AC 2008-210: DEVELOPMENT OF AN INTEGRATED SPIRAL CURRICULUM IN ELECTRICAL AND COMPUTER ENGINEERING

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Development of an Integrated Spiral Curriculum in Electrical and Computer Engineering

1 Abstract

This paper discusses the development and assessment of an integrated curriculum in electrical engineering (EE). The underlying spiral curriculum philosophy seeks to reduce the compartmentalizing of sub-disciplines within EE by creating courses that integrate material from different areas and that revisit concepts with deeper complexity in subsequent courses.

The paper describes adaptation and implementation of this paradigm in an EE program, and presents some preliminary results from the first two and one half years of effort. Multiple robot platforms provide a thematic project continuity across the curriculum.

2 Introduction and Background

Over the last 15 years, the Electrical and Computer Engineering (ECE) faculty at University of Detroit Mercy (UDM) have been exploring various approaches for the integration of a comprehensive autonomous ground vehicle (AGV) design project into the EE curriculum. Effective upper-division curriculum integration has been implemented and assessed, and an award winning paper describing our efforts published.[1] In fact, we have noted substantial improvements in a variety of learning outcomes due to the use of such an integrated and comprehensive project. These improvements include greater student enthusiasm, better concept comprehension, a much improved understanding of topical relevance, and significant demonstrations of successful independent enquiry and multi-cultural and multi-disciplinary teaming. These successes have been directly responsible for our continuing efforts to migrate these benefits downward in the curriculum, and the resulting comprehensive curriculum reform for the Electrical Engineering program described in this paper.

The EE program has for many years distinguished itself by focusing on both engineering design and practice while placing an emphasis on critical thinking, ethics, and social responsibility via an extensive humanities-based core curriculum. Mandatory cooperative education assignments and extensive laboratory and class-based projects ensure that students not only grasp theoretical concepts, but also know how to apply those concepts in practical situations. Before the curriculum reform described in this paper, the course sequences and content were traditional and reflected national norms, but several innovative courses presented unusual opportunities for interdisciplinary teaming. Examples included an integrated freshman engineering design course, three courses in the area of mechatronics, and a two-semester joint ME/EE capstone design sequence. Yet, despite this sound program structure, and the regular use of active and enquiry-based learning principles, students still questioned the relevance of the various topics, and did not become truly enthusiastic about the ECE discipline until late in their program of study. Furthermore, over the years, the program content expanded to match the dramatic growth in the ECE field, creating an overloaded curriculum and encouraging opportunism; that is, the development of strategies to cope with testing requirements without the attendant deep-seated learning.[2] The program we have developed directly addresses these issues while building on traditional program strengths, including design, practice, and a strong humanities-based core curriculum. The broad goals of our curricular implementation plan are summarized below.

- The plan is intended to improve student motivation, innovation, and learning through the use of teaching paradigms that are mindful of the learning styles that characterize this generation. Specifically, it seeks to increase student excitement and interest in pursuing engineering education via an integrated robotic theme. This involves the use of two robotic platforms: a small hobby robot platform in the lower division and an autonomous ground vehicle in the upper division. The integrated robot theme serves to provide continuity and concept context throughout the curriculum.
- The plan includes a thorough evaluation of existing curricular material to arrive at a new determination of what constitutes fundamentals and what does not. The object of this exercise is to create room in what has, over the years, become a highly overloaded curriculum. It is important to note that the new curriculum is based on a well-designed balance between fundamentals and specialization.

Spiral curriculum, a concept widely attributed to Jerome Bruner,[3] refers to a curriculum design in which key concepts are presented repeatedly throughout the curriculum, but with deepening layers of complexity, or in different applications. Such treatment allows the earlier introduction of concepts traditionally reserved for later, more specialized courses in the curriculum, after students have mastered some fundamental principles that are often very theoretical and likely to discourage students who are eager to apply the concepts they are learning to real-world applications. In earlier courses, it may be that students gain hands-on experience with components with little or no understanding of the theoretical bases behind their operation, but it is thought that such understanding will come more readily in the later courses if students already have a prior concrete experience to which to connect the theory.

