NSF: Integrative Manufacturing and Production Engineering Education Leveraging Data Science Program (IMPEL)

Prof. Mohsen Moghaddam, Northeastern University

Mohsen Moghaddam, Ph.D., is an Assistant Professor of Mechanical and Industrial Engineering at Northeastern University. Prior to joining Northeastern, he was with the GE-Purdue Partnership in Research and Innovation in Advanced Manufacturing as a Postdoctoral Associate. He received his PhD from Purdue University in 2016. His areas of research interest include cyber-physical manufacturing, human-technology collaboration, user-centered design, artificial intelligence, and machine learning. He is coauthor of over 40 refereed journal articles and two books including Revolutionizing Collaboration Through e-Work, e-Business, and e-Service (Springer, 2015), and Best Matching Theory & Applications (Springer, 2017). He also served as a reviewer for several international journals such as Int. J. Production Economics, Int. J. Production Research, J. Intelligent Manufacturing, Computers & Industrial Engineering, Decision Support Systems, Computers in Industry, IEEE Trans. on Industrial Informatics, IEEE Trans. on Systems, Man, & Cybernetics, and IEEE Trans. on Automation Science and Engineering. His scholarly research is supported by the U.S. National Science Foundation (NSF) and industry.

Dr. Jacqueline A. Isaacs, Northeastern University

Dr. Jacqueline Isaacs joined Northeastern in 1995 and has focused her research pursuits on assessment of the regulatory, economic, environmental and ethical issues facing the development of nanomanufacturing and other emerging technologies. Her 1998 NSF Career Award is one of the first that focused on environmentally benign manufacturing. She also guides research on development and assessment of educational computer games where students explore environmentally benign processes and supply chains in manufacturing. She has been recognized by Northeastern University, receiving a University-wide Excellence in Teaching Award in 2000, the President's Aspiration Award in 2005, and a College of Engineering Excellence in Mentoring Award in 2015. An ELATE Fellow, Dr. Isaacs has served in numerous administrative leadership roles at Northeastern.

Dr. Sagar Kamarthi, Northeastern University

Sagar Kamarthi is a Professor of Mechanical and Industrial Engineering and Director of Data Analytics Engineering Program at the Northeastern University, Boston, MA. He received his MS and PhD degrees from the Pennsylvania State University. He teaches courses in data analytics and visualization. His research interests are in machine learning applications in smart manufacturing and personalized healthcare. His published over 200 peer-reviewed research papers. He received multiple best paper awards. He secured over $11 Million worth of research funding from various funding agencies. He received the 2020 University Excellence in Teaching Award, 2019 College of Engineering Martin W. Essigmann Outstanding Teaching Award and the 2016 College of Engineering Outstanding Faculty Service Award.

Prof. Martin Storksdieck, Oregon State University

I am Professor of Education and director of Oregon State University's STEM Research Center. The Center consists of a team of dedicated professionals of various disciplinary backgrounds who conduct applied research on STEM education and science engagement at the intersection of research, policy and practice, with a strong focus on equity and social justice. Prior to joining OSU, I directed the Board on Science Education and the Roundtable on Climate Change Education at the U.S. National Academy of Sciences. Currently, I serve on the Science Advisory Boards for the National Oceanic and Atmospheric Administration (NOAA) and the Leibniz Institute for Science and Mathematics Education in Kiel (Germany). I am also the Chair of Trustees for TERC, a nonprofit R&D, and serve on the board of the Tree Media Foundation. Previously, I served on the boards of the Citizen Science Association and the Visitor Studies Association.

Prof. Xiaoning Jin, Northeastern University

Prof. Xiaoning (Sarah) Jin's research focus is in the area of modeling and analysis for intelligent and advanced manufacturing processes and systems, with a specialization in diagnostics and prognostics (D&P), control and predictive decision making. Her works have been applied to a variety of industry applications ranging from automotive manufacturing, roll-to-roll printing process monitoring, precision manufacturing processes, smart operations and maintenance strategy for maritime equipment, etc. Prof. Jin's research has been sponsored through multiple federal agencies, including NSF, Manufacturing USA Institutes and industry.

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Abstract

IMPEL is a transformative workforce education and training program that addresses the current and projected skills gaps and requirements in data science in the U.S. manufacturing sector. The mission of IMPEL is to facilitate lifelong learning for the production engineering STEM workforce through designing sustainable, pedagogically proven data science curricula via modular courses with interactive online learning labs and experiential project-based learning. The planned tasks for IMPEL include an online curriculum design and development targeting professionals, undergraduates and community college students interested in advancing their skills in data science in the context of Industry 4.0 and intelligent manufacturing. The project team has accomplished several main tasks towards the goals of the project in Year 1, to be detailed in this paper.

