Preparing the Engineers of Tomorrow: Standards Education for Infrastructure Improvement and Resilience

Greenwood, Lisa L.; Hargrave, Megan; Abraham, Yewande S.;
Mishra, Sumita; Schneider, Jennifer L.; Rochester Institute of Technology

Abstract

Standards are pivotal in managing safety, security, and risk across industries, facilitating innovation and societal resilience. However, gaps in standards literacy persist among future professionals, hindering their ability to navigate evolving technological advancements in society. This study addresses the need for standards education within higher education institutions, particularly in disciplines crucial for infrastructure resilience and sustainability. Our study examines the development, implementation, and assessment of portable curricular modules to foster standards literacy among undergraduate and graduate students. Drawing on the American National Standards Institute's (ANSI) advocacy, we present a case study focused on integrating standards education into environmental sustainability, health, and safety (ESHS) and environmental health and safety management (EHSM) curricula. We employ a mixed-methods approach, combining formative and summative assessment methods, including alumni surveys and student feedback, to evaluate the impact of standards literacy interventions. The findings underscore the significance of standards education in enhancing students' understanding and application of standards in real-world contexts. Moreover, the study proposes an expansion of this approach to civil engineering and cybersecurity-related programs, emphasizing the broader implications for workforce preparedness and infrastructure resilience. By highlighting the importance of standards education and offering a replicable model for curricular integration, this study contributes to advancing standards literacy initiatives within higher education and draws attention to their role in shaping the future engineering workforce.

Introduction

Standards form the foundation of many technologies and processes used in daily life. They help manage safety, security, and risk across countless industries and activities [1]. In simple terms, they are documents that disseminate best practices and technical specifications to help promote a common approach to a process or product. This helps ensure increased reliability in technology and procedures used to complete tasks [2]. Standards provide a framework for innovation that ultimately determines our ability to anticipate, adapt, and respond to shocks and stresses as a society [3]. They are developed through the process of standardization, which encompasses their creation and implementation as well as conformity assessment for products, services, processes, and even personnel to which they apply [4].

Standards bodies like the American National Standards Institute (ANSI) advocate that future professionals and the general public should understand the standardization process and the importance of standards in everyday life [4]. The United States National Standards Strategy published by ANSI stresses the importance of incorporating standards into the curricula of certain fields of study to create a standards-literate workforce [5]. With ANSI and other standardization bodies highlighting the importance of standards for students and future

professionals, there is a growing body of research on standards education, focusing on students entering engineering and related professions in other technical fields such as telecommunications or information technology. The National Standards Strategy specifically names clean energy, biotechnologies, artificial intelligence, and communication technologies, in addition to others, as critical technologies that will be prioritized in standards development.

With the enactment of the Infrastructure Investment and Jobs Act (IIJA) in 2021, it has become evident that there is a need for preparing future professionals that can understand and apply standards to innovate and enhance resilience in the built environment, including sustainable buildings and sites, as well as infrastructure security and resilience to disruption. Infrastructure systems involve numerous engineering-related disciplines such as civil, construction, energy management, environmental sustainability, occupational health and safety, and computer science. As the U.S. seeks to enhance its resilience, standards literacy for students in these disciplines is an increasingly important component of college and university curricula.

Our research involves the development, implementation, and evaluation of portable curricular modules that introduce standards to graduate and undergraduate students. While our broader project consists of a range of engineering and related disciplines, our initial research is designed as a case study on environmental, health, and safety (EHS) curricula to evaluate the importance of standards education in higher education institutions. We describe formative and summative assessments of a prior standards integration initiative and a survey of EHS program alumni at a large private university in the Northeastern United States to evaluate the impact of standards literacy interventions in the curriculum.

The paper is organized as follows. First, we review the literature on standards and standards education in higher education to identify gaps in knowledge and inform our approach for module development and deployment. This is followed by our methodology for the study, presentation and discussion of the results, and conclusion, with direction for future research.

Literature review

Standards education

Some disciplines rely heavily on standards to ensure the quality of their work. For example, in the 1980s, when the telecommunications industry became globalized, it became necessary to establish standards to enable connectivity and compatibility between countries. This was even necessary for establishing networks across the United States [6]. This reliance is seen in other fields as well. In software engineering, in particular, there is a risk of being seen as negligent and criminal if standards are ignored [7].