In the engineering education literature, there are several educators who report having implemented a spiral curriculum approach. Clark et al. discuss its application to curriculum reform in Chemical Engineering,[4,5] while Lohani et al. are implementing a spiral curriculum for a bioprocess engineering curriculum[6,7]. Herrick et al. have discussed the effect of using a spiral curriculum approach on retention.[8] Most recently, Collura et al. discuss the impact of a spiral curriculum approach implemented across several engineering disciplines for the first two years.[9]

Other aspects of the pedagogical principles underlying this curriculum reform are discussed in great detail in an earlier publication.[10]

3 Implementation of New Curriculum

The roll-out of this curriculum, diagrammed in Fig. 1, began in the 2005-06 academic year, with a robotics module for the Engineering Design and Graphics course that all engineering students take in their first year. In the 2006-07 academic year, a new course/laboratory *sequence* in Fundamentals of ECE was offered to sophomores. These courses include instruction in circuits, electronics and DC motors, aiming to integrate the treatment of all these areas through the use of hands-on projects that are coordinated with team-based laboratory courses.

In the second semester of this course sequence, close coordination with the project-based laboratory course associated with the introductory Digital Logic course allowed for a final robotics project that integrated concepts from circuits, analog and digital electronics, and DC motors.

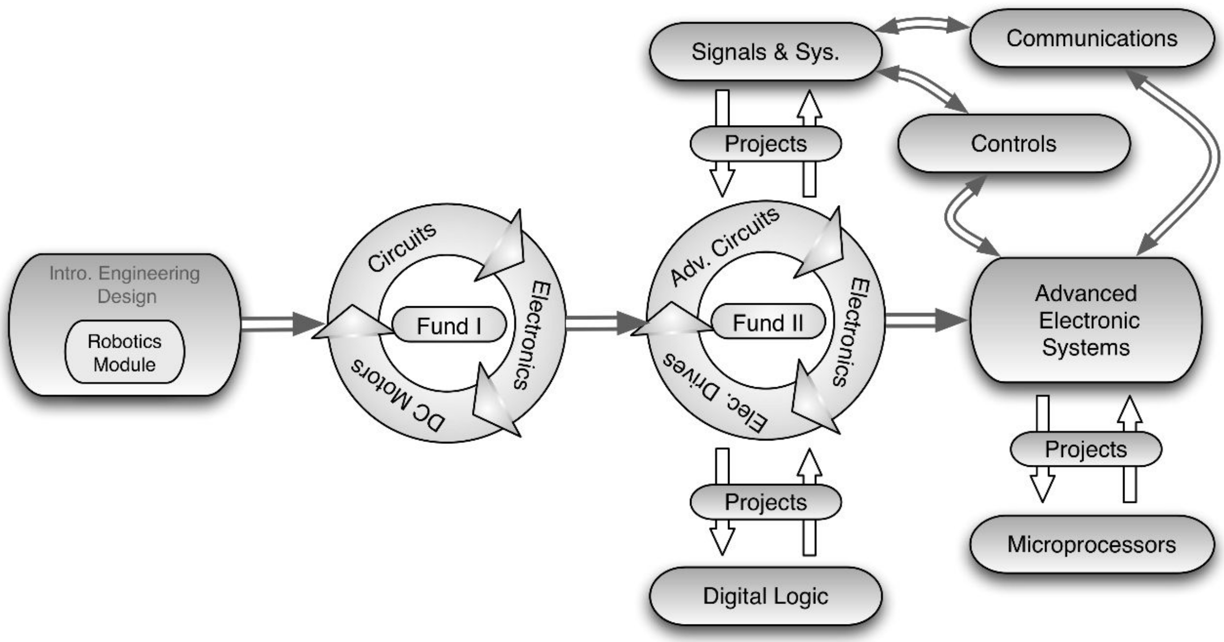

Figure 1: Spiral Curriculum Design

A new course in Signals and Systems integrates the mathematical foundations of circuit theory, control systems, communication theory and digital signal processing. This course featured a joint project with the Fundamentals II course in analog filter design.

Third year students just completed the new course/laboratory, Advanced Electronic Systems. This course makes a transition from the mixed device-system treatment of the Fundamentals I and II course offerings to a predominantly systems-oriented treatment. The project activities in the laboratory component of the course are chosen to highlight the concurrent application of the electronics, digital logic, microprocessors, and signals and systems knowledge areas.

3.1 Year 1, Introduction to Engineering Design and Graphics: 2005-2006

For a number of years our students have enjoyed an integrated, multidisciplinary introductory engineering course in their freshman year.[11] This course included discipline-specific projects from the engineering disciplines at UDM. The ECE department collaborated with Mechanical Engineering on a two-week mechatronics project, involving a variety of robotics platforms.

