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Integrating Engineering Standards into Manufacturing Engineering Curriculum

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Introduction

Standards and standardization are crucial in manufacturing because they help to ensure consistency, quality, and safety in the production of goods. Standards provide a common language and framework for manufacturers to adhere to, making it easier to communicate and collaborate with suppliers, customers, and regulatory bodies. By following established standards, manufacturers can improve their efficiency and reduce waste, as well as mitigate the risk of defects, recalls, and other product failures. Standardization also plays a key role in facilitating international trade, enabling manufacturers to enter new markets and compete on a global scale. Ultimately, adherence to standards and standardization helps to build trust and confidence among consumers, driving growth and innovation in the manufacturing sector.

ABET (Accreditation Board for Engineering and Technology) is a non-profit organization that accredits engineering and technology programs at universities and colleges in the United States and nationwide. The ABET criteria for accrediting engineering and engineering technology programs reflect the importance of standards competence for students. Specifically, the 2023-2024 Engineering Accreditation Commission (EAC) criterion 5d states, "The curriculum must include a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work." [1] Also, the Engineering Technology Accreditation Commission (ETAC) criterion 3 states student outcomes of "an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results" (3.A.4) and "an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes" (3.B.4); criterion 5 states the discipline specific content must "Include design considerations appropriate to the discipline and degree level such as: industry and engineering standards and codes;…" [2]. By requiring education on standards, ABET accreditation helps to ensure that engineering and technology programs in the USA are producing graduates who are well-prepared to meet the needs of the industry and contribute to the advancement of technology in a responsible and sustainable manner.

While education on standards is considered an important component of engineering and engineering technology programs in the USA, it is widely recognized that engineering students do not get much exposure to standards while in school [3-5]. Through a study done in 2004, it was revealed that standards education was not considered a priority at the institutions surveyed [6]. Nevertheless, employers expect new hires to possess knowledge of standards and their applications [5]. Moreover, collaboration between universities and industry is essential to ensure that education programs are relevant and up-to-date. However, not all universities may have established partnerships with industry, which can limit their ability to provide students with relevant and practical education on standards and standardization.

To bridge this gap, Georgia Southern University (GaSou) is planning and implementing a curriculum innovation to integrating engineering standards into manufacturing engineering curriculum. The goal of this project is to establish a structured framework comprising of lectures, labs, and industrial experience, to enhance experiential learning about robotics and additive manufacturing standards among engineering students.

Program and Course Design

This two-year project started from spring 2022 and will complete in spring 2024. To achieve the goal of this project, there are three objectives: 1) Innovate course modules (lectures, labs, and projects) to advance students' experiential learning of standards, 2) Produce virtual learning materials to improve students' career readiness, and 3) Establish a sustainable online course structure to enhance the impact of education.

The courses involved in this project are shown in Table 1. Six existing courses are selected to include the course modules and one new course is developed. The six existing courses are categorized into two tracks: 1) additive manufacturing and 2) robotics, and three levels, including freshmen (entry level), junior/senior (mid-level), and graduate students (advanced level). The entry level course modules are lecture based.

Table 1: Courses modified and developed in the project

	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

To enhance students' experiential learning, the mid-level and advanced level course modules are lab and project based, respectively. To advance students' career readiness, plant tours and interview of professional, seminar/webinar from internship students are organized. Figure 1 depicts how these revised and new courses are distributed in the Manufacturing Engineering curriculum and how the industrial experience and experiential learning are integrated in these courses.

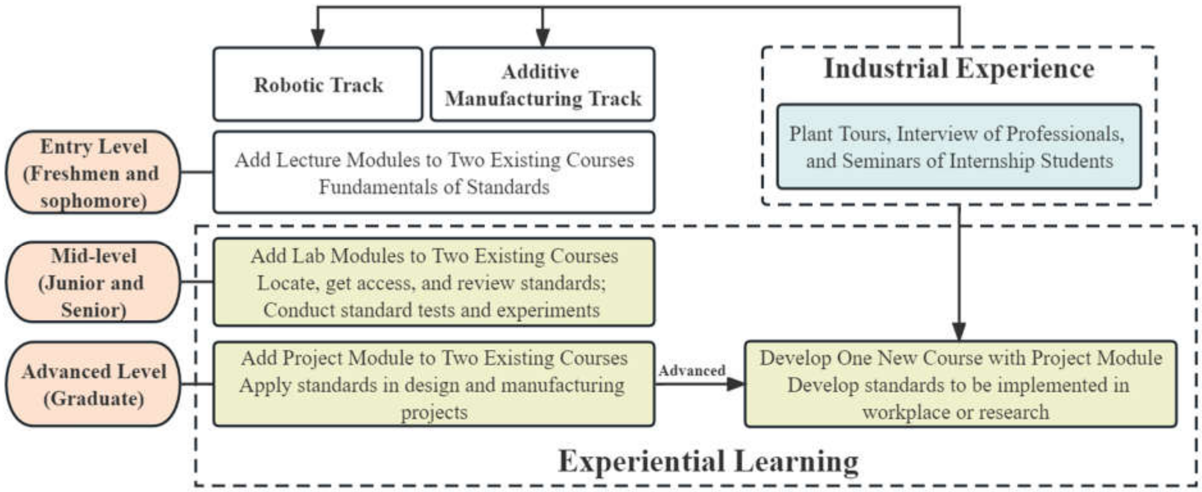

Figure 1. Integrate course modules into manufacturing engineering curriculum.

