AC 2011-361: THE PORTABILITY OF SYSTEMS-CENTRIC CONTENT TO EXISTING SUB-DISCIPLINE COURSES

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The Portability of Systems-Centric Content to Existing Sub-Discipline Courses

Abstract

A multi-university, NSF CCLI collaboration has developed a series of on-line learning modules and experiential projects intended to elucidate complex, systems-oriented concepts in the context of wireless sensor networks (WSN). Together these modules and projects comprise the essential content of a complete undergraduate course on WSN. As it is often challenging to add new courses to existing degree programs, ease of portability of the developed material has been emphasized. The goal was to facilitate selective integration into existing curricula, thereby enhancing sub-discipline-specific courses with systems-centric learning. In this paper, the adoption of systems-oriented material from the WSN course into existing courses on RF/microwave theory and design at three institutions is described. One of the adopters was involved in the original development of the material, and two additional adopters were not.

One of the adopting institutions modified a course on introductory microwave circuit design, which traditionally addressed topics such as transmission line theory, network theory and design techniques for various passive components including filters, matching networks and couplers. In the revised format, each topic is now covered in the context of satellite/cellular communications sub-system design and analysis. The on-line modules from the WSN course on system design concepts have been woven into the syllabus, and links between wireless sensor networks and communications networks are discussed. To accommodate the new material, less emphasis is placed on certain specific microwave components, which are often the subject of advanced courses. Early course assessment results indicate that the introductory systems-oriented material increases student interest in RF/microwave circuit design and improves understanding of how the performance of RF hardware impacts overall system performance. Instructor feedback indicates that the modules are effective in giving students a different and broader perspective on course content and in enhancing the systems thinking emphasis in their existing courses.

In another implementation, the WSN course material was used to supplement an introductory course on RF systems for undergraduates. The material provided an alternative viewpoint on RF components used in system design and exposure to advanced RF technologies, such as RF MEMS used as switches and for re-configurability, not easily available in an introductory published text used for the undergraduates. Students viewed this additional content as very useful to exposing them to advanced topics related to future RF systems.

The three examples of porting the WSN course material into sub-discipline-specific courses are detailed in this paper, including a description of the supplementary material that was developed to effectively merge the new content. A common outcome was that these materials effectively helped students develop conceptual frameworks that enhanced their understanding of multi-layered systems. All the developed course content is available through the project website www.uvm.edu/~muse.

Introduction

The primary objective of the NSF-sponsored CCLI project in which the curricular material addressed in this paper was developed was to enhance *systems thinking* in undergraduate EE students. Specifically, the work aims to increase the understanding, appreciation and application of systems-thinking concepts by students, using wireless sensor networks (WSN) for context. The material that has been developed under this Multi-University Systems Education (MUSE) project, its assessment and various course delivery and content format aspects, have been documented in other publications[1-7].

This paper focuses on the adoption and adaptation of the course material in existing courses within the EE sub-discipline of RF/microwave circuits and systems. Within the framework of the CCLI project it was natural to package the material into a single course, titled *Wireless Sensor Network Design* that was intended as a senior-level technical elective. Eleven on-line modules comprised of over 60 video clips, were developed to address major components of WSN that span communications theory to RF hardware design. While compiling the 30+ hours of material into one course provided a useful – if not indispensable – means of organization, this approach alone is more a hindrance than a help in achieving broad dissemination of the systems-thinking paradigm into the nation's EE curricula. The simple reason for this is that full course adoption by prospective faculty at other institutions is unlikely given the difficulty of fitting a new offering into existing programs. The potential impact is much broader by enabling adoption and/or adaptation of portions of the material that fit best with the curriculum of a given department. Furthermore, as was the case in our project, a faculty team of diverse backgrounds from multiple institutions can be leveraged to instill a natural degree of flexibility in the original content development. The creation of instructional aids that complement the material and provide guidance to adopting instructors is also enriched. In many ways, the examples discussed in this paper parallel the so-called *mash-up* approach[8] for electronic textbooks that enables instructors to piece together custom books using chapters from multiple sources.

In the following sections three cases of adoption/adaptation of the MUSE materials into existing, EE sub-discipline courses are described. They exemplify steps that can be taken to efficiently enhance courses with systems-thinking content, and assessment of the improvement in student understanding of systems concepts is reported in each case.