In 2005, we decided to base the mechatronics project on the new robot platform, pictured in Fig. 2. The BASIC Stamp robot we had been using was a good choice for a first-year course, but it had too many limitations to be used in more complex projects in subsequent years. A NanoCore12 processor module and an accompanying servo/sensor/motor interface board (available from Technological Arts - www.technologicalarts.com) are mounted on a 3-wheel platform configured with DC gearhead motors (www.lynxmotion.org). This platform allows us to incorporate many sophisticated activities spanning the first two and a half years of the EE program. Students in E105 used this platform to develop a robot, using input from infrared and ultrasonic sensors. E105 also included a four-week final project, and several teams elected to base their project on further development of the robot.

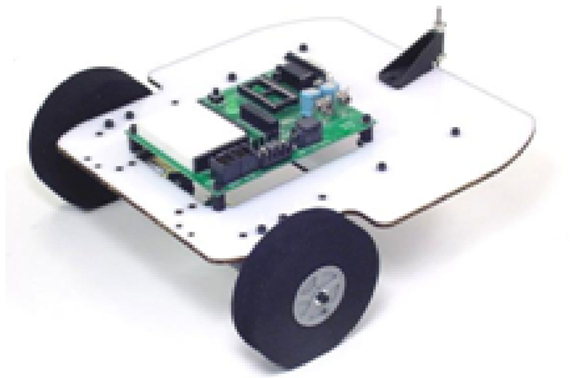

Figure 2: Small Gearhead-Motor Robot

3.2 Years 2 and 3, ECE Core: 2006-2008

A major part of the curriculum redesign and integration concerned the circuits and electronics course sequences. The previous curriculum included a two semester network theory course sequence, beginning in the first semester of the second year, with a two credit hour laboratory course taken in conjunction with the second of these two courses. The two semester electronics course sequence began in the second semester of the second year, with its two-credit hour laboratory course taking place in the first semester of the third year.

The new integrated curriculum features a three semester course sequence that integrates circuits, electronics, and motors throughout the three semesters, with a one credit hour laboratory course during each semester. Other courses integrate with this sequence. For example, a new course in signals and systems is coordinated with the second course in the sequence, and the digital logic laboratory course has a final project that is tightly integrated with the final project in the second course of the ECE Fundamentals sequence.

In this section we discuss these new courses, making sure to highlight how we included the integrated spiral concept in the design and implementation of these and other existing courses.

3.2.1 Fundamentals of ECE Course Sequence

At the beginning of the second year, EE students begin a two-semester course sequence in ECE fundamentals (EE250/251 and EE252/253). These courses provide a spiral treatment of the fundamental principles of Electrical & Computer Engineering, including DC and transient circuit analysis techniques, diodes, operational amplifiers, and DC motors. The second course moves into an integrated treatment of advanced circuits, electronics, and power electronics. The courses feature an intertwined development of theory and applications of the above topics.

The companion laboratory courses (EE251 and 253) provide practical insights for the theoretical topics covered in the fundamental theory courses (EE250 and 252). Analysis and design of simple circuits involving applications of diodes, operational amplifiers, digital logic circuits, and motors are integrated as much as possible with the students' previous experience with the small robotic platforms they used in their first year course. In the first laboratory course, students learn to use Electronic Design Automation software for basic simulation in the context of an overall design methodology. As students advance through the sequence, they learn how to use more of the features of the package. Students also learn how to use basic electronic instrumentation.

The inaugural offering of EE250 focused mainly on fundamental concepts related to network theory, but with a more focused integration of operational amplifiers. It also included brief modules on diodes and the fundamentals of DC motors.

Based on assessment data, the second offering of EE250 was modified as follows:

- Expanded treatment of circuits containing operational amplifiers to include more advanced applications.
- Continued development of the modules on DC motors and diode circuits
- Abbreviated treatment of basic circuit theory, especially the transient response of circuits containing capacitors and inductors.

The companion laboratory course, EE251, focused on using a structured design methodology to complete a number of projects involving resistive circuits, as well as RC, RL and RLC circuits, and circuits containing diodes, operational amplifiers, and DC motors.

The most notable feature of this course was that the mobile robot described earlier was used throughout to help the students exploit the integration of electrical and electronic circuit applications, as well as basic microcontroller and DC motor concepts. The students used infrared and ultrasonic sensors as well as photoresistors to sense light and obstacles in the robot's environment, and used electrical and electronic circuitry to process sensor outputs into signals that could be read into and interpreted by the program they wrote for the microcontroller. They learned how to use pulse width modulation to control the direction and speed of DC motors, so as to command the behavior of the robot in the presence of light and obstacles.