For the Robotics track, the three levels include:

1) Level 1: Entry level for freshmen undergraduate students **(lecture module)**: This course module will be designed to (a) introduce background and evolution of ANSI and ISO standards, and (b) introduce various safety requirements stated in the ANSI/RIA Robot Safety Standard 2012 and the ISO 10218 Standards. The course module will cover the background and importance of standards, the numbering system for standards work, and safety standards used in industrial robots. Upon complement of this module, the students will be able to (a) understand the necessity of safety standards in industrial robots; and (b) gain basic knowledge about safety standards that are deemed essential for use in industrial robots. The selected pilot course to test this module is *FYE 1220 First-Year Seminar*.

2) Level 2: Mid-level for junior/senior undergraduate students **(lab module)**: This module will cover the major sections and detailed information of ANSI/RIA Robot Safety Standard – 2012 and the ISO 10218 Standards. For ISO 10218, emphasis will be placed on manipulator and controller standards of robots (ISO 10218-1:2011) and application standards of robot system/cell (ISO 10218-2:2011). For ANSI/RIA Robot Safety Standard, ANSI/RIA TR R15.306-2016 will be used as an example to introduce Task Based Risk Assessment Methodology. Students will be introduced those topics and then are required to apply these standards in their lab work, where case studies will be performed to demonstrate the impact of industrial robot. Upon complement of this module, the students will be able to (a) identify necessary tasks and possible hazards involved in a robot system; (b) use furnished matrix to determine risk reduction requirements and present reasonable possible solution to reduce risk; and (c) document the risk assessment. The selected pilot course to test this module is *MFGE 3131 Design for Manufacturability.* It will be then introduced to capstone design courses in MFGE and other senior design courses in other engineering majors GaSou.

3) Level 3: Advanced level for senior undergraduate students and graduate students **(lab project module)**: It will be designed to provide students with hand-on experience on applying safety

standards when designing a robot system/cell. A group project will be designed within this module to allow students to design a robotic workcell which satisfies the requirements in the ANSI/RIA R15.06-2012 Robot Safety Standard by using the Robot Simulation Software Roboguide or CoppeliaSim which is free for educational purposes. Upon complement of this module, the students will be able to (a) reduce risk by enabling visualization of single and multi-robot workcell layouts; (b) perform task-based risk assessment using TR R15.306; and (c) design and validate proposed solutions. The pilot course is *MFGE 5331/5331G Advanced Robotics for Manufacturing* (undergraduate elective/ G-graduate level). The module will be then introduced to other courses related to robotics.

For the AM track, the three levels include:

1) Level 1: Entry level for sophomore undergraduate students **(lecture module)**: This module will introduce the AM standards to sophomore undergraduate students who have little knowledge of these subjects. It will be designed to (a) introduce how ASTM/ISO establishes and defines terms used in AM, and (b) introduce the requirements and guidelines for using AM in product design, and (c) introduce how file formats to be prepared, displayed, and transmitted for AM. Upon completion of this module, the students will be able to (a) understand the classifications of AM technologies, apply AM principle, and thereby build 3D geometries; and (b) determine design considerations to be utilized in a design project of AM process; and (c) cognize the interchange file formats for AM technology. The selected pilot course to test this module is *MFGE 2421 Introduction to Additive Manufacturing*. This module will be then introduced to other courses related to AM in the department.

Level 2: Mid-level for junior/senior undergraduate students and graduate students **(lab module)**: This module will introduce the existing AM related standards on manufacturing and testing of AM parts. Students will practice a project focusing on plastic part fabrication using extrusion-based AM process. Standards will be covered in the project including, but not limited to, ISO/ASTM 52903 Additive manufacturing - Material extrusion-based additive manufacturing of plastic materials (Part 1: Feedstock materials), ISO/ASTM 52903 Additive manufacturing - Material extrusion-based additive manufacturing of plastic materials (Part 2: Process equipment), ISO/ASTM 52902 Additive manufacturing - Test artifacts - Geometric capability assessment of additive manufacturing systems, and ASTM F2971 Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing. The project will provide students with hands-on experience on applying standards on AM parts fabrication and testing. Upon completion of this module, student should be able to (a) identify appropriate techniques for plastic characterization of extrusion-based AM processes; (b) familiarize the fused deposition modeling (FDM) process of PLA or ABS part fabrication; (c) determine the specific dimensional properties of FDM plastic parts; and (d) report results by testing or evaluating specimens produced by AM. The pilot course is *MFGE 5333/5333G Additive Manufacturing Studio*. It will be then introduced to other senior level manufacturing courses of other engineering majors.