Case #1: Adoption of MUSE Systems-Centric Material into RF/Microwave Circuits I

Department Profile – The Electrical Engineering Department the University of South Florida has approximately 200 undergraduate students and 25 faculty members. Every student is required to take a 2 credit-hour laboratory course called Wireless Circuits & Systems Laboratory, which is typically done in the junior or senior year. Thus, all students have some background in RF/microwave theory that is relevant to the WSN theme of the MUSE modules. However, the program allows for only two technical electives and there are no courses in the current EE curriculum that address systems-thinking concepts.

Course Overview – The course sequence into which the MUSE modules were integrated is RF/Microwave Circuits I, addressing basic transmission line theory and passive circuit design (e.g. matching network and filters). The typical undergraduate enrollment in the course is 10-20 students; 10-15 graduate students are also typically in the course. This course has traditionally followed a conventional approach of presenting the relevant theory and design techniques, with little attention given to how components fit into multi-layered systems or how large-scale application considerations impact technology/design directions.

Utilization of MUSE Modules – The decision to integrate systems-thinking concepts into the existing course via introduction of the MUSE modules provided an opportunity and motivation to restructure the entire course outline while retaining the material that provides the core fundamentals of microwave design theory. The steps taken in this restructuring can be summarized in two major parts: 1) introducing new content, based on and supporting the MUSE modules, which is application-oriented and provides context to which most of the microwave design theory can be related, and 2) emphasizing fundamentals that are common to many of the topics traditionally covered in an effort to improve the students' ability for future self-learning. The latter point, in addition to having pedagogical benefits, serves to facilitate a reduction in the pre-existing course content and thus enable introduction of the new systems-oriented material.

The application-oriented context introduced into the courses focused on a comparison and contrast between cellular and satellite communication systems (Figure 1). These are two systems that are very familiar to students and, from a simple block-diagram perspective, share much in common. There are, however, significant differences that have a substantial impact on the technologies and design practices used for the constituent components – power, cost, reliability and environment (signal propagation characteristics) are dramatically different. At the same time, there are fundamental performance parameters shared between the two systems, such as noise and linearity that have a pervasive influence on system and component level design.

- **Two main components:**
  - **Cellular: hand-sets and base-stations (towers)**
  - **Sat Comm: ground terminals and satellites**
- **Transmit power:**
  - **Cellular: ~1 W on hand-set, ~500 W on tower**
  - **Sat Comm: ~1 kW on ground terminal, ~100 W on satellite**
- **DC power and weight:**
  - **Cellular: hand-set – limited, tower – unlimited**
  - **Sat Comm: ground terminal – unlimited, satellite – limited**
- **Reliability:**
  - **Cellular: hand-set – low, tower – high**
  - **Sat Comm: ground terminal – high, satellite – high**
- **Antenna design:**
  - **Cellular: omni-directional on hand-sets, sector directional patterns on towers**
  - **Sat Comm: high-gain directional on ground terminal, contour patterns on satellite**

Figure 1. Comparison between various aspects of cellular and satellite communications systems.

Lecture material on these systems, in combination with MUSE modules on WSN and complex-engineered systems in general, provide an excellent foundation for subsequent course material on RF/microwave design fundamentals. For example, the importance of performance characteristics such as insertion loss, group delay, isolation, noise figure, linearity, and DC efficiency become more than just numbers when considered in the application domain. Furthermore, the foundation enables enlightened discussions on performance trade-offs when the overall system is understood.

One example of how fundamentals were emphasized in combination with systems-level perspectives relates to the subject of filtering. Traditionally, basic filter design techniques are first introduced followed by several lectures on filter transformations and methods for realization of different topologies. Much of the latter material could be easily put into practice by someone trained in the fundamentals, and is not critically vital to a solid understanding of basic microwave theory. Thus, in the revised course format the basic techniques were covered in depth and application-oriented material was delivered through the MUSE modules on filtering (primarily viewed outside the classroom) that address topologies, technologies and systems-level considerations. This general approach allowed the traditional lecture material to be compressed while expanding the systems-learning content. More importantly, the mixed level of presentation (basics and applications) is expected to enhance students' retention of fundamental concepts.

Table 1 gives a comparison between the material covered in the traditional course and in the revised course that incorporates systems-concepts and the adopted MUSE on-line modules. As indicated, there is a heavy emphasis on systems concepts in the first part of the semester which is then periodically revisited as different technical topics are introduced.

