Final Report

on the

Experiential Learning of Manufacturing Standards: from Lectures to Labs and Industrial Internships

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Abstract

This project, *Experiential Learning of Manufacturing Standards: from Lectures to Labs and Industrial Internships*, aimed to improve engineering students' awareness, understanding, and practical use of technical standards in the fields of additive manufacturing (AM) and robotics through structured curriculum innovation.

The project developed and implemented a three-level framework—entry, mid, and advanced—across two learning tracks: AM and Robotics. A total of six existing courses were enhanced with standards-focused modules, and one new graduate course was created. These modules incorporated lectures, hands-on labs, and project-based learning activities that integrated ANSI, ISO, ASTM, and other relevant standards. The curriculum also emphasized experiential learning through plant tours and guest speakers from industry.

To assess the impact, pre- and post-course surveys were conducted in core courses. Results showed significant increases in students' confidence and ability to apply standards in design, analysis, and manufacturing contexts. E-conferences were organized to share the outcomes of this project with faculty from over ten universities. Faculty participants reported increased awareness and interest in adopting the modules in their own institutions.

In conclusion, the project successfully met its objectives by advancing students' standards competency, supporting faculty adoption, and laying a foundation for long-term curriculum integration across engineering programs. The course materials and structure developed through this work will continue to support broader dissemination of standards education within and beyond Georgia Southern University.

1. Introduction

Engineering standards are foundational to modern manufacturing, playing a vital role in ensuring product quality, safety, consistency, and global interoperability. They provide common frameworks for design, testing, documentation, and production that enable manufacturers to meet regulatory requirements, reduce risks, and improve operational efficiency. As technology evolves, particularly in areas like additive manufacturing (AM) and robotics, new standards continue to emerge, shaping how innovation is implemented across industries.

Despite the central role that standards play in engineering practice, many students graduate from engineering programs with minimal exposure to technical standards or the process of standardization. National studies have consistently shown that standards education is underemphasized in engineering curricula, leaving a gap between academic preparation and industry expectations [1], [2], [3].

Recognizing this gap, Georgia Southern University launched this NIST-funded project to embed standards education into the core of its Manufacturing Engineering program. The project responds to several critical needs:

- Increasing students' awareness of the purpose, development, and application of standards
- Strengthening students' ability to use, interpret, and contribute to standards
- Aligning engineering education with ABET accreditation criteria, which explicitly call for the integration of appropriate engineering standards into major design experiences and technical competencies [4]

The project focused on two rapidly advancing domains—AM and robotics—where standards are actively evolving and industry demands are high. These topics were selected for their relevance to both undergraduate and graduate students and for their ability to connect theory with practice through hands-on labs and case studies.

In addition to developing standards-focused modules across multiple course levels, the project sought to promote broader adoption by:

- Demonstrating instructional use at other institutions (e.g., through guest lectures)

- Offering openly accessible course materials online
- Hosting events to engage educators and professionals

This report details the project's objectives, methods, outcomes, dissemination efforts, and long-term impact, showcasing a replicable model for integrating standards education into engineering curricula nationwide.

2. Project Goals and Objectives

The overarching goal of this project was to enhance manufacturing engineering education by integrating technical standards and standardization processes into the curriculum, with a focus on two high-impact domains: AM and robotics.

This effort was designed in response to documented gaps in engineering students' exposure to standards, as well as the need to better align academic programs with ABET accreditation requirements and industry expectations [1][2].

To accomplish this goal, the project team at Georgia Southern University developed a structured, multi-tiered curriculum framework that combines lecture-based instruction, hands-on labs, and industry-relevant projects. The project also prioritized broad dissemination of its outcomes to enable replication and long-term impact beyond the home institution.

The specific objectives of the project were:

1) Develop innovative course modules
   Create modular instructional content—lectures, lab activities, and project-based learning modules—that integrate engineering standards into existing and new courses across the undergraduate and graduate curriculum.

2) Advance students' professional and career readiness
   Incorporate industry practices and tools, such as real-world standards (e.g., ISO, ANSI, ASTM), software simulations, and case studies, to prepare students for applying standards in manufacturing environments.

3) Establish a sustainable online course structure

   Develop an open-access platform to share instructional materials, including lecture slides, plant tours, and downloadable LMS-ready course packages.

4) Promote institutional replication and dissemination

   Conduct symposiums, guest lectures, and e-conferences to introduce the course modules to faculty at other institutions of higher education (IHEs) and support their adoption.

3. Project Activities and Methodology

To achieve the stated objectives, the project implemented a comprehensive curriculum innovation model focused on two technical domains—AM and Robotics. The model was designed around three levels of student engagement—entry, mid, and advanced—corresponding to lecture, lab, and project-based modules. The methodology incorporated course design, industry-aligned instruction, faculty outreach, and experiential learning.

