Development, Deployment, and Evaluation of Instructional Modules for Current and Future Practitioners of Model-based Systems Engineering

Abstract

A team of faculty and staff at Purdue University has received funding to design, develop, deploy, and evaluate the effectiveness of a set of vertically integrated online modules that will employ a convergent science approach along with innovative pedagogies to teach model-based systems engineering (MBSE) to current and future practitioners. The team will collaborate with industry partners, faculty at community colleges, and faculty at 4-year colleges to prepare online modules for three different audiences: practicing engineers, undergraduates at 4-year institutions, and students pursuing 2-year degrees. The project began on January 1, 2020. The team of systems engineers, manufacturing engineers, instructional designers, computer graphics technologists, and engineering educators, some with expertise in learning assessment, will share the materials developed, data gathered, and results of the analyses broadly.

Introduction

The purpose of our poster presentation will be to communicate the goals and progress made to date on the NSF project, *Development, Deployment, and Evaluation of Instructional Modules for Current and Future Practitioners of Model-based Systems Engineering.* We anticipate interacting with engineering education colleagues and potential industrial partners about the project and getting feedback on our approach.

Ensuring proper function of an engineered system or a complex product, e.g. aircraft, automobile, smart phone, or pharmaceutical, often involves many considerations that span multiple engineering and other disciplines. For example, for an automobile, attention may be given to fuel economy, handling, styling/aesthetics, cost, power, ease of maintenance, component life, durability, etc. Teams designing and manufacturing these products must not only understand the technical details required to produce the individual components but also master the tools necessary to assess how changes in any one component of the system can affect each of the others. For complex products, the traditional philosophy of iterative design, build, test, examine, and refine becomes cost and time prohibitive for discovering these interdependencies and engineering the desired product behavior. MBSE, as a relatively new methodology in systems engineering, can be used to achieve such interoperability and replace traditional, document-based system engineering [1], [2]. MBSE provides a methodical and structured approach to build a holistic model in digital space that elucidates functional, physical, and behavioral interdependencies and guides the entire product life-cycle development and engineering.

MBSE is defined as “the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases” [3]. MBSE delivers a holistic approach that connects digital representation of system models across system life-cycle stages including manufacturing and production. The benefits of employing MBSE practices include decreased project risks, shorter lead times and decreased development costs (by avoiding the

traditional design-build-physical test-learn process), and higher product quality. Moreover, while the use of simulation models was once largely limited to large manufacturers, there is a growing interest in pushing MBSE down through the supply chain to smaller manufacturing suppliers. A recently conducted survey of MBSE adoption shows that 50-75% of respondents note improvement across all systems engineering activities as a result of MBSE [4].

A workforce that is able to leverage the benefits of MBSE in the design of products, processes and systems is necessary for manufacturing enterprises to improve their efficiency. Despite the abundance of available engineering and manufacturing workers in the U.S., companies continually struggle to hire qualified employees for existing MBSE-related jobs. This lack of qualified employees which limits the efficiency and productivity of companies and hinders economic growth can be attributed to the shortage of course work and instructional methodologies for teaching and developing an MBSE skillset.

Our multi-disciplinary team, consisting of system engineers, manufacturing engineers, instructional designers, computer graphics technologists, and engineering educators, seeks to design, develop, deploy, and evaluate the effectiveness of a set of vertically integrated online modules that will employ a convergent science approach along with innovative pedagogies to educate current and future MBSE practitioners. Online modules for employees already in the workforce, students at four-year undergraduate institutions, and students at 2-year community colleges will be developed to serve a large group of learners with different knowledge backgrounds and learning needs.

Project Objectives

The overarching objectives of the proposed project are to:

1. Develop, deploy, and evaluate a series of vertically coherent online educational modules that will provide effective instruction in the focal area of MBSE and associated workforce skills for practicing professionals and future practitioners.
2. Make both the process for assessing effectiveness of the instructional modules and the de-identified data gathered during the project available to other researchers.
3. Ensure that the materials and methods developed during this project reach a large number of current and future members of the workforce.