The second semester of the ECE fundamentals sequence (EE252/253) was very tightly integrated with a new signals and systems course (EE388), so we describe them together in the following section.

3.2.2 Fundamentals of ECE II/Signals and Systems

Because we wanted to tightly integrate applications of electric circuit theory, electronics, and DC motors into a single course, much of the content of a traditional second course in network theory had to be relocated elsewhere in the curriculum. A new signals and systems course allowed us to integrate the mathematical foundations of many areas of application into a single course. Learning Fourier analysis, Laplace transforms, transfer functions, Bode analysis, z-transforms, etc. in a unified context made more sense than teaching, for example, Fourier transforms in a communication theory course, z-transforms in a digital signal processing course, and Laplace transforms in a control systems course. This organization also provides another layer in the spiral, in that students learn these mathematical foundations and some simple applications in the signals and systems course, and then revisit these concepts in the upper division courses where more specialized and complex analysis is required.

To provide some idea of the tight integration between the ECE fundamentals course and the signals and system course, we provide several examples:

- After an introduction to continuous and discrete time signals and systems, we move rather quickly into the Laplace transform so students can learn the transfer function representation of a system. As they learned this in the signals and systems course, they had the opportunity to apply these concepts to solving for various voltages and currents in electric and electronic circuits in the ECE fundamentals course.
- We designed an early project that was assigned jointly in the EE388 course and the EE253 laboratory. Students were to explore two different active bandpass filter configurations: a cascade of a low-pass filter with a high-pass filter, and the Delyiannis-Friend filter configuration. They were to determine the transfer functions of the two configurations, choose component parameters to meet design criteria, perform simulations to compare frequency responses, and collect and plot frequency response data for the actual circuits. Because students received credit for this project in two courses, it was easier for them to understand that what they learn in one course truly applies to other areas. The other advantage was reduction in student workload. Instead of having two separate projects in these two courses, recognizing that active filter design and frequency response pertained to both courses allowed us to make the joint assignment.
- Passive and active filters were revisited in EE252 later, at the time when students were learning Fourier analysis in EE388. This allowed us to make the connection between signal spectra and signal processing circuits.

In addition to the integration with signals and systems, the five-week final robotics project in EE253 was designed to serve as a joint final project with the Digital Logic Design laboratory also taken that semester.

A brief problem statement for this project is given as:

> *Design a system that will enable a small robot to be remote controlled from a distance of about 25 feet. There are six basic commands that the robot should be able to receive and execute: forward, backward, turn left, turn right, spin left, and spin right. It is assumed that the robot's default behavior (in the absence of any other command) will be to remain stationary (stopped).*

Figure 3 shows a system block diagram for both the transmitter and receiver modules of the system. Note that within the digital design block on the receiver, there are also requirements to take into account readings from sensors that will affect the behavior of the robot. These requirements are implemented in an earlier project in the logic design course.

(The reader may wonder why there is a separate logic design course if we are aiming for complete integration of fundamental ECE concepts. This is primarily an issue of logistics, in that the Computer Science (CS) program requires its students to take the logic design course. Integrating the logic design course over a two or three semester sequence would fail to provide these students with the focused knowledge they need to master in a single course. Currently, there are not enough ECE faculty to teach the CS students separate from the EE students.)

3.2.3 Advanced Electronic Systems

The Advanced Electronics Systems lecture and laboratory courses that students take in the Fall term of the junior year are additional courses constructed to fulfill the philosophy of the spiral

