

## EDITORIAL

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### Editorial: Special Issue on Education and Curriculum for Smart and Sustainable Manufacturing

#### Reference

J. L. Rickli and Y. Huang, "Editorial: Special Issue on Education and Curriculum for Smart and Sustainable Manufacturing," *Smart and Sustainable Manufacturing Systems* 5, no. 2 (2021): 1–3. <https://doi.org/10.1520/SSMS20210999>

Manuscript received April 2, 2021; accepted for publication April 5, 2021; Issue published May 27, 2021.

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Smart and sustainable manufacturing are future strategies for global competitiveness by manufacturing industries. Smart manufacturing intersects operational technologies and information technologies to develop sensor networks, autonomous controls, and high level enterprise management software to enhance manufacturing operations. Implementing smart manufacturing strategies is predicted to result in step changes in efficiency and productivity, offering a competitive advantage for smart manufacturing adopters. Sustainable manufacturing incorporates environmental, social, and economic aspects into manufacturing design, operation, and decision making in order to establish a sustained competitive advantage locally and globally. Research into technical challenges has been ongoing for numerous years, but adoption by industries requires not only technical achievements in smart and sustainable manufacturing methods, but also advancements in education and curriculums for smart and sustainable manufacturing. When combined, educational and technical advancements in smart and sustainable manufacturing will contribute to an increase in adoption of smart and sustainable manufacturing methods.

The papers in this special issue of *Smart and Sustainable Manufacturing Systems* focus on advances and outcomes of traditional and non-traditional education initiatives, learning approaches, and curricula in smart and sustainable manufacturing systems. Theoretical and practical knowledge in smart and sustainable manufacturing will be critical in the future manufacturing workforce. New approaches to teaching, training, and designing programs around smart and sustainable manufacturing systems, which can have complex and multi-scale interactions, are necessary to developing these skills in the next generation of engineers. The issue welcomed submissions across a spectrum of smart and sustainable manufacturing learning approaches and engineering disciplines, including but not limited to research experiences for undergraduates and teachers, new teaching methods for smart and sustainable manufacturing, community engaged teaching elements, and new programs or curriculum development to close the smart and sustainable manufacturing skill gap.

This special issue provides an avenue to disseminate and share educational results and experiences in designing, operating, and evaluating smart and sustainable manufacturing based research experiences for undergraduate, graduate, and teacher education initiatives, learning approaches, and curriculum. In total, the special issue contains 7 papers that focus on new education methods and curriculum designs that foster knowledge and skills in smart and sustainable manufacturing. Topics within these 7 papers range from household decision making to course-based learning approaches and curriculum innovations.

Research experiences in smart and sustainable manufacturing aim to provide learning experiences that are able to incorporate the multi-disciplinary and complex system aspects of smart and sustainable manufacturing systems. Research projects can span a broad array of research topics due to the wide scope of smart and sustainable manufacturing system research, thus, these experiences can involve multiple faculty members along with discussions that aim to connect sub-topics to broader smart and sustainable manufacturing concepts. Kovalenko et al. present the design and outcomes of a Secure Cloud Manufacturing Multidisciplinary Design Program where students learn smart manufacturing through multi-semester long projects advised by multiple faculty members, graduate students, and research scientists. Upon completion, the program expects that students understand the needs and capabilities of future manufacturing systems.

Course level education approaches that aim to implement teaching pedagogies can support smart and sustainable manufacturing learning. This issue contains 3 papers that highlight advancements in course level pedagogies for smart and sustainable manufacturing system education. Amini-Rankouhi and Huang develop team-based learning approaches into a senior chemical engineering design course in order to incorporate and assess sustainability learning gains. Implementation in a senior design course allowed them to assess sustainability learning of students that already have foundational knowledge in chemical engineering and how students integrated sustainability concepts into high level senior projects required near the completion of students' chemical engineering degree. Lou et al. developed a problem-based learning approach for an advanced analysis course in chemical engineering that aims to teach advanced data analytics skills to chemical engineers using problems based on real-world scenarios. Student perceptions of the problem-based approach were evaluated, and follow-up was assessed to determine if student work benefited from the approach. Menandro and Arnab reviewed game-based teaching and learning approaches, specifically in mechanical engineering programs. More than 200 papers were reviewed and evaluated based on the gamification approach, education objectives, and fit in a mechanical engineering curriculum.

Two curricula level papers are included in this issue. These papers go beyond a single course and aim to transform entire curricula for smart and sustainable manufacturing education. Raoufi et al. developed and implemented an adaptive undergraduate curriculum in manufacturing. The curriculum contains a set of foundational courses that are supported by courses in manufacturing systems and product development. The adaptive aspect enables educators to address needs for manufacturing systems, product development, smart manufacturing, and sustainable manufacturing learning while being able to support local industry needs. Li and Lin emphasize curriculum innovations that enable the integration of manufacturing based materials and quality control standards. This NIST-supported project incorporates development for in-class and online formats.

Smart and sustainable manufacturing systems take into consideration life cycle stages beyond the scope of the factory, such as use phase and end-of-use or end-of-life phases. Browne and Moloney evaluated recycling and landfill sorting initiatives in the end-of-use stage in order to understand the effectiveness waste education interventions that aim to decrease contamination in recyclable material collection. The impact of recycling and landfill waste stream education interventions was evaluated and compared.

Smart and sustainable manufacturing education and curriculum research is an active area both nationally and globally. Developments in this area are being undertaken by a group of researchers who recognize that technical research efforts must be combined with education efforts in order to implement and integrate smart and sustainable manufacturing systems into current industry practices. The selection of papers in this issue provides a look into the state-of-the-art of smart and sustainable manufacturing education programs that are currently being developed or executed. We anticipate that academic researchers, educators, and industry organizations or professionals will be

attracted to this issue as universities aim to offer cutting edge manufacturing education programs and industries aim to attract top-tier talent with next-generation manufacturing skillsets.

We acknowledge the financial support from the U.S. National Science Foundation (Award No. 1461031 and 1950192), and we appreciate all the authors and the editorial office of the journal for their efforts in the development of the special issue.