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LEVERAGING MULTI-UNIVERSITY COLLABORATION TO DEVELOP PORTABLE AND ADAPTABLE ONLINE COURSE CONTENT

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ABSTRACT

Individual faculty and institutions regularly develop novel educational materials that could benefit others, but these innovations often fail to gain traction outside the developers' circle as barriers to adoption are numerous. We present evidence that development targeting adaptation, rather than complete adoption, of innovative materials and methods may be a more successful approach. Specifically, if faculty members from multiple institutions are involved in the development, agility across diverse academic requirements and institutional cultures informs that process. In the described example, faculty members from multiple institutions developed online learning modules based on their individual areas of expertise related to the topic of wireless sensor networks. The modules integrated learning of systems thinking with traditional sub-disciplines in electrical and computer engineering and were delivered in a blended-learning format. While faculty from three institutions developed the original content for a single course, materials have been successfully utilized in multiple courses at several institutions.

Keywords: Systems thinking education, Multi-university collaboration, Blended learning

INTRODUCTION

Our nation spends significant resources to continuously improve STEM education. For example, NSF's Division of Undergraduate Education, one part of its Directorate for Education and Human Resources, spends approximately $290M annually. Expectations for transformation of undergraduate STEM education have not been met, however, since new techniques, tools, and paradigms are not easy to integrate into curricula beyond the institutions involved in the development process [1]. Faculty members cite situational factors that prevent them from implementing new methods or materials into their teaching [2]. These factors include lack of time to explore and implement new teaching strategies and materials, pressure to "cover the material," and constraints on student time. Faculty also report lack of resources at the departmental level; this can also inhibit the adoption of new materials [3].

In this paper, we argue that the diffusion of innovative educational practices should be addressed as an intrinsic part of their development. First, we propose that the goal should not be *full adoption* of innovations, but *adaptation* (including partial adoption) of them to use in existing courses. The goal of full adoption is often unattainable because restructuring at the course level is too disruptive. In addition, curricula and course content vary from institution to institution and thus so does the background and knowledge base of students. Thus, we should *design for portability*, so that learning resources can be easily modified and adapted to local environments, increasing the likelihood that curricular innovations will be used [5]. Second, innovations in education are often developed within the unique environment and culture of a single institution, and where faculty and administrative buy-in follow from the external funding.

This paper describes the Multi-University Systems Education (MUSE) project, involving the participation of electrical and computer engineering faculty from four universities (University of Vermont (UVM), University of South Florida (USF), Northern Arizona University (NAU), and University of Hawaii (UH)), each with a different mix of educational missions, cultures, and student demographics. We present the development and delivery of new curricular content related to systems thinking and wireless sensor networks, and its adaptation at multiple universities to enhance existing electrical engineering courses such as electromagnetics, radio frequency (RF) circuit design, communication systems, and embedded systems.

DESIGN FOR ADAPTATION

Reform of higher education is the topic of the day, with a spate of books and an avalanche of coverage in the popular media. The most attention has been given to high-profile institutions and consortia (e.g., EdX, Coursera) whose massively open online courses currently target students not at the partner institutions and not seeking degrees. On the other hand, many colleges and universities are offering on-line courses to their own degree-seeking students, driven by the hope of simultaneously reducing costs and improving learning outcomes. All these approaches attempt to increase geographical reach and/or to capture students for the offering institution.

Institutions are also starting to offer courses using a blended-learning [3] or inverted classroom [4] approach that combines face-to-face (synchronous) classroom instruction with on-line (asynchronous) learning and reduced classroom contact hours. This approach combines discussion and social learning in the classroom with technologically enhanced learning experiences outside of classroom time. Studies of blended learning methods have shown that student learning in these environments equals or exceeds performance in fully on-line or traditional face-to-face environments and results in a more flexible learning approach for students [17, 5, 6].

While MUSE also uses the blended-learning paradigm, its design emphasizes attributes that promote diffusion [7, 8] of innovations (of, in our particular case, the learning of systems thinking in ECE) to other institutions. First, the MUSE approach focuses not on students, but on faculty who are interested in course innovation via integration of new material and learning experiences. Second, most initiatives have targeted *adoption* of content by other institutions at the level of curricula or courses. These approaches are disruptive, often requiring buy-in at the department level, where dynamic conservatism of social groups is expressed as resistance to change [9]. To enhance portability, MUSE was designed from the outset for *adaptation*: One-week MUSE learning modules enable instructors to select specific on-line content for integration in existing courses, enabling course evolution rather than replacement via wholesale adoption.