Level 3: Advanced level for senior undergraduate students and graduate students **(lab project module)**: This module will develop students an ability of formulating standard operating procedure (SOP) and facilitating the SOP to new standard, if there is no standard dealing with a specific AM project. A project in a laboratory class will be used to cover the topics on AM lightweight part design, manufacturing, and testing. Students will design lightweight part (such as lattice or topology optimized structure), practice fabricating AM parts, and perform mechanical testing of the AM lightweight parts, using the AM laboratory. Due to the geometrical characteristics, AM lightweight part requires specific test protocols to develop an appropriate database of engineering design properties, including specimen design, test fixtures, and data analysis. The existing AM standards are covering only a few of these aspects. Students will have an opportunity to develop new SOP and standards. Upon completion of this module, students should be able to (a) develop SOP of specimen and fixture design and data analysis, if there is no specific standard available; (b) identify ASTM and/or ISO standard(s) which can be referenced to the developed procedure; (c) document the developed SOP and prepare for further evaluation and improvement for evolving it to be a standard. The pilot course is *MFGE 5334/5334G Additive Manufacturing of Lightweight Structures*. It will be then introduced to other graduate level AM courses.

The new graduate-level course:

A new graduate level course, MFGE5339G- Manufacturing Standards and Standardization, has been proposed and approved with the aim of advancing students' experience in using standards in manufacturing industries and enhancing their career preparedness. This course will provide a thorough and structured overview of the basics of standards and equip students with the necessary skills to apply them effectively in their work. Moreover, this course provides an in-depth study of standards development process, drafting a standard (BS 0:2021. A standard for standards —Principles of standardization), and evaluate a standard. A final project will be used to enhance students' abilities in developing a standard that can be implemented in their workplace or academic research.

To introduce industrial experience to students, plant tours and seminars will be offered:

To accomplish this objective, these courses will involve interaction with students from the Department of Manufacturing Engineering who are participating in internships or co-ops at local manufacturing companies. These students will be invited to give seminars to share their experiences of using standards in their roles and discuss how industry professionals in those companies develop and implement standard procedures. To demonstrate the implementation of standards and standardization in manufacturing plants, students will be organized to visit these local manufacturing plants to observe the standardized process/product. During the visit, industrial professionals at those plants will be interviewed to share their experience of developing and applying standards. All these virtual tours and interviews will be captured on video and included in the course materials.

Discussion and Conclusion

The project team used a comprehensive evaluation plan to guide the development of the project from start to finish [7]. The plan comprises two components: 1) An objectives-based evaluation plan, which utilizes internal research objectives to monitor progress toward meeting proposed research objectives, and 2) An outcomes-based evaluation plan, which is designed to assess project success. The evaluation plan incorporates specific quantitative and qualitative measures to 1) assess techniques and methods and their suitability for proposed research objectives, 2) evaluate achievement of objectives at the end of the project, and 3) disclose both anticipated and unanticipated project outcomes. During the survey, the students are requested to select the most appropriate term to describe the degree of their involvement in the courses, their confidence in applying standard skills, and the degree of mastering the standard knowledge. The available options comprised of five options, namely strongly agree, agree, neither agree nor disagree, disagree, and strongly disagree.

Before offering the modified course, we conducted a survey to assess 1) students' potential interest in learning about standards and standardization, 2) as well as their beliefs about the potential benefits of this knowledge for their future studies and career. Based on the responses from 31 students, 97% of them expressed interest in learning about standards, and an equal percentage (97%) believed that such education would be beneficial to their future studies and career.

Following the project's launch in February 2022, the team developed and offered two modified entry-level courses (MFGE 2421 and FYE 1220), two modified mid-level courses (MFGE 5333 and 4533), and one new advanced level course (MFGE 5339) during the Spring and Fall semesters of 2022. Anonymous surveys were conducted immediately after the new course modules were offered to assess their effectiveness and suitability for the research objectives. At the end of each semester, the project team collected survey results from all courses offered that semester and compared them to expected outcomes. Two advanced level course (MFGE 5334G and 5331G) are under development. The project team will continue to gather assessment results to evaluate the achievement of objectives at the end of the project (January 2024).

