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A Pedagogical Module Framework to Improve Scaffolded Active Learning in Manufacturing Engineering Education

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Abstract
Recent interest in improving pedagogical approaches in science, technology, engineering, and mathematics (STEM) fields has stimulated research at many universities. Several educational methodologies are reviewed in the context of manufacturing and through the lens of sustainability. It is found that there is a need to identify and understand the STEM educational challenges, and to assess the usefulness of existing methodologies using case-based analyses. In particular, this research aims to support student learning in manufacturing engineering through real-time process evaluations. A pedagogical framework is presented that can assist engineering educators in developing learning modules in support of this goal. The framework encompasses four steps: define the learning outcomes, create instructional resources, create active learning resources, and create a summative assessment mechanism. The framework emphasizes engagement of manufacturing engineering students in psychomotor learning, which remains a challenge due to the high cost of instructional laboratories. The framework is applied to develop a participatory pedagogy for manufacturing courses through the use of computer numerical control of manufacturing operations, and real-time monitoring, visualization, and data analysis of machine energy use. The framework is demonstrated for upper-level undergraduate and graduate manufacturing engineering courses at two universities (i.e., Computer-Aided Design and Manufacturing at Oregon State University and Precision Manufacturing at University of California, Berkeley). It is found that the framework can effectively support learning module development in manufacturing engineering education.

Keywords: Manufacturing Engineering, Learning Module, Active Learning, Participatory Pedagogy, Sustainability

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1 Introduction

The global challenges of the 21st century include energy depletion, water scarcity, and growing emissions levels (McCool and Stankey, 2004). Existing curricula and courses are deficient in training engineers to overcome the emerging manufacturing challenges through the lens of sustainability (Allen et al., 2009). Allen et al. (2009) identified several gaps in engineering curricula and courses, which include the lack of courses (e.g., sustainable engineering), the lack of engineering educators' expertise, and the lack of technical materials to support educators. Thus, there is a need to understand and address the educational challenges identified in prior work, and, subsequently, to assess the usefulness of existing engineering educational methods through case-based analyses. Case-based analysis is a bottom-up method that can be applicable in teaching environment by using practical test cases in a classroom (Quinn, 2006).

One of the key solutions to overcome the identified challenges is the pursuit of new learning approaches for engineering education (Allen et al., 2009). In particular, to address the deficiency in engineering curricula for training engineers versed in analyzing and solving technical challenges, while being cognizant of relevant economic, environment, and social issues, sustainable manufacturing must be integrated as a curricular specialization through the development of scaffolded (instructor-supported) learning materials (Kumar et al., 2005; Jawahir et al., 2007).

In addition to the continued development of novel manufacturing processes, recent interest in smart manufacturing and automated process planning supported by new technologies and standards (e.g., machine interoperability standards) has stimulated research and educational developments (Davis et al., 2015). Recent advances in manufacturing technologies and tools can address current challenges in the engineering field. Manufacturing organizations need new solutions to improve their efficiency, and subsequently, reduce overall cost through new emerging technologies. Sensors and sensor networks for process monitoring and real-time control have emerged to support sustainable manufacturing efforts (Lajevardi et al., 2014). These technologies can be adapted to the learning environment to support mechanistic understanding of manufacturing processes and process performance, in addition to familiarizing students with the application of sensor technologies and monitoring and analysis approaches.

While moving from manual assignments to computer- and machine-based activities, especially using team-based assignments, would be reflective of industry practice (Laughlin et al., 2006; Ferster, 2014), this approach faces several pedagogical challenges. Limited access to manufacturing facilities may be possible, depending on the location of the university to these resources. Yet, even if available, difficulties arise with visit logistics (e.g., student travel and availability of facility personnel), and can place a strain on the facility, especially for repeated public visits. These challenges have led to inherent disconnects between student learning environments and actual manufacturing environments. This situation demands the development of campus-based instructional capabilities to support manufacturing engineering education. Specifically, equipment and scaffolded learning materials are needed to support hands-on experimentation and analysis and real-time monitoring and control of manufacturing processes. Training of future engineers in this manner will enable the continued performance improvement of manufacturing industry beyond addressing technical process challenges, but also in addressing broader sustainable manufacturing challenges through life cycle assessment, energy monitoring and analysis, process optimization, social assessment, and other approaches.

Thus, the overarching goal of this work is to improve student understanding of smart and sustainable manufacturing at the macro and micro level and to bridge the gap between knowledge discovery and technology implementation in manufacturing. The specific goal is to develop a pedagogical framework to assist engineering educators in developing learning modules, and subsequently, supporting student learning in sustainable manufacturing engineering. The framework presented here focuses on developing active learning resources to improve participatory pedagogy and educate undergraduate/graduate engineering students in various manufacturing areas (e.g., sustainable