Applying Social Constructivism in Model-based Systems Engineering Online Instructional Module for Engineering Professionals

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Abstract*—This research-to-practice WIP (Work In Progress) presents the design and assessment of online Model-Based Systems Engineering (MBSE) modules for practicing engineers using social constructivism as a theoretical framework. Despite many advantages of MBSE, experts in this field are still scarce in the current engineering workforce. To address this need, an online module that will be deployed in the summer of 2020 targets practicing engineers as its learners to equip them with MBSE-related knowledge and skills. In industry, teams working on MBSE-related projects usually collaborate across multidisciplinary units. Therefore, social interaction plays an integral role in MBSE training programs. To understand how group interaction could foster learning in online engineering modules, we apply social constructivism as a theoretical framework to engage learners in meaningful interactions and facilitate the acquisition and application of knowledge. The modules will utilize deep-level, student-centered, small-group discussions, and peer review between student groups as forms of social learning in authentic engineering assignments. The assessment of the modules will focus on the effectiveness of social learning in promoting the mastery and application of content knowledge.

Keywords—online learning, Model-based systems engineering, professional development, social constructivism

I. Introduction

As technology advances, consumers have a growing appetite for products with high performance and quality. An increasing part of the manufacturing industry relies on complex systems to generate products that meet the requirements and demands of the market. Model-based Systems Engineering (MBSE), as a relatively newly developed methodology of systems engineering, provides engineers means to achieve the successful realization of these complex systems [1]. MBSE provides a product-centric, model-based approach to abstract the complexity and facilitates common understanding across multidisciplinary teams [2]. Due to this encompassing and broad scope of MBSE, a team that specializes in this field usually comprises of members from multiple disciplines. Therefore, it is essential to design MBSE training programs and courses that include aspects of communication and knowledge construction within teams of diverse technical backgrounds.

Engineers can use MBSE to improve efficiency, increase productivity, and face the ever-growing technical complexity of the products. However, companies are having difficulties hiring engineers with expertise in MBSE since the approach is a relatively new engineering subdiscipline [3]. Thus, training for engineering professionals should be the priority of industry and educational programs to equip them with MBSE-related knowledge [3], [4].

Practicing engineers, as learners, have several unique characteristics. To start with, they are usually located across the globe. Also, unlike full-time college students, professional development activities for engineering practitioners need to be more flexible to fit into their already packed and drastically different schedules. Moreover, they also tend to come from diverse technical backgrounds and have varying levels of expertise. Our research team is developing a set of online modules to allow learners to access the course content according to their own pace. We also adopt the lens of social constructivism and implement an innovative instructional design to ensure sufficient emphasis on learners' strengths.

Social constructivism emphasizes the role of social interaction during knowledge construction and application [5]. Although many online courses utilize group discussions as tools to integrate social interactions and replace the traditional lecture-capture delivery of course content, a majority of the discussions focus mainly on topics instead of learners [6]. Topic-centered discussions may result in the neglect of learners' learning circumstances, which can be immensely different, especially for practicing engineers [7], [8].

This paper presents the instructional and assessment design for an online module on MBSE for practicing engineers that will be deployed in the summer of 2020. The course will use social constructivism as a theoretical framework and focus on engaging learners in meaningful interactions to facilitate learning and application of knowledge.

II. Literature Review

A. *Model-based Systems Engineering*

As modern technology advances at an astonishing speed, the manufacturing industry becomes filled with complex, elaborate systems that involve collaboration among multiple disciplines. More factors need to be considered in these large systems, from hardware to software, from personnel to information, and from processes to facilities [9]. Apart from these factors, engineers also have to consider the interest of stakeholders. This intertwined web of factors encourages the use of systems engineering in the manufacturing industry. However, such complexity leads to misunderstanding, both within and across teams, due to the involvement of different viewpoints. At the same time, systems engineering traditionally addressed these challenges by creating documents and text-based artifacts, but the information contained in these documents is often difficult to maintain, synchronize, and assess in terms of quality [2]. Such challenges give rise to a new approach that shifts from the traditional document-centric one: Model-based Systems Engineering (MBSE).

MBSE can be defined as the "formalized application of modeling principles, methods, languages, and tools to the entire lifecycle of large, complex, interdisciplinary, socio-technical systems" [9]. Model in MBSE is defined as the representation of a system along with its artifacts. This representation can take many forms, including mathematical, logic, and physical [10], allowing the abstraction of complex systems and processes into holistic views with interdependent socio-technical factors that influence the systems in different ways. As a result, MBSE enables the transition from the traditional document-based systems engineering to a model-based new approach [11].

Due to the features mentioned above, MBSE has many applications. It can help address the issue of communicating the design and manufacturing process of complex systems to stakeholders from multiple backgrounds and reducing risks by avoiding misunderstandings among the personnel involved in this process. Since it provides a means to avoid the traditional process of designing, building, and testing a physical model, MBSE also has a greater chance of achieving higher efficiency and reducing project costs since the entire process can be moved to digital space.