Introduction

Northeastern University (NU), in collaboration with three Manufacturing USA Institutes, proposes to build an Integrative Manufacturing and Production Engineering Education leveraging Data Science (IMPEL) Program to address the current and projected skills gap in manufacturing which is anticipated to leave an estimated 2.4 million manufacturing positions unfilled between 2018 and 2028 [1]. This skill gap is projected to put $2.5 trillion in US manufacturing GDP at risk [1]. The IMPEL program's mission is to design, develop and deploy sustainable, online curriculum and courses to bridge the production-oriented data science skills gap among incumbent professional engineers and new engineering workforce entrants. To realize this vision, IMPEL builds on a substantial research literature in the learning sciences [2]–[5], along with Northeastern University's century-long tradition of experiential learning through six-month-long cooperative education (co-op) placements (+11,000 students/year), in which traditional undergraduates are placed in paid roles at partner companies. We seek to extend the benefits of deliberate experiential learning [6] into an online format accessible to working professionals, traditional undergraduates, and community college students.

The IMPEL program takes a convergent science approach involving the active and iterative contributions of industry and academic experts from multiple relevant disciplines, including manufacturing/production, learning science, digital education, data science, optimization, robotics and automation, internet of things and sensor analytics. The learning objectives of these courses are designed to help learners master fundamentals, develop sophisticated conceptual understanding, and hone ways of thinking that are essential to lifelong learning career success in the Industry 4.0 environment. To this end, IMPEL offers use-driven curricula that address the critical data science skill gaps of current and future workforce in production engineering. Figure 1 presents the connection between five production engineering functional areas and the data science course proposed as part of the project. Each course will have several self-contained modules.

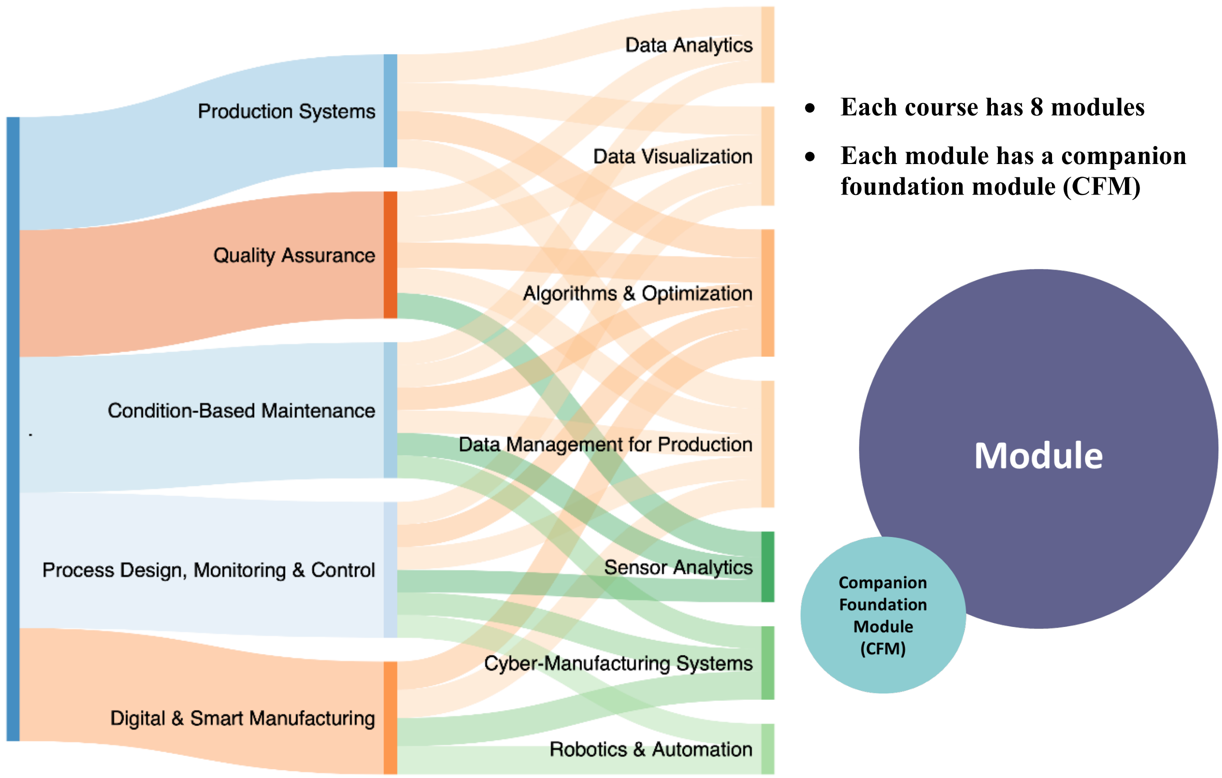

Figure 1. IMPEL focuses on five functional areas and corresponding relevant data science courses; each course has 8 modules, and each module has a companion foundation module (CFM), which makes the module independent of other modules.