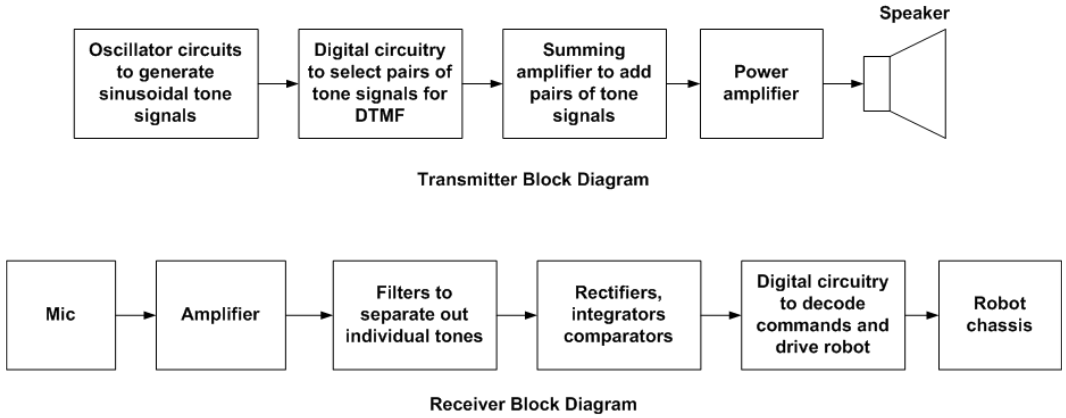

Figure 3: Final Project System Block Diagram

curriculum. In earlier courses in the spiral containing electronic circuit topical content, a mixed device-system treatment was adopted. Here a transition is made to a predominantly systems-oriented focus.

The operational amplifier circuit plays a significant role in this course. The basic theory and its use in simple applications were covered in earlier course offerings. Here its use in advanced linear and non-linear applications is taken up, as is treatment of its internal construction. Other topics addressed are the frequency response of amplifiers, analysis and design of power amplifiers, and motor drive electronics.

It is the content of the companion Advanced Electronic Systems Laboratory course that is most effective in the task of ECE topic integration. Students work in teams to complete two major multi-week design projects with strong cross-sub-disciplinary implications (more on this later). The course also consists of a couple of auxiliary exercises that enable the understanding and exercise of common tools and practices for electronic design automation. The technique of Monte Carlo analysis for the design of circuits taking into account component tolerances is discussed. The technique is applied to the design of a band pass filter to meet specifications including considerations of component variability. The chosen design task is in keeping with the spiral philosophy since students have designed band pass filters in an earlier laboratory course, but using ad-hoc methods to account for tolerances. Students are also exposed to the concept of virtual prototyping for carrying out circuit design and testing to formalize design skills taught earlier in the curriculum. This is accomplished through instruction in LabVIEW®.

The first design project required the design of an electronic circuit to measure and display the shaft speed of a DC motor. Completing this project called for the exercise of knowledge from a wide variety of ECE sub-disciplines - circuit theory, analog electronics, digital logic, sensors, signal conditioning, and motors. A second design project requires the design and implementation of an analog closed loop speed control system for a DC motor. In this project, in addition to the sub-disciplines listed earlier, knowledge from control theory is also required. This project was intended to be extended to the real world by using the developed design to implement feedback control of the motion of the mobile robot used earlier in the curriculum; the robot uses a tank drive locomotion paradigm, and hence speed control of its two drive wheels controls both speed and direction. However, in this first offering of the course, the extension could not be completed due to lack of time; room will be made for it in future offerings. Since the robot operates through software written in a version of the BASIC language running on a dedicated microprocessor, the extension will establish the linkage between analog/digital hardware and software running on a microcontroller, an architecture which is commonly found in many stand-alone embedded system applications. It also ties in with the broader robotic theme of the curriculum.

4 Evaluation and Assessment

The established assessment plan for the EE program includes course-level assessment that is reviewed and approved by department faculty. Many instructors gather survey data from students regarding their perceived level of attaining course learning outcomes. In this section, we will provide some relevant data from course assessment reports, as well as some results from a survey given to freshmen who had completed the robot project in the Intro to Engineering Design and Graphics course. We also include results from focus groups and observations conducted at the *beginning* and at the *end* of the first offering of the Fundamentals of ECE II course.

4.1 Survey Data

4.1.1 E105: Intro to Engineering Design and Graphics

On the survey given to these students, two questions were chosen as indicators of our success in increasing the motivation of students to learn more about embedded computer based projects. To the statement, *"The experience made me feel more motivated about studying engineering,"* 71% of those who responded either agreed or strongly agreed. To the statement, *"I would be interested in exploring other engineering topics via the use of robot or embedded computer based projects,"* 86% of those who responded either agreed or strongly agreed.

These responses seem to indicate a motivation to engage in deeper learning of the concepts encountered while getting the mobile robot to complete the required tasks. This prepares the students to enter the second round of the spiral in their second year of courses.

4.1.2 EE250: Fundamentals of ECE I

The self-assessment given at the end of the first offering of this course revealed the following results. To the statement, *"I know the operating principles of diodes operational amplifiers, motors/generators, and can analyze/design simple diode/op-amp circuits,"* 60% of those who responded either agreed or strongly agreed.

These results suggest that students' first exposure to these important components has given them the confidence to go deeper in subsequent courses.