MUSE explicitly recognizes that the student's learning context—including institutional mission and departmental history, expertise and culture—matters. The blended-learning format used in MUSE enables an instructor at one institution to use in-class activities to provide tailored course- and program-specific context for the on-line content, since they are aware of what students already know from their previous coursework. A relevant example where students at different institutions can have different learning experiences is in the type of computer-aided engineering programs that are in common use; in the MUSE project some institutions emphasize circuit-intensive tools for the wireless courses whereas others emphasize systems-intensive and mathematics-oriented tools (e.g., Matlab). The MUSE curriculum was developed in recognition of these differences and flexible tools were utilized that bridge this circuit-to-systems gap.

MUSE emphasizes authentic learning experiences [10] in the in-class portion of the course, consisting primarily of hands-on experiments and course projects defined by student teams. The experiments range from software simulation of microwave devices and communication links, to programming embedded system hardware, to integrating transducers with a wireless sensor platform. That is, the experiments provided both opportunities to apply techniques either first learned in the *WSN Design* course or to apply in a new context material they may have studied in an earlier course. In course offerings so far, projects have included a wireless HVAC control system, a snow-depth monitoring system, and development of a multi-hop routing protocol for wireless sensor networks.

The MUSE project is also based on *collaborative* course development *across institutions*. In this model, faculty members with diverse areas of expertise work together in developing content, maximizing the effective use of limited resources. Collaboration can also reduce faculty time for course development while increasing the quality of the classroom experiences for students [11, 12, 13]. In addition, involving multiple institutions significantly broadens access to faculty expertise beyond that which is readily available on a single campus. Multi-institutional collaboration may also alter the development process itself, such that the new content captures the needs of diverse departments, further increasing the probability of adoption. While this outcome is not addressed in our work, learning about the unique aspects or needs of other departments and their students may encourage creativity and risk-taking in developing new approaches to teaching and learning [14].

WIRELESS SENSOR NETWORK DESIGN COURSE

As engineering students progress through their studies, their courses typically become increasingly specialized. While such specialization provides focused learning of specific topics, the trade-off is limited opportunity to integrate topical content and little understanding of the contextual issues driving the technologies. Recognition is increasing that engineering students should, as part of their undergraduate educations, construct “a proper intellectual framework within which to study, understand, and develop large, complex engineered systems” [15] since today’s problems require not only specialization but also systems thinking skills, i.e., the ability to envision architectures of complex-engineered systems, their underlying principles and how they impact our world [16, 17].

The topic of wireless sensor networks (WSN) coherently integrates a range of technical topics and motivates awareness and learning of systems thinking. As illustrated in Figure 1, WSN not only serves as a vehicle for studying an array of electrical and computer engineering (ECE) sub-disciplines

