Development of a Systems Engineering Course for Multiple Delivery Methods

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Introduction and Motivation

The Department of Engineering Management and Systems at the University of Dayton delivers master's level courses in multiple delivery modes to accommodate traditional on-campus students and non-traditional working professionals. Courses are offered over a 16-week semester in a traditional classroom setting on campus and are also simulcast live over the Internet via web conferencing software. In addition, the lectures are recorded and available for later viewing through our learning management system. Recently, our university has partnered with an online learning services company (LSC) to also offer our degree program via a series of 8-week accelerated, online courses.

One of the first courses set for delivery in all three modes – live classroom, simulcast online, and online accelerated – is the Management of Engineering Systems course. In its previous format, the course topics significantly overlapped with other required and elective courses. Therefore, the department decided to revamp the course for all the delivery methods beginning with the offerings in Spring 2014. This situation allowed for the unique opportunity to develop a course from the ground up as a traditional live class, a simulcast classroom experience, and as an accelerated online class.

The redevelopment of this course is derived from the need for engineering professionals to understand the benefits of following a sound systems engineering process. This redesigned course addresses systems engineering concepts and processes and incorporates activities and tools for developing system solutions to meet customer needs. While the development of a systems engineering course is not a new concept, we have taken a unique approach to developing this course for the multiple modes of delivery. First, a common, story-line theme has been incorporated to tie together the course concepts. A series of characters, representing subject matter experts, deliver technical and non-technical content thus morphing from a traditional lecture paradigm to one that is more interactive for students. Next, the Systems Engineering Body of Knowledge (SEBoK) [1] is used as the foundational text for the course. In addition to being available to students free of charge, the SEBoK offers a common terminology, framework, and a coverage of topics that are not available in more traditional texts. Finally, active learning and experiential learning techniques [2] are incorporated into the course to facilitate learning based on the course learning outcomes [3]. All of these decisions were made and undertaken in such a way as to allow the same material and presentation of such to be delivered in all three delivery modes. This paper describes the process the faculty and web-designers used to create this new course and the techniques and the challenges associated with its development.

Course Design

Each year, the University of Dayton offers the Teaching Fellows program in which an inter-disciplinary group of faculty attends a year-long series of seminar-style discussions of pedagogical concepts and their implementation in the classroom. The program culminates with a

capstone experience in which each Fellow shares his or her "personal experiences in reflecting and making changes in the way a course is structured or delivered."[5] This year, the two texts that guided the program discussions were *Teaching Tips: Strategies, Research, and Theory for College and University Teachers*[2] and *Facilitating Seven Ways of Learning*[3]. Concepts from these texts have guided the redesign of the Management of Engineering Systems course.

Another guiding concept that has influenced the redesign of this course is that most courses in the Engineering Management curriculum will eventually be delivered in the 8-week accelerated online program. Once each course is developed, it will be offered on a rotating schedule based on the needs of the cohort in the accelerated program. The overarching plan for these courses is that they typically will be designed and developed by full-time faculty or other subject matter experts and then offered repeatedly by adjunct professors. The intent is to design and produce accelerated on-line courses that (a) have the same rigor as those taught on campus, (b) can be taught effectively by faculty other than the course designers and (c) achieve the same student learning outcomes.

Currently, the Management of Engineering Systems course is scheduled to be taught every Fall and Spring in our traditional 16-week format and two or three times a year in the accelerated, on-line format. Since the accelerated on-line courses are being designed for reuse and since the effort required to initially develop and revise such courses is expected to be significant, once a course has been produced and launched by our LSC, it is anticipated that only minor modifications will be made between offerings until the entire course is reviewed for any major required updates (typically every two or three years). Therefore, it is imperative to use an instructional systems design (ISD) model to ensure the course is developed in a way that addresses the needs of both traditional and non-traditional student stakeholders, course delivery methods, and pedagogical and andragogical considerations. Perhaps the most recognized framework in ISD is the ADDIE model which focuses on five phases for course development [4]:

- Analysis – determining course objectives and learning environment
- Design – identifying learning objectives, assessment techniques, and course content
- Development – assembling content into a final format
- Implementation – training facilitators and students on learning environment
- Evaluation – assessing both the process (formative evaluation) and the students (formative and summative evaluation)

Representatives from our learning services company worked closely with the faculty member during each phase of the course development for the accelerated version of the class. A strict framework was provided by the LSC that defined the course structure, delivery method, and user interface. Furthermore, the fact that the faculty member delivering the course may not be the person who developed the course, influenced us to initially elect to limit the amount of video or audio presentations to be incorporated by the developer into each course; we want our students to recognize each of our faculty as authoritative subject matter experts and not confuse them with multiple presenters. Some of the challenges associated with developing and producing a course within this somewhat rigid structure are discussed later in this paper.