Table 1. Comparison between course topics in the traditional and revised RF/microwave circuit courses. Highlighted cells indicate topics addressing systems-level thinking and concepts.

Traditional Course Format	**Revised Course Format**	
In-Class Material	In-Class Material	Outside Class Material
Course Overview	Course Overview	*GPS & Micro-Satellites*
Transmission Line Theory	*Cellular and Satellite Communications Systems*	*WSN: Environmental Monitoring and Economics of Sensing*
Network Theory	*Link Budgets*	*Complex-Engineered Systems*
Transmission Line Types	*System Block Diagrams; Noise and Linearity*	*RF Block Diagrams*
Impedance Matching	Transmission Line Theory	
Signal Flow Graphs	Network Theory	
Couplers	Impedance Matching	*Amplifier Designs & Technology*
Filters	Signal Flow Graphs	
Resonators	Resonators	
Diodes	Filters	*Filter Designs & Technology*
Mixers	Diodes	
Switches	Mixers	*Up/Down Conversion, Modulation*

Instructional Aids – The main instructional aid developed for this course was an overview, intended for instructors and students that summarizes each of the MUSE modules and describes the relationships to the course syllabus and the textbook. For example, the description of the MUSE module on complex-engineered systems states the following: *Provides an introduction to complex-engineered systems with examples that include an automobile and a biomolecular network. The module discusses layered representations and partitioning as an approach to designing and comprehending robust systems. A direct analogy to communications networks is provided, which is analogous to the different layers of the satellite communications sub-system that is studied in RF 1.*

Student Feedback on MUSE Modules - To gather student feedback on use of the MUSE modules in the RF/Microwave Circuits course, we developed a survey administered to students via an on-line link. Survey questions were designed to understand student perspectives on how the modules affected their interest in course material, and how well the modules contributed to their understanding of the relationship between RF hardware performance and overall system performance. Twenty-three students, including 5 undergraduate seniors and 18 graduate students responded to the survey.

Overall response to inclusion of the MUSE modules in the course was highly positive. The majority of students (83%) indicated that the modules increased their interest in RF/microwave circuit design. All students (100%) agreed that the MUSE modules gave them a foundation for understanding how the performance of RF hardware impacts overall system performance. Students responded to an open-ended survey question asking them to explain how the systems-oriented perspective presented in the MUSE modules applies to understanding the relationship between RF hardware performance and overall system performance. The most common student response was that the videos gave them a clear understanding of how performance of individual components affects the overall system performance. Typical student comments included the following:

> *The system-oriented perspective gives us a better idea of how the pieces come together as a whole rather than simply how the individual pieces function.*
>
> *The MUSE modules point out that the performance of each RF hardware will affect overall performance of the system. It is better to 'look forward' at the system and choose individual hardware components, than to choose individual hardware components and connect them together and 'look backward.'*
>
> *The systems-oriented perspective made it apparent that the overall system performance depends on the RF hardware performance. For example, the lower the noise of the receiver front end, the more accurately the received signal can be reconstructed to match the transmitted signal.*
>
> *The overall system performance depends fully on RF hardware performance. RF hardware is used in sensor networks, GPS, RFID. If the performance of the hardware is low then it will lead to decrease in efficiency of the overall system. The modules also made me understand how the hardware is applied at different stages of a system in order to transmit data from one block to other block. The modules helped me to understand how RF circuits are applied in various engineering systems.*

Students appreciated the systems-oriented approach to course content facilitated by the MUSE modules. Of the respondents, 96% indicated that they would like to see the same amount or more of the systems-oriented materials covered at the beginning of the semester for this course.

Students indicated that to them, "systems thinking" in engineering includes taking into account all aspects of a system when designing a solution to a problem or need. They wrote of applying skills from different disciplines, "seeing the problem from top-down", and of approaching a problem from different perspectives “to find the most optimum result or the desired result.” In this respect, the MUSE modules were a useful tool for supplementing and supporting course content and a systems-thinking approach.

Case #2: Adaption of MUSE Systems-Centric Material into EE 4607: Wireless Hardware System

Department Profile – The Electrical and Computer Engineering Department at the University of Minnesota (UMinn) has approximately 425 undergraduate students and 50 faculty members. Students join the department in their junior level to take core courses at the 3000 level. As seniors, they are allowed to choose 12 technical elective credits from courses in the 4000 level.