Standards are essential in governing the design and management of community critical infrastructures and risk. Computing and cybersecurity professionals must be trained and educated to effectively integrate standards-based security features in hardware and software deployments for critical infrastructure protection. The National Initiative for Cybersecurity Education (NICE) Cybersecurity Workforce Framework (NIST SP-800-181) acknowledges that “academic institutions are a critical part of preparing and educating the cybersecurity workforce” [8].

Although the need for a standards-informed curriculum for cybersecurity professionals has been identified in the literature [9], there is negligible curricular material available for standards-based critical infrastructure protection education.

In EHS disciplines, employers expect these professionals to facilitate compliance with the various standards applicable to operations and activities in their workplace, making it necessary for them to know these standards [10]. EHS disciplines encompass multiple fields, such as environmental management, environmental engineering, occupational health, occupational safety, industrial hygiene, environmental, social and governance (ESG), and emergency preparedness and response, aimed at risk mitigation and management, protection of the environment, and worker health and safety. Voluntary EHS management systems standards such as ISO 14001 and ISO 45001 are widely used and implemented internationally in industrial and manufacturing sectors. Conformity with these standards can increase compliance with regulatory standards, help meet goals within a company, satisfy customer demands, and improve risk management, among other benefits [11]. ISO environmental management standards and other voluntary environmental standards have also become critical to managing environmental concerns, independent of government enforcement [12]. While studies suggest that standards education in universities and on the job is beneficial in various fields, it is yet to be widely examined in the EHS context, despite the heavy reliance on conformity with regulatory and voluntary standards in related professions.

As seen with telecommunications, the globalization of the economy has been credited for spreading standardization to ensure consistency between businesses operating in different countries. Similar sentiments are found with the development of the internet, which ultimately contributed to further globalization [13, 14]. Standards organizations exist nationally and internationally, with some pushing for standards education in universities, including the Institute of Electrical and Electronic Engineers (IEEE). In 2003, the IEEE developed a task force that decided, among other things, that graduates of engineering and technology programs should be familiar with standards organizations and be able to identify and apply relevant standards. Still, in IEEE's survey of professors of technology and engineering programs, 29% of respondents answered that they did not teach standards and regulations to their students [13].

The 2003 IEEE survey also examined why some educators do not incorporate standards into their curriculum [13]. The top reasons included a lack of textbooks that include standards, cost of access to technical standards documents, and lack of faculty experience with the standards. This resulted in the authors recommending the development of standards education materials to be implemented in existing courses and creating courses dedicated to standards education [13]. Other studies have also looked at the barriers to standards education. Phillips et al. [15] investigated standards access and integration in engineering technology (ET) programs across several universities. In this subset of degrees, 79% of faculty surveyed said they incorporated standards in their classes. Access to standards was not singled out as a barrier to implementation, but the study provided insights into access issues. 58% of libraries at universities with ET programs subscribed to certain standards, while larger universities had a higher percentage. Several universities also used free or low-cost standards resources like the ANSI University Outreach Program. Despite many universities providing access to these standards, the study

posits that the problem is associated with a lack of cooperation between professors and libraries [15].

Standards for sustainable and resilient infrastructure

Disruption in society is inevitable due to a range of factors, including increasing threats associated with aging infrastructure, terrorism, information security, changing climate, natural hazards, and legacy pollution. In today's ever-changing world, we are vulnerable to shocks and stresses that can disrupt industrial operations and supply chains as well as civil society. Engineering and risk management standards are part of what Jeffrey [3] referred to as the "innovation infrastructure" that determines our nation's ability to be competitive, and our ability to adapt and respond as a society.

The passing of the IIJA in 2021 and related funding for infrastructure projects establish a clear need for future engineering, science, and management professionals who can understand and apply standards to improve infrastructure and enhance its resilience to disruption. Three areas for which significant funding was authorized are improved power infrastructure, sustainable buildings and sites, and enhancing infrastructure resilience to climate change and other disruptions. For example, in relation to power infrastructure, a large portion of the US electric grid is aging and is being replaced by the smart electric grid that incorporates cyber elements with the traditional physical elements. In relation to sustainable sites, there are approximately 1,300 Superfund sites where cleanup activities are either incomplete or have not yet begun [16]. Further, regarding infrastructure resilience to disruption, the American Society of Civil Engineers (ASCE) [16] recommends enhancing the use of standards to mitigate risks related to climate events and prioritizing projects that "improve the safety and security of systems and communities."