Scenario-based Education

Current best practices in higher education support the need to shift from a traditional lecture paradigm to one that is more conducive to learning. This includes taking advantage of technology to provide experiences to students that cannot be achieved with a traditional lecture model. One major aspect of the new course is a scenario based experience in that the student is immersed into a realistic project and interacts with characters. The storyline presented is one in which the student plays the role of a new engineer working for a company that is bidding on and developing a light rail system to connect three cities. As students progress through a series of PowerPoint presentations, they are introduced to various systems engineering topic areas via different subject matter experts. These experts "talk" to the student and explain their area of expertise and how it relates to systems engineering on the light rail system. Students must occasionally answer questions during these exchanges within the PowerPoint show, which encourages engagement and provides the student with instant feedback on their comprehension of a concept or idea from the lesson. Figure 1 includes slides depicting various characters in the scenario.

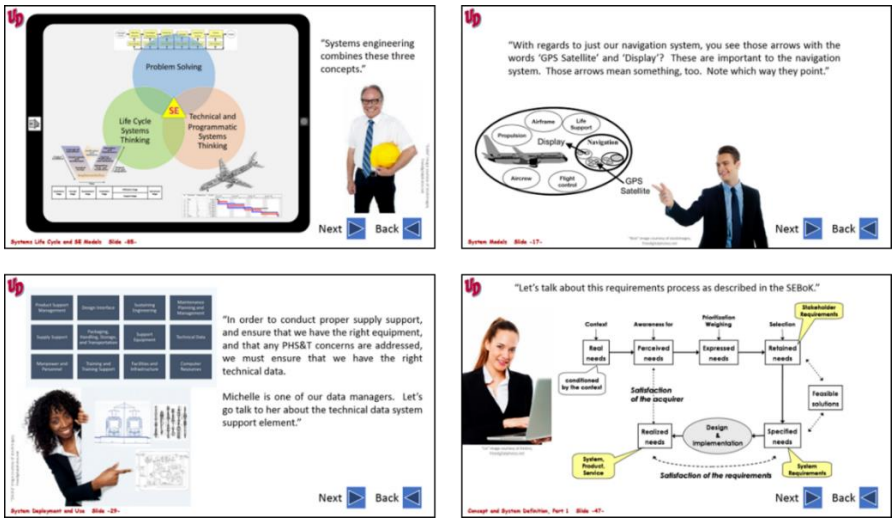

Figure 1. Characters from the Management of Engineering Systems storyline.

The use of the light rail scenario allows the various systems engineering topics to be integrated into a common theme. The scenario based education directly relates to the learning outcome associated with "practicing professional judgement"[3]. In this light rail scenario, students are given opportunities to make decisions in "complex, context-specific situations". Since many of our students are working professionals, this skill is directly transferrable into their current work scenarios.

This new scenario-based format is also used to "flip the classroom" for all delivery modes of the course. Students are expected to view the PowerPoint presentations to obtain a baseline understanding of the course material and then engage in exercises, discussions, and question driven inquiries facilitated by the course instructor, either in the classroom or online via live web conferencing sessions or asynchronous online forum postings. These methods directly address

the learning outcome associated with "developing critical, creative, and dialogical thinking"[3]. In addition to improving critical thinking, these activities are designed to allow students the opportunity to work in groups which further enhances communication skills.

The SEBoK

The decision to use the online Systems Engineering Body of Knowledge (SEBoK) [1] as the foundational text for the Management of Engineering Systems course was done for several reasons. First, an extensive review of commercially available systems engineering textbooks found that they do not adequately cover all of the topic areas of systems engineering that are covered in this course. Most of the textbooks reviewed are particularly strong on the engineering design sections, but lack heavily on requirements writing and what are often referred to as technical management processes like configuration and data management, planning, and risk management. The SEBoK, however, actually has discussions on all of these areas. Students will be provided with supplemental readings on topics that require depth not provided in the SEBoK.

The second reason we have chosen to use the SEBoK is that it is managed and endorsed by three internationally recognized organizations – the International Council on Systems Engineering (INCOSE), the Institute of Electrical and Electronics Engineers Computer Society (IEEE-CS), and the Systems Engineering Research Center (SERC) – resulting in an emphasis on the interdisciplinary and cross-functional nature of systems engineering. Given the diversity of our student body as well as the need for our graduates to function in a global economy, using a text that is internationally recognized and implemented is invaluable to our students.