The Approach and Major Accomplishments

The IMPEL program team has been working on designing the curriculum addressing the critical data science skills gap of current and future workforce in intelligent and cyber manufacturing, and production engineering. To achieve this goal, the team has conducted two parallel studies to better understand the state-of-the-art technologies and trend in academic research and the manufacturing industry. We summarize our main approaches and key findings of these two studies as follows:

Gap Analysis of Data Science Skills and Domain Knowledge Requirements in Industry: In this study, we have developed a data-driven skills gap and requirement analysis that utilizes the Emsi Labor Market Analytics data to understand the supply-demand tradeoff of critical skills and domain knowledge perceived in the U.S. manufacturing industry. Emsi is selected as the data source because it is a more comprehensive databased than those provided by sources such as LinkedIn or Burning Glass Technologies. This study aims to analyze the data science and analytics skills gap in today's manufacturing job market to identify critical technological skills and domain knowledge required for data science related jobs that are highly in-demand in today's manufacturing industry. The gap analysis provides insights for educators and employers to recognize the trends and potential of high-skilled manufacturing jobs leveraging data science and work together to train the next generation manufacturing workforce. Specifically, we have: (1) presented the overall trend in manufacturing job postings in the US including job titles, frequency, and skills requirement, (2) summarized the major skills in both market supply and demand sides; (3) identified the gaps in skills and domain knowledge in the current U.S. manufacturing job market, and (4) revealed the opportunities of (re)training workforce by accelerating data science learning to address the widening skills gap.

Application of Gap Analysis: This comprehensive gap analysis can be used to inform and guide the collaboration of academia, government, and industry to develop necessary workforce training initiatives for the transforming manufacturing sector. The study has identified and ranked gaps in hard skills and domain knowledge in four major job clusters. The implications of research findings can guide manufacturing graduates and employees to upgrade their skillsets according to emerging and future skill requirements. Well-structured skill sets would help job seekers be more competitive on the labor market and find more suitable jobs. In addition, our study discussed a broad job clusters and related job skills sets that provide the implications for designing data science related curriculums for undergraduate and graduate program. The findings of this study have been summarized in a paper to be submitted to the Journal of Manufacturing Systems.

A Systematic Review on Trends in Cyber-Physical Manufacturing Technologies and Skill Requirements: In this study, we have conducted a systematic review of the trends in data science topics in the manufacturing literature over the past two decades to inform the industry of the technology and workforce needs for Industry 4.0. This main objective is to develop a comprehensive analysis of the current state of data science and techniques in the research literature. Specifically, we developed a novel Keyword Co-occurrence Network (KCN) methodology based on network science and data mining techniques to study the evolution of research topics and data science methods, Internet of Things (IoT), cloud computing, and cyber manufacturing. The KCN methodology is applied to systematically analyze the keywords scraped from over 8,000 papers published in top-tier manufacturing journals between 2000 and 2020. The results reveal essential knowledge components and structure of the intelligent and advanced manufacturing literature. This study maps the keywords that occur with high frequency in the recent literature to potential data science courses and manufacturing functional areas. This mapping helps design course curricula to train and prepare future manufacturing workforce for emerging trends and technologies in Industry 4.0. The findings of this study have been summarized in a paper submitted to the Journal of Intelligent Manufacturing.

Conclusions

The IMPEL program builds on a substantial research literature and data-driven analysis in the area of data science, intelligent and cyber manufacturing technologies. The curriculum is comprehensively designed to cover main functional areas in production and manufacturing engineering by seven distinct courses which covers essentials for highly needed knowledge and skills for existing and future manufacturing workforce. The findings from the studies completed in the first year will be collectively used to tailor the curricula and courses, and in turn address the skills gaps of individuals in the current and future workforce through optimized modularization and customization of learning materials. The IMPEL team has completed the design and development of the first course, "Data Analytics", and would be completing the second and third courses, "Sensor Analytics" and "Algorithms for Engineering Applications" in next phase of the project.

Acknowledgement

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