MBSE was first adopted by the Department of Defense and NASA in defense and aerospace industries [9]. However, it does not stop there. MBSE has proven to have applications in other fields, such as disaster-management, transportation, automobile industry, and health-management [12], [13]. As MBSE is finding its applications in a wide array of industries, the lack of skilled professionals is becoming evident. Numerous surveys conducted are reporting that the challenge of adopting MBSE lies in the lack of training programs and skilled professionals in this field [3], [4]. Therefore, creating MBSE training programs for professional engineers is paramount in improving the efficiency and product quality of the increasingly complex systems in the manufacturing industry.

B. *Theoretical Framework*

As mentioned above, this study will use social constructivism as its theoretical framework [5]. Social constructivism is the theory of psychologist Lev Vygotsky, stating that knowledge is constructed through social interactions. Vygotsky proposed that meaning-making occurs only when the learners were able to integrate themselves into the broader knowledge community [14]. For Vygotsky, three aspects were essential in the process of learning: the individual, the interpersonal, and the cultural-historical. It was the interdependent relationship among these three factors and their combined influence that affected the cognitive development. This idea hinted at a "dialogic inquiry" between the learners and the wider context under which the learning occurred [15]. Contrary to many other theorists that focused on assessing actual development, which is the assessment that tests learners' ability to complete a task individually, Vygotsky suggested that proximal development, instead, should be the center of attention. Proximal development is what the learners can do with assistance from more experienced individuals, including instructors and more knowledgeable peer learners. Based on this suggestion, some call for the revision of the definition of "scaffolding" to make it into a bi-directional flow instead of a unidirectional process that is heavily teacher-dominated [15].

There are multiple ways to interpret and apply Vygotsky's theory as a research paradigm [15], [16]. In this paper, we utilize Vygotsky's theory as the third version of social constructivism in Prawat's work [17] since this version can address problems with dualism associated with social constructivism when the other versions cannot. Therefore, from this perspective, social constructivism theory postulates that meaning originates from an individual's mind and is further refined in the social domain by the shared knowledge from the community [17]. By this definition, we assume an active character of the learners, which resonates with other constructivism paradigms such as Piagetian and Kantian [16], and emphasizes on the role of social and cultural influences during the refining stages of meaning making process.

Some existing works provide insights into the instructional and assessment design of this study under the social constructivism framework. Woo and Reeves called for the reconceptualization of interactions in web-based courses and provided definitions for the kind of "meaningful" interactions needed to facilitate effective knowledge acquisition and application [18]. Bryceson integrated a Japanese concept 'Ba', which is a concept that focuses on the physical or virtual locations of knowledge construction, with social constructivism into scaffolding mechanisms to facilitate student learning in an online program [19]. Swan proposed to explore the usefulness of the Research Center for Educational Technology (RCET) model in the online learning environment [20].

III. Design of MODULE Content, Pedagogy, and Assessment

A. Design Overview

This WIP presents the design of content and assessment for an online pilot module to equip professional engineers with necessary knowledge in MBSE. The instructional materials consist of six vertically coherent modules in total, including introduction to systems engineering, introduction to MBSE, advanced MBSE, applications of MBSE, digital engineering and the model-based enterprise, and capstone project. The content of the modules was built in consideration of inputs from industrial partners by conducting interviews with company representatives who have expressed interest in urging their employees to utilize the modules. By contacting these companies that require MBSE professionals, we were able to acquire the content that is of high demand from the employers of our targeted learners. In addition, comparison across some of the existing MBSE online master's programs also provided our team with an initial idea about the key topics to include in the modules. Communication with manufacturing companies and comparison with existing programs eventually resulted in the overall module structure mentioned above. Then, the content in each module was developed following their sequential order. We utilize a student-centered backward course design model. The design process is circular and iterative, consisting of the following elements:

1) Identify the desired learning outcome.

2) Identify the main topics and detailed content based on learning outcome.

3) Determine the learning objective of each main topic.

4) Develop an assessment plan that aligns with the learning objectives of the main topics.

While we understand that deeper levels of learning can be achieved through discussions and groups of learners, learning materials designed for practicing engineers must also take into consideration the challenges that working professionals face. Unlike most traditional full-time students, many practicing engineers are juggling personal lives/families, and learning, with demanding work schedules. Thus, our design team limits the individual module length to be within the range of 1 to 2 Continuing Education Unit (CEU). A CEU is equivalent to 10 "contact hours", which include the time spent on watching the modules, completing individual assignments, interacting with teammates for group assignments, and reporting out [21]. In addition, our goal was to create genuine opportunities for learners to solve MBSE problems together while keeping in mind the practical challenges and time constraints the learners would have in meeting together.

To maximize flexibility, our team designed the modules to enable learners to access all course content, including the group assignment asynchronously. To promote social interactions among learners, we utilize group activities such as discussions and assignments in each module. Groups of learners are assigned based on their time zones and work contexts, where they plan to apply MBSE skills. Assignments were created for groups of learners to work on both synchronously and asynchronously to model how teams work on projects in industrial environments more closely. These design considerations allow learners to arrange their learning according to their preferences and pace, as well as provide them with structures and opportunities to communicate and exchange ideas with instructors and peers.