Finally, the SEBoK is available to all of our students online, free of charge. With the rising cost of tuition and fees associated with post-secondary education, it is nice to offer students a reprieve in the cost of their textbooks. A quick on-line search of some of the top systems engineering texts reveal that the cost of a new systems engineering text is in excess of $100, with several books in excess of $150. Also, the fact that the SEBoK is available online offers numerous benefits. It is accessible anywhere, anytime a student has internet access. It is regularly updated to reflect the latest processes and techniques important to the implementation of systems engineering, and it is immediately accessible to students upon entering the classroom, whether that be in-person in the classroom or a distance student taking the course virtually. This eliminates the lead time associated with online ordering or requiring a trip to the campus bookstore. Upon completion of the course, students will be able to continue to use the Body of Knowledge throughout their career.

Given that the SEBoK is a wiki site and will be regularly upgraded, it is important to ensure that the course content with respect to the PowerPoint scenario presentations and assignment questions are properly managed to the current configuration of the SEBoK. With this in mind, a large majority of the content written is essentially "SEBoK neutral" in that it should be rare that changes to the SEBoK should cause changes to the other course material.

Active and Experiential Learning Activities

Once a set of course learning outcomes has been developed, it is important to associate those with a particular way of learning. Davis and Arend [3] provide a framework for identifying the method of learning that is best is suited for a given learning outcome. These are summarized below in Table 1. In the Engineering of Management Systems course, the use of the light-rail scenario described above allows students to *practice professional judgment* by *learning through a virtual reality*. (McKeachie and Svinicki [2] provide a nice overview on the essence and types of experiential learning in chapter 15.)

Course activities were selected to facilitate the most appropriate way of learning for a given course objective, including practice exercises, discussion questions, quizzes, and a group project. Whenever possible, active learning techniques are employed. These activities were also developed such that their content and delivery is as similar as possible for all delivery methods.

Examples of activities conducted both in the classroom and virtually include having students utilize SE techniques like building graphical and IDEF0 system models, creating Functional Flow Block Diagrams and Entity-Relationship diagrams, building a House of Quality, conducting system analysis, developing test plans, and creating Monte Carlo simulations. Other activities include reading and critiquing Systems Engineering Plans and doing calibration probability assessments. For assignments, students must read applicable portions of the SEBoK and submit answers to questions on the readings and PowerPoint shows. For the group project, teams must research a major technical project that failed and explain how good systems engineering could have prevented or lessened the failure. Project deliverables include both a written report and a team presentation.

Course Content

The systems engineering course is divided into four sections and each section is further divided into a series of lessons. The sections include: Introduction to Systems Engineering (lessons 0-5), System Life Cycle Management and Technical Processes (lessons 6-9), Systems Engineering Technical Management Processes (lessons 10-16), and Other Systems Engineering Topics (lessons 17-24). Table 2 below provides the lesson topics and the corresponding week of delivery in both the traditional and accelerated format.

Table 1. Seven Ways of Learning [3]

Intended Learning Outcomes (What students learn)	**Way of Learning** (Origins and theory)	**Common Methods** (What the teacher provides)
Building Skills Physical and procedural skills where accuracy, precision, and efficiency are important	**Behavioral Learning** Behavioral psychology, operant conditioning	Tasks and procedures Practice exercises
Acquiring Knowledge Basic information, concepts, and terminology in a discipline or field of study	**Cognitive Learning** Cognitive psychology: attention, information processing, memory	Presentations Explanations
Developing Critical, Creative and Dialogical Thinking Improved thinking and reasoning processes	**Learning through Inquiry** Logic, critical and creative thinking theory, classical philosophy	Question-driven inquiries Discussions
Cultivating Problem-Solving and Decision-Making Abilities Mental strategies for finding solutions and making choices	**Learning with Mental Models** Gestalt psychology, problem solving, and decision theory	Problems Case studies Labs Projects
Exploring Attitudes, Feelings and Perspectives Awareness of attitudes, biases, and other perspectives, ability to collaborate	**Learning through Groups and Teams** Human communication theory, group counseling theory	Group activities Team projects
Practicing Professional Judgment Sound judgment and appropriate professional action in complex, context-dependent situations	**Learning through Virtual Realities** Psychodrama, sociodrama, gaming theory	Role playing Simulations Dramatic scenarios Games
Reflecting on Experience Self-discovery and personal growth from real-world experience	**Experiential Learning** Experiential learning, cognitive neuroscience, constructivism	Internships Service-learning Study abroad