4.1.3 EE251: Fundamentals of ECE I Laboratory

The self-assessment given at the end of the first offering of this course revealed the following results. To the statement, *"The laboratory exercises are interesting and effective in providing practical examples of the theory topics covered in the lecture course (EE250),"* 50% of those who responded either agreed or strongly agreed. To the statement, *"The fact that the laboratory exercises involve different areas of Electrical Engineering such as amplifiers, sensors, motors, and software, has helped me see the connections between these areas even though I have not had* *formal instruction in all of these areas,"* 50% of those who responded either agreed or strongly agreed. To the statement, *"I liked the overall organization and content of this course,"* 37% of those who responded either agreed or strongly agreed.

We believe that these disappointing results reflect some resistance from the students to engage in the kind of independent enquiry-based learning that the instructor expected from them throughout the course. After discussion, it was suggested that in the second offering of the course, the instructor provide a little more structure and guidance early on to gradually build up the students' confidence in their ability to seek the relevant information needed to solve novel problems.

4.1.4 EE355: Advanced Electronic Systems

To the statement: *"I find the design projects interesting and effective in connecting theory with practice,"* 83% of those who responded either agreed or strongly agreed.

The students who responded to this survey item were the same ones who gave low ratings to the items from EE251, even though the projects in EE355 were even more open-ended than those in the earlier course. This result seems to suggest that it takes some time for students to reach a level of comfort with the demands of self-directed learning.

4.2 Focus Group and Observations

Pre- and post-course focus groups were conducted with second semester sophomores to try to see if their motivation and ability to engage in self-directed learning changed at all as a result of the active learning techniques employed by the instructor in the EE252/253 Fundamentals of ECE II course, and the EE388 Signals and Systems course. Students were also observed attempting to solve a problem for which they had not yet been given any instruction to see what behaviors they actually exhibited in such situations. These observations were also conducted pre- and post-course.

In the focus groups, students were asked questions that addressed four themes:

- Strategies: What are some strategies you use when you need to learn new concepts or apply concepts to a new problem?
- Self-Efficacy: What do you do when you get stuck on a homework problem or project?
- Group Benefits: If you study with other students, describe how you interact with group members when you study.
- Novel Problems: How well do you do when the homework problem looks completely different from problems the professor has done in class? Or when the exam problem looks a lot different than the homework problems?

The preliminary analysis of the focus group transcripts do not reveal any significant changes in learning strategies used by the students, although several mentioned that they felt the active learning environment in the classroom was more effective and engaging for them than the traditional lecture style they had experienced in other courses.

The other significant finding from these focus group sessions was the persistent experience of overload that students reported. Despite our efforts to reduce student workload by having joint projects, students still felt overworked. This may suggest that in our curriculum redesign, we have still retained some legacy materials that may not really be necessary for today's practicing electrical engineer. Because of increasing availability of and emphasis on simulation tools and hands-on projects, the curriculum has become very demanding. Unless we trim more of some of the traditional topics from our courses, there will be no relief for students and more frustration for both students and faculty.

The real-time problem-solving sessions did not reveal any significant differences in observed student behavior. For example, the students who began the course by blindly searching through the text for something that looked similar to the problem at hand still relied on that strategy at the end of the semester. And the students who had an organized strategy for finding what they need to know to solve the problem continued to demonstrate that behavior.

It is possible that the interventions will bear fruit a little later in the students' academic program. Perhaps it is too soon to expect students to integrate self-directed learning strategies just as they are being exposed to these new strategies. We are noticing that the current senior class exhibits a marked improvement in strategic learning as they participate in the capstone design sequence. While these students did not go through the new integrated curriculum, they were the first to be exposed to a systematic intervention aimed at developing their ability to become better self-directed learners.

5 Next Steps

The assessment results seem to indicate that the benefits of the spiral curriculum approach delivered in active learning settings may not be immediately apparent after a single semester. So one next step for this work would be to conduct a longitudinal study of students as they progress through their entire program. This would give us more information on the long-term impact of the interventions we have been conducting.

Another area for future development is to find a way to achieve greater integration of digital logic principles in the ECE fundamentals sequence. This will not be easy, given the need to accommodate Computer Science students in a single course. If we undertake this challenge, the entire ECE course sequence will have to redesigned, because there is simply no space to add significant digital design content to the existing courses.

Finally, the persistent experience of overload reported by students tells us that we need to have a second look at the collection of topics in the curriculum and make some hard choices to trim some of the less critical topics. If we are truly inspiring our students to become effective self-directed learners, we can let go of our own need to try to teach them everything we feel they need to know.

6 Acknowledgments

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