Course Overview –The EE 4607 course provides an introductory overview of basic hardware communication system design and the development of core components (i.e. filters, matching circuits) used in those systems. The presentation of system design is followed by brief descriptions of the core components. Extensive discussions of the core components are taught in the two 5000 graduate level versions of the course. Applications are not the focus of this course. The course pre-requisite is EE 3601- transmission lines, fields and waves and it is open to all students who pass with a C- or better in EE 3601 as a technical elective in the undergraduate electrical engineering program. The offering is once per year and averages 35-45 students per semester. Students with 3.2 GPA or better or with instructor approval can subsequently take the more advanced courses at the 5000-level with graduate students.

Utilization of MUSE Modules – The MUSE modules introduce applications and connect applications, communications, signal processing and hardware to students in the undergraduate program. UMinn does not have such a course for either applications or combined technologies. The web-based MUSE modules presented a flexible soft method for providing this exposure to students without altering the curriculum or creating a need to develop course material to address these objectives. The students were required to review the overview slides presented on the MUSE website for in-class discussion. As the course progressed, the MUSE material was used to supplement topics discussed in the course text[9]. Students were asked to review selected material presented in class and on the MUSE web-site, and to take the on-line quizzes and submit them as part of homework assignments. MUSE content was included on exams to reinforce student engagement and knowledge retention.

The MUSE material presented a refreshing way to teach the EE 4607 course at Minnesota for the faculty member and a pseudo-personalized interaction for the students with course content and material. (1) It allowed students to see that material learned in the classroom was applicable and valued at other academic institutions. (2) It provided access to a current application topic - wireless sensor networks – which the students could relate to better than the conventional 20 year old topics in textbooks. (3) It also helped the faculty member create a diverse learning environment for her students that expanded on an in-class course, with notes, a textbook, and one faculty member’s viewpoint on the subject to an on-line course with active learning activities (on-line quizzes) and interactions with multiple faculty viewpoints from around the United States. For example, when a student had a question about one part of the module the direct interactions between myself (faculty member) and MUSE faculty provided near real-time feedback to student questions. This is not typical of interactions between authors in a text and instructors using a text.

This seemed to provide a more personalized feel to the learning experience. Overall, the MUSE material was well-received by UMinn students taking EE 4607 in Spring 2010.

Additional Instructor Feedback on Use of MUSE Modules. In a structured interview with the external evaluator for the MUSE project, the instructor for this course provided additional feedback on the use of the modules. The instructor felt that the MUSE modules enhanced the course in a number of different ways. Use of the modules provided students with a perspective different from the instructor's and allowed for more in-depth exploration of the material to "inform at a more elevated level" than what she had provided as an introduction to the topic. Related to this, students appreciated the advanced level of the discussions stimulated through use of the modules. Additionally, the MUSE modules provided real-world connections to current technology and its uses. She noted, "The section on filters used in the marketplace was fascinating to the students. I liked how it walked them through the details and let them hear someone describe it." Use of the modules reinforced student learning through a progression that included 1) learning about the design, 2) reading about it in a textbook, 3) watching the module for a more in-depth explanation, and 4) informing on applications in the real-world. This sequence allowed for a "big picture" view of the content covered in the modules.

This faculty member noted a few areas where portability of the modules could be improved for instructors at other institutions. She suggested that the MUSE website include a section for instructors on how they might use the modules to either create a complete course on wireless sensor networks, or integrate the modules into existing courses. She suggested that the website include a "map" of the modules, experiments and materials that an instructor could review to see how best to integrate the modules into courses for supplementing and enhancing content. This section of the website could also include mapping the MUSE modules onto commonly used textbooks to enhance use and portability.

To enhance student learning and engagement, she suggested a student section of the website that would provide students with resources for viewing the modules including guidelines for pacing the material and a series of homework problems or questions for students to answer after viewing portions of the module.