Table 2. Course Topics by Lesson and Week

Accelerated Program	Traditional Program	Lesson	Topic
Week 1	Week 1	0	Introduction
		1	System Fundaments
	Week 2	2	Systems Science and Approaches Systems Thinking
		3	System Models
Week 2	Week 3	4	Systems Approach to Engineering
	Week 4	5	System Life Cycle and SE Models
Week 3	Weeks 5-6	6	Concept Definition System Definition
	Weeks 6-7	7	System Design and Realization
Week 4		8	System Testing
	Week 8	9	System Deployment and Use
Week 5	Week 9	10	SE Planning
		11	Assessment and Control
	Week 10	12	Risk Management and Decision Making
Week 6		13	Measurements
	Week 11	14	Configuration Management
		15	Interface Management
		16	Data and Information Management
Week 7	Week 12	17	Reliability, Availability, and Maintainability
		18	Affordability
	Week 13	19	Human Systems Integration
		20	Safety and Security Engineering
		21	Environmental Engineering
Week 8	Week 14	22	Systems Engineering and Software
		23	Systems Engineering Standards
	Week 15	24	Business Enterprise Strategy Integrated Product Teams

Structural Challenges

Designing a single course for multiple modes of delivery has proven to be quite challenging. This section describes some of the specific challenges based on the delivery mode.

Design Challenges with Simulcast Course Delivery

In the traditional classroom, numerous techniques exist to engage students in active learning through various structured activities, but with our program, we have the added complexity of engaging students that are attending class but are not physically in the classroom. However, with the use of web conferencing software, such as Blackboard Collaborate, distance students are able to access real-time video and audio of the classroom. They are also able to participate in small group discussions using Web 2.0 tools like Skype, SMS, Twitter, Facebook, etc. Particular attention was given at the beginning of the course outlining expectations with respect to student participation.

Design Challenges with Accelerated 8-week Course Delivery

One of the biggest challenges in developing this course has been working with the third party LSC that our university has contracted with to build and manage the accelerated 8-week online courses. In order to provide a consistent learning experience, the LSC takes the approach that all courses, regardless of content, should be delivered online in one common format using the same predefined (and highly structured) framework, terminology, and development method. While this model may work well in some educational settings, it does create challenges with respect to the development and presentation of graduate-level engineering coursework.

In keeping with best practices, the authors believe that the educational content should be delivered in a mode that best facilitates student learning. Learning outcomes should be developed for a class, with the content and delivery then molded to best fit a particular way of learning depending on the desired outcomes [3]. Instructional outcomes or objectives help lay out the precise requirements for lessons, with each lesson tailored to a particular method of instruction. While our LSC does take a particularly high interest in the development and assessment of these outcomes, it seems that once these objectives are written, the structure tends to limit the developer's flexibility with respect to optimizing the delivery of the actual content material.

This became especially evident in developing the Management of Engineering Systems course. Using a cascading delivery approach of course material, the course was developed to be a sequential offering of content broken into twenty-four lessons such that subsequent lesson content and assignments would be made available as previous lessons are successfully completed. While it is acknowledged that asynchronous courses require some form of modularization of the material to be delivered on a periodic basis (normally weekly), the LSC assumed that the course material would be developed entirely as weekly modules where effectively one-eighth of the course material is presented in each week. Since the course was designed for more than just the 8-week format, this mindset of grouping material by weeks was not employed.

The LSC also provided a generic webpage shell for the classes that distinguishes "content" from "activities" for each individual week. Content primarily consists of the compendium of learning objectives, readings, and media, while activities include forum discussions, interactive sessions, assignments, and quizzes. The intent of this format is that all of the weekly content and activities are lumped into the two respective subpages. The course developer found that modifying the course from its original lesson-based structure to fit into this webpage format to be incredibly difficult, especially because each of the twenty-four lessons has its own set of objectives, readings, and assignment questions and together, they do not necessarily does not break or flow naturally within eight relatively equal subsets. However, the developer does acknowledge that learning to tailor and optimize content delivery within the constraints of the delivery system is a great skill to possess.

Future Work

The first offering of the revamped Management of Engineering Systems course is being offered in the traditional 16-week format beginning in January 2014 and in the accelerated 8-week format beginning in March 2014. As of mid-March, student response to the course is overwhelmingly positive. We plan to solicit feedback from the students through a mid-term evaluation in addition to the traditional teaching evaluations. It is still too early to make comparisons in student learning between the different delivery modes, although we do plan to assess student's performance in the course to see if there is a difference between students that take the course in the 16-week format, the 16-week simulcast format, and those participating in the accelerated 8-week format.

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