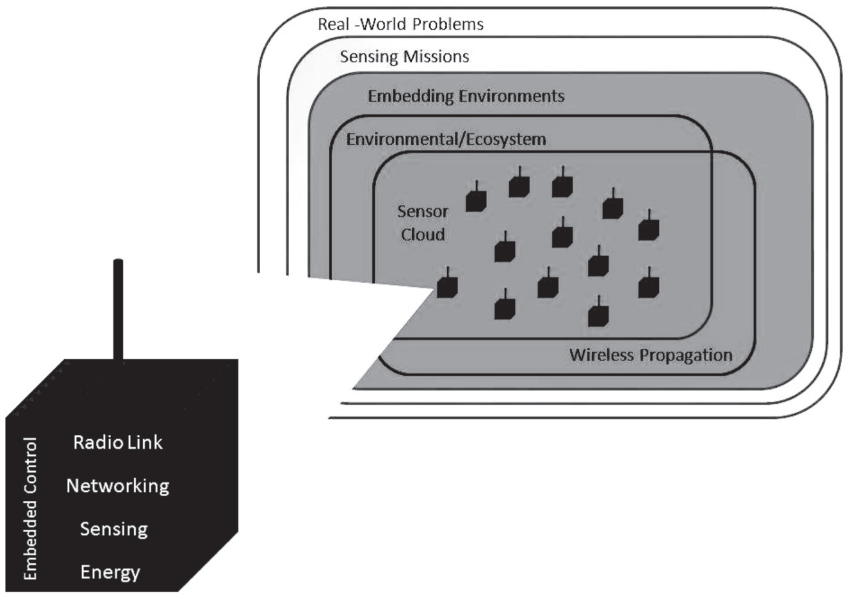


Figure 1. Wireless Sensor Networks as an Example of a Complex Engineered System

such as sensors, embedded systems, wireless communication circuits and systems, networks and energy efficiency, but also serves as an example of a complex engineered system in which these topics are highly interrelated and in which the system design is influenced by factors external to the technology (e.g., overall sensing mission, deployment environment, etc.).

Table 1 lists the ten on-line modules (with embedded links) developed for a senior elective course: Wireless Sensor Network Design. Typically, each of these topics is taught as the sole subject of an upper-division course. The MUSE content reinforces how these diverse aspects of WSN are interrelated by introducing each topic in the context of the overall system (e.g., by regularly referencing Figure 1). Since the content is broad, collaboration of multiple faculty members from the different institutions provided the breadth of expertise needed as well as a means to test the materials in multiple learning contexts, ensuring easy and ready use by other instructors. Each module was developed by a single faculty member based on a course plan developed by the team, and the content and presentation were refined based on feedback from the team during development and following pilot offerings at the different institutions.

The course content was selected and presented to accommodate the background of students from the different institutions. For example, UH and USF students' background in microwave systems is far more extensive than that of students at either UVM or NAU, whereas UVM students have

Module	Label	Title	Developer
1	[MOT]	Overview: Why Wireless Sensor Networks?	Joint
2	[SEA]	Systems Engineering Applied to WSN	NAU
3	[TDX]	Transducers	USF
4	[ADC]	Analog-to-Digital Conversion	NAU
5	[EMC]	Managing the Sensor: Embedded Computing	NAU
6	[CTA]	Communication Theory Applied to WSN	UVM
7	[RFH]	Radio Frequency Hardware	USF
8	[WCC]	The Wireless Communication Channel	UVM
9	[SNA]	Sensor Network Architectures	UVM
10	[FIN]	Bringing It All Together – Examples	Joint

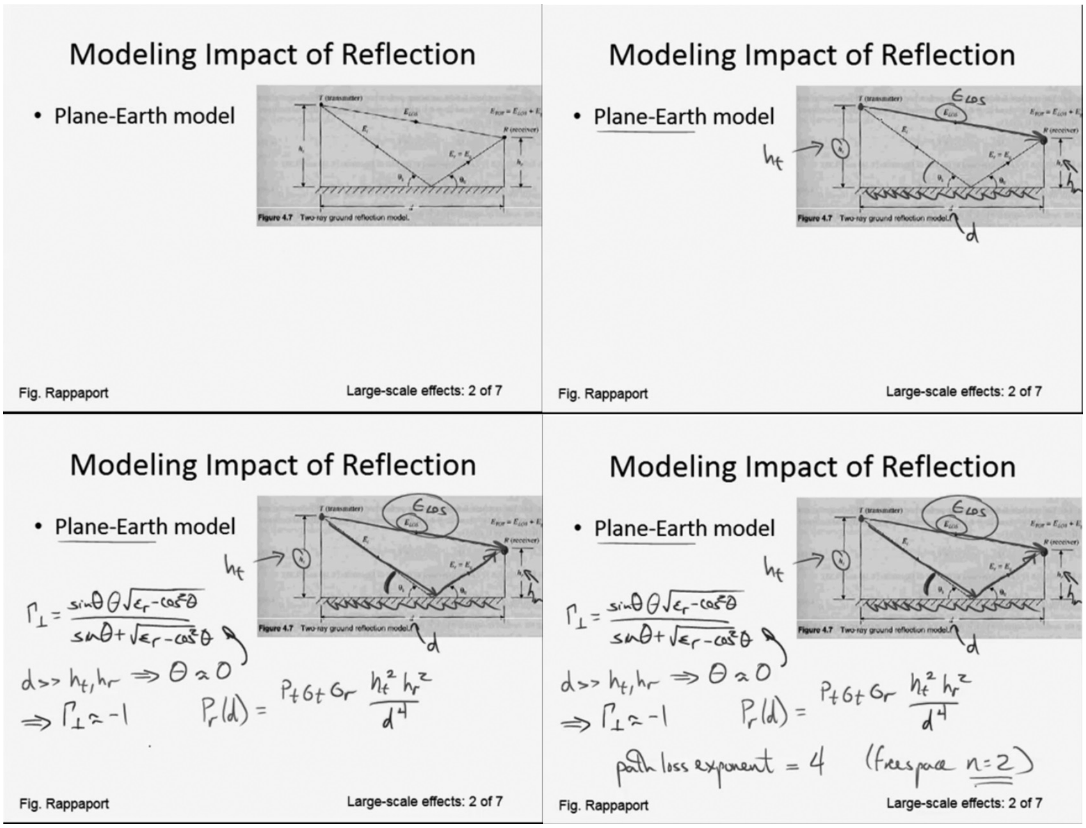
Table 1: Online curricular content for WSN Design course