B. Example ModuleDesign Process

The design process for the pilot module is guided by the social constructivism defined in previous section. We plan to use authentic activities and group activities as the learning context necessary for the application of social constructivism [22] to refine learners' individual understanding of MBSE. Meanwhile, we also incorporate a suitable amount of flexibility for online learning format and the targeted learners of this course.

To demonstrate the design considerations involved in finer detail, a section of Module 1: Introduction to Systems Engineering will be used as an example. Although the modules aim to train learners in MBSE, an overview and introductory session on systems engineering are necessary, since MBSE is a relatively new approach and rooted in the broader scope of systems engineering. Table I below shows the content, learning objectives, and assessment of a part of Module 1.

TABLE I. PARTIAL DESIGN FOR MODULE 1

Module 1: Introduction to Systems Engineering			
Topic	***Content***	***Learning Objective***	***Assessment***
Motivation for SE	Case study of manufacturing failures.	Describe the importance of the interdependence of factors within an engineering system.	Group assignment
Systems	Definition	Define a system	Essay question
	Types of systems	Describe an engineering system, including the characteristics and properties in the learner's work environment	
	Environment, boundary, function, form, and interface	Given an example system, correctly describe the decomposition of a system, including the boundaries and interfaces	

Module 1: Introduction to Systems Engineering – Continued			
Topic	***Content***	***Learning Objective***	***Assessment***
Systems Thinking	What is systems thinking?	Explain why systems thinking is important for problem solving in engineering.	Essay question
	Distinctions-Systems-Relationships-Perspectives (DSRP) Mechanism	Apply the DSRP framework to understand a problem holistically	

While it is straightforward to design module videos for asynchronous online courses, designing group assignments that can offer learners the same amount of flexibility requires our team to be more creative. Take the assessment method for the first learning objective in Module 1 for an example. To stress the importance of considering factor interdependencies in a manufacturing system, we propose to introduce cases of large-scale manufacturing failures in previous years. Our instructional team will select manufacturing failure cases from a wide array of industries with various types of causes to illustrate the importance and broad application of systems engineering.

The learners are assigned into small groups based on their subject expertise and availability according to the applications of Vygotsky's zone of proximal development in the context of distance learning [22]. Each group will be provided detailed documents about one malfunction incident and analyze the possible reasons leading to such manufacturing failures. Our team hopes that through interactions within their groups and comparison between different groups, the learners will be able to realize one of the common factors leading to these failures: the neglect of interdependencies among factors.

The asynchronous format of module brings several challenges when it comes to group activities. First, for many synchronous classes, similar group activities can be conducted face-to-face through some web-based meeting applications. For asynchronous classes, however, groups will not be able to meet and have discussions immediately after the introduction of the case study. To compensate for this, we allow learners a longer time to complete the assignment and submit the assignment deliverable via online discussion platforms.

In addition, opposite to a synchronous class where instructors can provide real-time feedback and insights to emerging problems encountered by the learners, an asynchronous class does not allow instant communications between instructors and learners. To ensure that our expectations of group assignments are conveyed clearly, we plan to include precise explanations of the assignment and give an example in the instruction videos before setting learners to work on the deliverable in groups.

Finally, an asynchronous class, while offering learners more flexibility, may also increase the probabilities of uneven distributions of work among the group members. To ensure that groups are working together efficiently and dividing the workload in an equal manner, our instructional team plans to implement online peer evaluation tools such as CATME in this module [23]. CATME SMARTER Teamwork is a web-based system to improve the learners' experience involving teamwork. One of CATME's functions is to analyze data from learners' self and peer evaluations to provide instructors insights on the quality of teamwork. The learners will be asked to participate in short surveys to evaluate their experiences within the team several times throughout the duration of the module to offer the instruction team a means of monitoring the quality of teamwork and social interactions within each team.

C. Assessment Plan

Given the sample size and contextualized nature of the pilot module, the analysis of the social constructivism's effectiveness in MBSE learning for the pilot module described above will be a case study based on the applications proposed by Yin [24]. Data will be collected in multiple forms, including results from assessments that measure complex engineering competencies (i.e., MBSE knowledge and skills), use of course materials, learners' artifacts (i.e., group assignments and group discussions, etc.), and end of module surveys. Results of MBSE competencies measurement and use of instructional materials will be analyzed qualitatively while the learners' artifacts will be collected and analyzed quantitatively. Finally, these data will be triangulated with the end-of-course survey to understand learners' perceptions of social interactions in this module and the extent to which they met their original learning objectives prior to participating in this module.

Future Steps and Implications

Our research team will continue refining the content and assessment design of the modules and utilize innovative pedagogies suitable for the subject matter and online format. The pilot module will be deployed in the summer of 2020. It will be a relatively small class session consisting of learners who are currently working as engineers in the manufacturing industry. After deploying the pilot module, our research team will evaluate the effectiveness of social interactions on learners' knowledge construction and application in the context of online learning. Data on course assessments, surveys, and learners' behavior during team interactions (if applicable) will be gathered. The results of this study will provide insights on instructional design for MBSE online modules of different lengths and levels, such as two-year and undergraduate programs, to respond to the rapidly growing request for complex manufacturing systems and demand for MBSE experts in the industry.

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