the classroom model.

vi) Switching the traditional lecture model for an active learning model requires the course instructor to spend significant time on preparing the pre-work material, collating the common student doubts/queries, chopping the entire class lecture into multiple mini-lectures, maintaining coherence between the mini-lectures, developing appropriate group-work questions, and distilling the student reflections. Thus, the professional development of the faculty is a key aspect of this work. Importantly, we need to be strategic so as to best utilize available resources on campus, thereby reducing the burden on the instructors in a research-intensive university. To this end, campus organizations focusing on teaching and pedagogy (e.g., The Institute for Teaching and Learning (TILT) at Colorado State University) can provide valuable advice, facilitate meetings with other faculty members who have successfully navigated such a transition, and help the instructor to identify electronic materials useful for the active learning model.

5. Conclusion

During of the early years of the RED project, the authors realized that to maximize the benefits of the KI-based environment required the students to be adequately trained in the higher level learning skills such as synthesis and evaluation of knowledge. Thus, it was necessary to couple the KI modules with a classroom learning model that would effectively prepare and train the students in these higher level skills. For this purpose, the authors have developed an active learning model that was pilot tested in the Electronics Principles I course in the fall 2017. This model consisted of separate concept introduction, exploration, and reflection stages. These stages were designed to encourage students to question, assess, and interrogate their own understanding of the course topics. New assessment techniques have been developed for this new learning model and currently relevant student data is being gathered for these techniques. The lessons

learned from this exercise and the future steps have been identified and presented. We anticipate that as this active learning model is expanded, the experience of the authors will be shared with the engineering education community in an effort to inform better learning outcomes.

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