more extensive communication systems experience and NAU more embedded system experience. As such, the content begins with fundamentals but extends through the unique application of the theory to wireless sensor networks. Even students that are familiar with the subject matter find new applications for the techniques and, more importantly, improved understanding of how design choices are influenced by other subject areas. With this approach, content developed for, as an example, the [RFH] module provides new insight for students studying microwave systems as we illustrate in detail in the next section.

Each module consists of several video clips, each detailing a different aspect of the module's topic. In total over 60 video clips comprising over 30 hours of on-line instruction were created. Video clips for the modules were developed using Tablet PCs and screen capture software (TechSmith's Camtasia Studio) [18]. The developer first created a series of PowerPoint slides outlining the subject matter. These slides were saved as a Microsoft Journal document for subsequent inking. With the Journal document opened, a Camtasia screen capture window was set up and recording initiated. The recorded video captured both the inking of the Journal slide and the audio of the instructor discussing the content. This process enables images to be annotated, allows for natural development of equations, and use of color to highlight specific concepts (Figure 2).

ADAPTATIONS OF MUSE CONTENT

In the following two sections, we detail three cases of adaptation of the MUSE materials into existing ECE courses. These cases demonstrate the success of the design for portability approach and



Note to printer: video link - http://www.uvm.edu/~muse/modules_h264/%5bWCC%5d%20The%20Wireless%20Communication%20Channel/3-03%20Large-scale%20Phenomena%20and%20Models.mp4

Figure 2. Evolution of an Example Slide from a MUSE Video from the [WCC] Module. Full video [26:18] provided below.

its ability to efficiently enhance a range of courses with systems-thinking content. Example syllabi for other implementations for a course in [RF/microwave circuit design]() or [wireless communications]() are available. Table 2 illustrates the timeline related to the diffusion of these materials.

Case #1: RF/Microwave Circuits

Department Profile – The Electrical Engineering Department at the University of South Florida (USF) 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* 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

Institution\Term	FA'08	FA'09	SP'10	FA'10	SP'11	FA'11	SP'12
NAU	**Adopt**	**Adopt**		*Adapt*	*Adapt*		
UVM		**Adopt**			**Adopt**	**Adopt**	
USF			*Adapt*	*Adapt**	*Adapt**	*Adapt**	*Adapt**
UH**			**Adopt**			*Adapt*	*Adapt*
UMN**			*Adapt*				

*** Utilized by non-developing instructor**
**** Utilized by non-developing institution**

Table 2: Diffusion of Adoption and Adaptation of Course Materials.

technical electives and there are no courses in the current EE curriculum that address systems thinking concepts.

Though one of the course developers is at USF, the MUSE material was adapted by an ECE faculty member not belonging to the cohort of developers. This adaptation project thus served as a transition case between use by the developer cohort and adaptation by a non-developer institution, since barriers to cross-institutional adaptation will be of a different nature, if not necessarily higher.

Course Overview – The MUSE modules were integrated into *RF/Microwave Circuits I*, a course that addresses basic transmission line theory and passive circuit design (e.g., matching networks and filters). The typical enrollment in the course is 10–20 undergraduate and 10-15 graduate students. This course has traditionally followed a conventional approach of presenting the relevant theory and design techniques, with little attention given to how they fit into multi-layered systems or their design context.