The project modified six existing courses and created one new graduate-level course. Each module was aligned with specific ANSI, ISO, ASTM, and RIA standards. The curriculum was structured as follows:

Table 1: Courses Modified and Developed

	Robotics Track	Additive Manufacturing (AM) Track	New Course
Entry Level (Lecture)	FYE1220 First-Year Seminar	MFGE2421 Introduction to AM	
Middle Level (Lab)	MFGE 4533 Industrial Robotics and Automation	MFGE5333 AM Studio	
Advanced Level (Project)	MFGE5331G: Advanced Robotics for Manufacturing	MFGE5334G AM of Lightweight Structure	MFGE5339G Manufacturing Standards and Standardization

4. Results and Findings

A key objective of this project was to assess how effectively the developed course modules improved students' understanding, confidence, and ability to apply engineering standards. The project team conducted pre- and post-course surveys in all participating courses.

Course Survey Results

Pre- and post-course surveys were conducted for all course modules developed or modified as part of this project, including six existing courses and one newly created graduate-level course. This section presents the survey results specifically for the new course, MFGE 6339 – Manufacturing Standards and Standardization. The course was offered in Fall 2022 and Fall 2024, with pre- and post-course surveys administered to evaluate its impact. Responses used a 5-point Likert scale (Strongly Agree to Strongly Disagree).

In Fall 2022, 8 students completed the pre-course survey and 6 completed the post-course survey. In Fall 2024, 6 students responded to the pre-course survey, and 1 student completed the post-course survey. The 2022 data showed significant improvement in students' ability to evaluate, develop, and search for standards, with agreement levels rising from approximately 50% in the pre-course responses to 100% in the post-course responses. Students also consistently indicated that the course enhanced their overall knowledge and understanding of standards. Although the 2024 post-course response rate was limited, the single response aligned with previous findings, suggesting that the course continues to deliver consistent outcomes in key learning areas.

Guest Lecture Survey Results

The project team delivered a guest lecture on *Industrial Robot Safety Standards* to 19 undergraduate students enrolled in ME 192 – Robotics and Manufacturing Systems at San Jose State University. The lecture aimed to introduce core concepts from the standards-focused robotics module developed through this project and to demonstrate how such materials could be integrated into existing coursework at external institutions.

To assess the impact of the session, students completed pre- and post-lecture surveys measuring their understanding and confidence in using robotic safety standards. The results indicated measurable improvement across all evaluated areas. Before the session, only 68% of students agreed or strongly agreed that robotic safety standards were valuable in education; after the lecture, that number increased to 94%. Similarly, confidence in acquiring safety standards increased from 26% to 47%, and the percentage of students who felt capable of interpreting robotic safety standards rose from 26% to 68%. Notably, students' confidence in operating industrial robots safely increased from 42% in the pre-survey to 74% post-survey. These

outcomes demonstrate that even a single, focused guest lecture can significantly enhance students' understanding of engineering standards and their practical relevance.

E-conference Survey Results

To support broader dissemination and faculty engagement, the project team hosted e-conference in December 2022 and 2023, bringing together educators from U.S. and international institutions. These e-conferences served as platforms for sharing course modules, demonstrating instructional materials, and discussing the integration of standards into engineering curricula. Participants completed follow-up surveys to evaluate the usefulness and applicability of the materials presented.

In both years, all faculty respondents (100%) agreed that the symposium helped them understand the value of standards and the importance of standards education. In 2022, faculty unanimously agreed that the modules were easy to adopt, but none indicated plans to implement them at that time. However, by 2023, there was a noticeable shift: 67% of participants stated they intended to adopt the modules in their own teaching, and while two-thirds agreed the modules were easy to adopt, the remaining third responded neutrally. These results suggest that with repeated exposure and practical demonstrations, faculty become more confident and willing to implement standards-based content in their courses.

5. Impact and Significance

This project has made a meaningful impact on students, faculty, and the broader engineering education community by directly addressing the gap in standards education within university curricula. Through the development of modular course content, immersive hands-on instruction, and strategic dissemination efforts, the initiative contributed to both improved student learning outcomes and increased institutional awareness of the critical role of standards in engineering practice.

At the student level, the project reached learners across a wide academic spectrum—from first-year undergraduates to graduate students—by embedding standards-focused modules into seven courses organized into two technical tracks: AM and Robotics. More than 200 students participated in either pilot or final implementations of these modules. Surveys and class feedback indicated significant gains in students' confidence and capability in applying ANSI, ISO, ASTM,

and RIA standards; performing risk assessments and design evaluations; and interpreting the structure and development of standards. The MFGE 6339 course and the guest lecture both demonstrated measurable improvements in students' understanding and readiness to apply standards in real-world scenarios. Additionally, students developed practical skills such as creating standard operating procedures and evaluating safety documentation for robotic and AM systems.