One important objective of this project is to distribute the course modules to other Institutes of Higher Education (IHE) and facilitate the replication of these modules to promote standard education across these IHEs. A project website has been developed to disseminate the project outcomes to a wider audience, which is available at this URL: https://sites.google.com/view/gsmanufacturingengineering/home?authuser=1. Upon completion of the courses previously discussed, the project team shared the course materials in the format of online course package and uploaded these packages under the page of “Course Module” on the website (Figure 2). Audiences can download these online course packages and import them into Learning Management Systems (LMS) like Blackboard, Canvas, Desire to Learn, and Moodle. These course materials include lecture presentation slides, lab instruction, project, assignments, course videos, etc. The “Gallery” page is used to display the videos and pictures of plant tour, seminars, and lab activities.

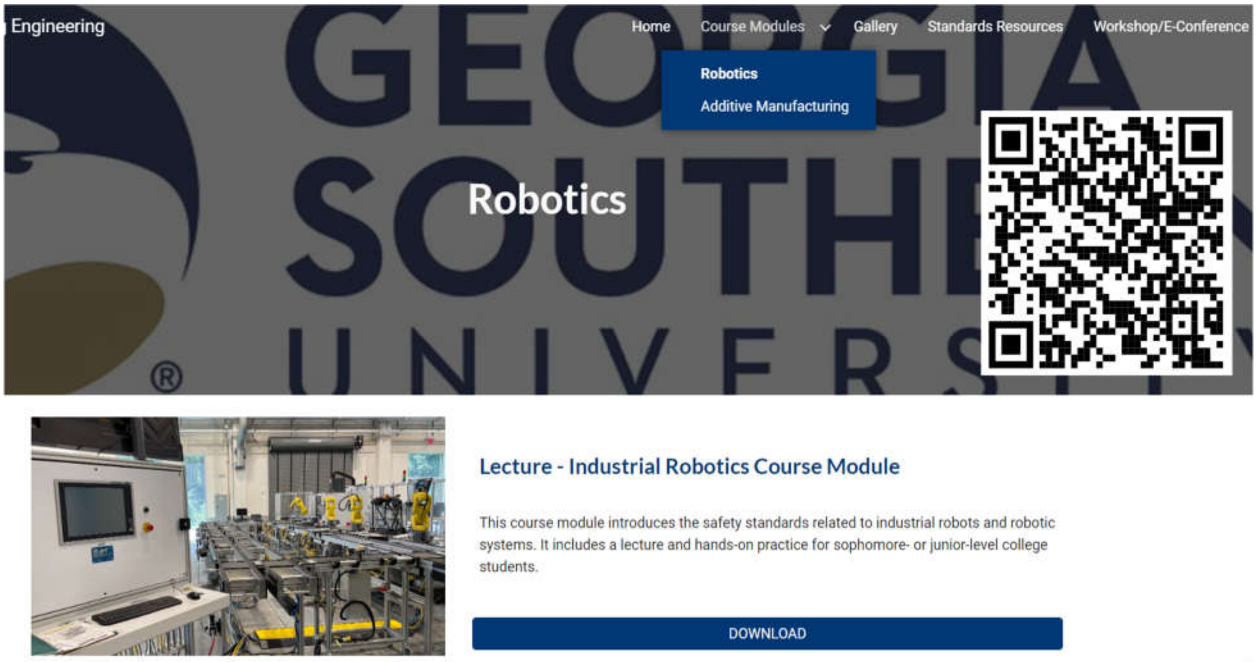

Figure 2. Project website with website QR code

In addition to the “Course Modules” materials developed by the project team, there are additional resources that are openly accessible and can be utilized by educators and industry professionals for teaching and learning standards. Most standards developing organizations (SDOs) rely on the income generated from the sale of standards to fund their programs and services. However, an increasing number of these organizations are now providing free access to their standards for viewing or downloading. National Institute of Standards and Technology (NIST) keeps updating the list of these SDOs on its website, which can be accessed through the "Standards Resources" page or via this URL: https://www.nist.gov/standardsgov/standards-organizations-offer-free-access-their-standards. The project team provides workshops and e-conferences to anyone interested in using these course materials. The information of these events can be found on the "Workshop/E-Conference" page.

Due to crucial role that standards play across all industries, it is essential to incorporate education on standards into curricula of engineering and engineering technology majors. The experiential learning and industrial experience is important to make the curriculum relatable and engaging. The outcomes of this pilot project would provide guidance for educators to develop curriculum that involves industry. Additive manufacturing and robotics are fundamental curriculum components for Manufacturing Engineering, Mechanical Engineering, Electrical Engineering, Materials Science and Engineering, and Industrial Design, instructors of these majors can adopt these course materials directly into their teaching. Users of these course materials are invited to the e-conference to share the new contents they developed and their experience, which helps to make the course materials sustainable.

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