Utilization of MUSE Modules – The opportunity to integrate systems-thinking concepts into the existing course via the MUSE modules motivated a restructuring of the course outline. The restructuring 1) introduced new content involving the MUSE modules, which is systems-oriented and provides context to which most of the microwave design theory can be related, and 2) emphasized fundamentals that are common to many of the topics traditionally covered in the course. As the comparison in Table 3 shows, the revised course emphasizes systems concepts in the first part of the semester, with periodic reinforcement as technical topics are introduced.

The example topic of filter design shows how fundamentals were emphasized in combination with systems-level perspectives. 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 essential 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

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*

Table 3. Comparison between course topics in the traditional and revised RF/Microwave Circuit courses. Highlighted cells indicate topics addressing systems-level thinking and concepts.

through the MUSE modules on filtering 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 assessment data strongly indicates that the blending of theory and applications enhanced student retention of key concepts.

Case #2: Wireless Hardware Systems Design

Department Profile – The Electrical and Computer Engineering Department at the University of Minnesota (UMN) has approximately 425 undergraduate students and 50 faculty members. Students join the department in their sophomore year to take core courses at the 2000 and 3000 levels. As seniors, they are allowed to choose 12 technical elective credits from 4000-level courses over a variety of topical areas.

Course Overview – The 4000-level course, *Wireless Hardware Systems Design* provides an introductory overview of basic hardware communication system design and the development of core components (e.g., filters and matching circuits) used in those systems. The presentation of system design is followed by brief descriptions of the core components design. The average enrollment is 35-45 students.

Utilization of MUSE Modules – The MUSE modules introduce applications and connect them to communications, signal processing and hardware. UMN does not have such a course for either applications or combined technologies. The online MUSE modules presented a flexible method for providing students with this exposure without altering the curriculum or creating a need to develop new course material to address these objectives. Students were asked to review selected MUSE learning modules in tandem with material presented in class, and to take the on-line quizzes and submit them as part of homework assignments. MUSE content was included in exams to reinforce student engagement and evaluate knowledge retention.

Case #3: Microwave Engineering

Department Profile – The Electrical Engineering Department at the University of Hawaii (UH) has approximately 200 undergraduate students and 20 faculty members teaching courses in 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. The course in the EE curriculum that could come closest to addressing systems thinking is the Capstone Design, but there is no uniformity in treatment of systems thinking since students find an individual faculty member to supervise the course. Whether or not systems thinking is involved depends on the project. UH was part of the four universities in the MUSE project, but its role from the outset was to be that of an adapter.

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 undergraduate and 2-3 graduate students, and in almost all cases the students were in the electrophysics track. The traditional course content is similar in nature to that shown in Table 2, 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 complete a paper design of a communication or radar system involving a transceiver radio frequency (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 a 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 the Department, rather than the electrophysics track. Adopting MUSE modules that covered these topics allowed electrophysics track students to get a deeper exposure without them having to take entire courses in those topics.

Coincidentally and fortuitously, a new textbook [19] appeared on the market at the same time 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 watch the corresponding MUSE module videos without relying on in-classroom teaching.

Figure 3. Iterative development and evaluation of MUSE modules.

EVALUATION

Evaluation of the MUSE materials followed an iterative process from development through pilot and field testing and finally, through evaluation of the portability of the materials to courses and institutions outside of those involved in development (Figure 3).

To understand student acceptance of the MUSE learning materials and thus their viability for use by others, formative assessment (detailed in [20] and summarized here) was conducted through student surveys for each module noted in Table 1. During pilot and field testing, students from NAU and UVM rated individual modules for various aspects of quality and responded to statements about how well the modules supported their learning of key course content. Evaluators conducted student focus group interviews to gain a more in-depth understanding of student perceptions of module quality and course format. Additionally, students completed beginning- and end-of-course surveys. The following questions guided evaluation of the MUSE materials:

1. What are student perceptions of the MUSE delivery format, content and materials?
2. What are the impacts of the MUSE materials on student understanding of key content?

Pilot and Field Testing

Pilot testing occurred at NAU in the fall of 2008 with 11 students including 10 males and one female, all of whom were senior undergraduates. Pilot test findings informed revisions to the modules including: (1) rerecording of some videos to improve quality and delivery, (2) including an introductory video for each module tying it to other modules, (3) revisions to modules to emphasize systems thinking and systems view of module content, and (4) addition of hands-on experiments to supplement the modules, and (5) inclusion of a Wiki at UVM to allow for communication between students and faculty.