To achieve the objectives listed above, the module content needs to be aligned with industrial needs and relevant academic degree curricula. Each module will be designed around a specific set of technical and workforce learning outcomes with each activity, assignment, or quiz question linked directly to one or more learning outcomes. Means for students to receive recognition will be identified for individual or groups of modules. The recognition can be in the form of a certificate, continuing education units, academic credits, badges, etc. The design for each module needs to be suitable for students from diverse backgrounds while engendering a sense of belongingness in the course and technical field for all students.

In addition, two introductory webinars will be developed to increase the effectiveness of the modules. One webinar will provide instructors with training on the innovative pedagogies used in the modules and helpful tips for teaching these modules. The other introductory webinar will

familiarize learners with tools used in online learning and equip them with strategies for successfully completing the MBSE modules.

Any academic credit-bearing or not-for-credit courses developed under this program and taught at Purdue will be made available to others under Open Education Resources (OER) to achieve Objective 3 for at least 5 years after the initial deployment of the courses. Articles written on this project will be published in journals and conference proceedings to share the results of our research.

The research questions for this project and the data sources required to answer these questions are listed in Table1.

Table 1. ***Project Research Questions and Data Sources***

Research Questions	Quantitative Data	Qualitative Data
How does applying a three-pronged approach (community of inquiry, social learning theory, and experiential learning) support online engineering learners to acquire deep levels of understanding and skills in MBSE?	1. Assessments that measure complex engineering competencies – MBSE knowledge and skills 2. Use of course materials	1. Learner artifacts (assignments) 2. Recordings from group meetings (if approved and acceptable to participants)
To what extent does a three-pronged approach support online engineering learners' sense of belongingness in their MBSE program?	Belongingness Survey data of Social Connectedness and Social Assurance scales [5]	Open-ended questions in end of course evaluations
When applying a three-pronged approach, what types of learning and belongingness patterns emerge for diverse groups of engineering learners in an online MBSE program?	Learners use of materials triangulated with Sense of Belonging and learning outcomes, and learner grouping	

Activities under this project include collaborating with industry representatives and faculty to identify essential knowledge and skills for practitioners of MBSE, assembling those topics into modules and submodules whose successful completion can lead to credentials for professionals and students, and preparing a set of specific learning objectives for each module. Next the team will develop, pilot, assess, revise, deploy, and evaluate a set of online modules using innovative pedagogies to engage a diverse group of professionals and students. In addition, the team will develop a pair of webinars to familiarize faculty members with new online technologies and pedagogies utilized and provide students, especially those unaccustomed to online learning, with an introduction to the tools and technologies utilized and effective strategies for mastering material presented online.

Current Work

The team has begun to identify specific topics to be included in the MBSE curriculum through interviews with industrial partners and searching peer-institution curricula. As of January 20, 2020, our team had spoken with eight people at three partner corporations who have further validated the need and demand for a vertically integrated program of MBSE education. Discussions with industry partners has revealed that it is useful for all employees involved with

manufacturing and upper management, to be familiar with the concept of model-based systems engineering, while design engineers must be able to apply the concepts. Some companies want their employees to learn how to use specific software while others prefer to teach specific tools themselves. In addition, we have reviewed ten MBSE-related programs offered on-campus or online by various organizations and found limited simultaneous coverage of the three intended audiences, i.e., practicing engineers, undergraduates at 4-year institutions, and students pursuing 2-year degrees.

A preliminary list of key topics taught at various universities and important to our partners is presented in Table 2.

Table 2. ***Programs and Topics Covered.***

Topic	MIT	Coursera	Caltech	edX	John Hopkins	Georgia Tech	Purdue	Missouri S&T	AFIT	Worcester Polytech
System Engineering Foundation	x	x			x		x	x		x
Risk Management	x			x						
Design & Architecture		x		x	x		x	x	x	x
Model Lifecycle	x	x	x							
MBSE Methodology	x	x		x	x	x				x
MBSE Tools & Diagram	x	x	x	x	x	x			x	x
Document Management		x				x				
Project Management	x		x							x
Business Impact		x	x			x	x			x

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