Case #3: Adaptation of MUSE Systems-Centric Material into Microwave Engineering

Department Profile – The Electrical and Computer Engineering Department at the University of Hawaii (UH) has approximately 200 undergraduate students and 20 faculty members teaching courses in the computer, electrophysics, and systems tracks. Every student takes courses in all three tracks, and chooses two technical electives for depth and another two for breadth. Although "systems" is one of the three tracks, it focuses primarily on signal processing, communication theory, and feedback/control, and is not truly geared toward "system thinking" in the same way that we have been referring to it in this paper. The course in the EE curriculum that could come closest to addressing systems thinking is the Capstone Design course for seniors, but there is no uniformity in treatment of systems thinking since no one faculty member teaches this course. Rather, individual students find an individual faculty member to supervise the course, and whether or not "systems thinking" is involved depends on the actual project.

Course Overview – The course sequence into which the MUSE modules were integrated is Microwave Engineering, which is similar in scope to the course described in Case Study #1. The typical enrollment is 10-15 undergraduates and 2-3 graduate students, and in almost all cases they are already within the electrophysics track. The traditional content is similar in nature to that shown in Table 1, but with amplifiers and oscillators replacing diodes, mixers, and switches. The hallmark of the course is a 5-week take-home final exam in which students have to do a paper design of communication or radar system involving a transceiver RF front end. Thus, even before adaptation of the MUSE modules, this course emphasized systems thinking to some degree.

Utilization of MUSE Modules – What the existing course lacked, however, was more than cursory coverage of the wireless communication channel, digital modulation schemes, and network architectures since these topics are covered by faculty specializing in these topics in the systems track within our Department, rather than the electrophysics track in which this course was taught. Adopting MUSE modules that covered these topics allowed electrophysics track students to get a deeper exposure without them having to take a whole course in those topics.

Coincidentally and fortuitously, a new textbook[10] appeared on the market at the same time that the course was being modified, and it dovetailed with the MUSE philosophy as applied to microwave engineering. Thus, students were able to read a textbook chapter, e.g., on digital modulation, and listen to the corresponding MUSE module all on their own time and without having to rely on in-classroom teaching on that subject.

Additional Instructor Feedback on MUSE Modules – The faculty member teaching this course indicated in a structured interview that the modules worked well by providing flexibility as to when and how they could be integrated into the course. He commented, "*Faculty members often have unavoidable travel schedules that prevent their presence in the classroom, forcing them to either re-schedule the class, find a substitute instructor, or schedule an exam on the travel day. Having a repository of stand-alone MUSE modules offered great flexibility, as those modules could be assigned on travel days.*"

He also felt that the modules reinforced a systems-approach to the course content. He commented, "*I like teaching students from the systems perspective. I chose the text for this course because it was systems oriented. The MUSE materials stress the systems approach and that made it work well together with the text.*"

With respect to improving the materials, the instructor indicated that providing challenging homework problems that students could work through while viewing the modules could enhance the modules. He noted that the modules were long and having homework problems could increase interest and enhance the learning to promote student engagement.

Student Feedback on MUSE Modules. We gathered student feedback on the MUSE modules through course surveys and a focus group interview with the six students who took the course. In surveys and in the interview students indicated that they liked the flexibility of viewing the modules on their own time. One said, "*You can watch the videos at your own pace and you can rewind and re-watch the parts you don't understand*." Students noted, however, that watching the videos separate from class meant that interaction with the instructor was absent. Subsequent in-class discussions with the instructor allowed them to ask questions and to get clarification on any concepts that were confusing and provided an overview of the key points of the module.

Students commented that the quizzes built in to the modules were helpful for their learning. Like their instructor, they indicated that more in-depth assignments to go along with each module would "*make it more interesting and break up the lecture*" as well as reinforce the learning. With respect to interest and understanding, students commented in the interview that the modules "*gave a good sense of what systems engineering is*" and raised their interest in the communications aspect of the course. Introductory modules were helpful in giving the "big picture", but as the modules got more detailed, one student noted this was less true.

Conclusion

We have presented three case studies illustrating how materials developed for a stand-alone course on wireless sensor network design can be incorporated in core EE classes with the objective of helping students develop *systems thinking* skills. The on-line format and modular organization of the materials enables portability to diverse instructional environments at different universities. Assessment results indicate that from both student and faculty viewpoints, these materials can enhance specialized courses by providing a broader perspective on the roles of technologies in overall system design.

In each of the case studies, the adopting instructor was required to sort through the MUSE modules to find appropriate content for his/her course. As indicated in the feedback received, this extra effort could be a roadblock to portability. In response, we have revised the project website to incorporate example syllabi illustrating how the MUSE content can complement core courses typically found in the junior year of EE curricula.

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