After revisions, the modules were field tested at NAU and UVM in the fall of 2009 with 27 students across the two institutions including 14 undergraduates and 13 graduate students of whom, 26 were male and one was female. Quality ratings across all modules increased from the Fall 2008 offering to the Fall 2009 offering on all aspects including organization, graphics, format, pace and overall quality. Field test results also indicated that the revised modules were successful in linking module content together and in making the systems emphasis more overt for students.

Students indicated that what they most liked about the blended-learning classroom format was the flexibility it allowed them in accessing course content. They appreciated that they could watch the modules on their own time and could proceed at their own pace through the material. This capability allowed them to repeat parts of the videos that they initially found confusing, something they are unable to do in a face-to-face lecture experience. Having the material in a video format helped students when reviewing for course exams by allowing them to go back to specific clips to revisit key concepts and diagrams and examples.

Evaluating Portability

As the needs of different institutions and instructors may vary widely, feedback was collected from students and instructors at each institution utilizing the MUSE materials. At USF, feedback was solicited from students (through surveys and interviews) about the integration of MUSE modules into the *RF/Microwave Circuits I* course. At UMN, the external evaluator interviewed the faculty member who used the MUSE materials in the *Wireless Hardware Systems Design* course. At UH, students completed feedback surveys and participated in a focus group interview with the external evaluator, who also interviewed the faculty member that taught the course. The following questions guided this stage of the evaluation:

1. How effectively can the MUSE materials be exported and used by other institutions?
2. What are faculty perceptions of the quality and utility of the MUSE materials for use outside developing institutions?

Student Feedback from Adapting Courses

At USF, 23 students, including 5 undergraduate seniors and 18 graduate students responded to an online survey 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.

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 appreciated the systems-oriented approach to course content facilitated by the MUSE modules. At the end of the course, students indicated that “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 optimum result or the desired result.”

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. As one student commented,

> *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 at UH provided 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. 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.

Faculty Feedback From Adapting Courses

Faculty members who integrated MUSE modules into their course felt that the video modules were useful to plug into existing courses. They found the modules easy to adapt to their courses and instruction and appreciated the flexibility to either support content they were already teaching or to supplement and "provide a different perspective" on the content. Instructors also noted that the MUSE modules were effective in helping to show a systems approach to engineering. One 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 them work well with the text."

One faculty member noted that the MUSE material presented a refreshing way to teach the course and created "pseudo-personalized" interaction for the students with course content. The inclusion of MUSE content allowed students to see that material learned in the classroom was applicable and valued at other academic institutions. The multi-university network of MUSE content developers and users helped the faculty member create a learning environment that combined the instructor's viewpoint with the perspective of other faculty from around the United States. This is not typical of interaction between textbook authors and instructors, and seemed to provide a more personalized and relevant learning experience. This approach also provided access to a current application—wireless sensor networks—which the students could relate to better than the conventional, sometimes archaic, topics in textbooks.

Use of the MUSE 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.

The faculty member at UH who integrated the MUSE modules into the *Microwave Engineering* 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 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." These findings indicate that the MUSE modules were a useful tool for supplementing and supporting course content and providing a systems-thinking perspective.

CONCLUSION

This paper presents a model for multi-university, collaborative development of curricular materials using a design for portability approach, and their use in different educational settings. A modular course design enables the adaptation of learning materials for use in existing courses, as well as full adoption. Using the modules in a full-course design or integrating them as appropriate into existing courses provided added value in multiple ways: the modules incorporate the expertise of multiple faculty members at varied institutions and provide flexibility for instructors in teaching and students in learning. The breadth of faculty involvement, with each team member providing particular insight, also enables development of modules and courses that span traditional subdisciplinary boundaries; we demonstrated this approach in a set of learning materials that emphasize systems thinking in the context of wireless sensor network design.

The three presented case studies illustrate how modular materials can be used for a stand-alone course and incorporated in upper-division ECE courses to help students develop systems thinking skills. However, the approaches presented are not unique to this discipline or the subject matter. Design-for-portability, integrating blended-learning and modular materials lowers barriers to adoption by different universities. Assessment results indicate that it enables both full-course adoption and various levels of adaptation, providing an avenue to greater portability and large-scale impact on student learning.

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