Faculty and institutional impact was also evident through e-conferences and targeted outreach events. Faculty from more than ten institutions engaged with the course modules and received training and instructional support to facilitate adoption. These participants were given access to LMS-ready teaching materials and industry-relevant case studies. Survey data collected after the 2023 symposium showed that 67% of faculty intended to adopt the modules. The project helped forge or strengthen relationships with these institutions. These connections lay the groundwork for continued inter-institutional collaboration and broader curriculum reform in engineering education.

Beyond the immediate classroom, the project contributes to ongoing national efforts—supported by organizations like NIST—to promote technical standards education across engineering disciplines. Its most significant contributions include the creation of a scalable and replicable curriculum model, the public release of instructional materials for instructors nationwide, and the promotion of experiential learning that bridges classroom theory with industrial practice. By equipping students with the ability to engage with standards in thoughtful and applied ways, this project advances the broader goals of improving product reliability, supporting international competitiveness, and driving innovation across the U.S. manufacturing sector.

6. Challenges and Lessons Learned

The process of developing, implementing, and disseminating standards-focused curriculum presented several challenges that provided meaningful insights for future work.

One of the most consistent challenges was the limited prior exposure students had to standards-related content. Many students, particularly at the undergraduate level, had never encountered engineering standards in any structured way. This required instructors to allocate additional time at the beginning of each module to cover fundamental concepts, which occasionally limited the

time available for deeper application and case studies. Despite these challenges, students showed strong engagement once they understood the practical relevance of standards.

Another recurring issue was low survey participation, especially in post-course assessments. While surveys were administered across all participating courses, response rates were inconsistent. In some cases, such as MFGE 6339 in Fall 2024, only a single student completed the post-survey, despite full course enrollment. This limited the ability to draw robust conclusions from the data in some semesters. The team identified that embedding survey completion directly into the course schedule, rather than assigning it as homework, improved participation and data quality.

There were also challenges in encouraging immediate adoption of the shared materials among faculty at other institutions. While initial interest was high during the 2022 symposium, no faculty reported plans to adopt the modules at that time. Some cited a lack of experience with the covered standards or constraints within their existing course structures. However, by the following year, faculty exposure to more detailed demonstrations and downloadable LMS-ready packages helped increase confidence, and adoption interest grew significantly.

On the implementation side, developing hands-on modules that aligned with actual industrial standards was time-intensive and required continuous collaboration between faculty, industry partners, and standards organizations. Additionally, coordinating plant tours, guest speaker webinars, and interviews posed scheduling difficulties, especially during busy academic semesters. When in-person activities were not feasible, virtual alternatives such as recorded interviews and video-based site tours proved effective substitutes.

Despite these challenges, the project yielded several important lessons. Integrating standards education at earlier points in the curriculum helped build student readiness and interest, leading to stronger engagement in advanced courses. Demonstrating course modules live during faculty events significantly increased external adoption intent. Flexibility in how the modules could be used—whether as standalone lectures or full course integrations—proved crucial in allowing faculty to adapt the materials to their own institutional needs.

7. Future Work and Sustainability

The project team has established a clear pathway to ensure that the educational innovations developed through this initiative will continue to benefit students and faculty well beyond the funding period. All course modules have been fully integrated into the standard rotation of the Manufacturing Engineering curriculum at Georgia Southern University. Courses such as MFGE 2421, MFGE 5333, MFGE 5334G, FYE 1220, MFGE 4533, MFGE 5331G, and the newly developed MFGE 6339 will continue to deliver instruction grounded in ANSI, ISO, ASTM, and RIA standards. These courses will be updated regularly to reflect evolving standards and to incorporate feedback gathered from student surveys and instructor evaluations.

Expansion to related departments is also under consideration. Faculty in Mechanical Engineering, Electrical Engineering, and Civil Engineering have expressed interest in adapting the modules for their courses. Workshops will be offered to facilitate this cross-departmental integration, ensuring a broader institutional reach. Designed to support long-term use, the site hosts LMS-ready course packages, recorded seminars, and plant tour videos, making it easy for faculty at other institutions to adopt or adapt the content.

Externally, the team plans to continue organizing e-conferences to support faculty development and encourage peer sharing. These gatherings will also serve as a platform for collecting user feedback and tracking module adoption across institutions. Industry partners and professional societies, such as ASTM and SME, will remain involved to help maintain alignment with current standards and industry needs.

References:

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