Communities that access this funding and organizations that perform work on their behalf will need knowledgeable and skilled engineering, EHS, construction management, computer science, and cybersecurity professionals. In addition to technical knowledge, this work requires practical skills in integrating standards for resilient and secure infrastructure, including applied skills related to planning, design, development, and operation. The future workforce should be able to identify standards relevant to their work and apply the requirements set out in standards to real-world situations. Standards-based curriculum and the skills that result are key for preparing tomorrow's graduates to lead and support infrastructure improvement efforts as the U.S. seeks to enhance its global competitiveness and resilience.

Approaches for integration of standards in higher education curricula

Standards education can involve integrating standards in the curriculum by knitting the content into existing courses or integration at the program level by creating courses focused on standards. Some classes focus entirely on the standards used in a specific discipline, while others incorporate projects and modules that involve standards to some degree [17, 18, 19]. Purdue University took an approach where they worked with faculty to improve standards education within their Mechanical Engineering Technology curriculum and created a separate set of modules that offers a general standards education applicable to many disciplines [19]. These

efforts also take place outside of specific universities. The American Society of Mechanical Engineers (ASME) took a similar approach with researchers at Purdue University to develop modules for ASME standards to be infused into mechanical engineering and mechanical engineering technology programs. From the field test, ASME members got feedback that required minor changes to the modules to help engage students, but otherwise the main feedback was that educators wanted more modules [20].

In contrast to creating modules for integration within existing classes, a single comprehensive class or series of classes can be developed focusing only on standards, as described in the approach of Choi et al. [17]. This involved a course focused on construction safety standards and included enough standards content to allow students to receive their Occupational Safety and Health Administration (OSHA) 30-hour construction safety card [17]. El-Bawab & Effenberger [21] describe another example of such an approach involving a project to introduce standards into telecommunications engineering education by developing a new course on telecommunications standards. This course used conventional learning with lectures to educate students on the vocabulary and background necessary for working with standards, in addition to interactive workshops. The course was evaluated based primarily on student feedback, which was generally positive, agreeing with statements that indicated the course was useful and standards were important. Most students also indicated a preference for the workshops, finding them helpful while also recognizing that both conventional teachings and workshops were necessary [21].

Our broader research involves developing modules on infrastructure resilience standards, including those related to power infrastructure, sustainable buildings and sites, and infrastructure resilience to climate change and other disruptions. We sought to develop portable standards modules that enable and empower instructors in a wide range of academic programs at graduate and undergraduate levels to identify and incorporate content relevant to their individual courses. This allows for broader implementation, emphasizing content that is relevant and accessible for instructors. While our study involved embedding modules within existing courses, these modules can be combined and delivered as a stand-alone course on infrastructure resilience, consistent with the literature review.

To test and assess our modules, we first evaluated course results and student feedback in our EHS programs. Our paper is structured as a case study, focusing on the design, implementation, and evaluation of our risk, disruption, and continuity modules in the environmental sustainability, health, and safety (ESHS) and environmental health and safety management (EHSM) programs. To gain deeper insights into the perspective of graduates in professional practice, we surveyed alumni of the ESHS and EHSM programs in the Civil Engineering Technology Environmental Management and Safety Department within the College of Engineering Technology. The methodology section outlines our approach to module development and the case study.

Methodology

To address the need for standards education in higher education institutions, this research adopts a mixed-methods approach, incorporating qualitative and quantitative techniques to

comprehensively investigate the integration of standards education into university curricula (Figure 1). A literature review was completed to identify the gaps in existing studies related to standards education in higher education and inform our approach for module development and deployment. We employed a case study design to explore standards education within a higher education institution, specifically focusing on a large private university in the Northeastern United States. Participants in the study comprise students and alumni from EHS-related disciplines. Purposive sampling is utilized to ensure representation across these disciplines, allowing for a comprehensive understanding of the integration of standards education.

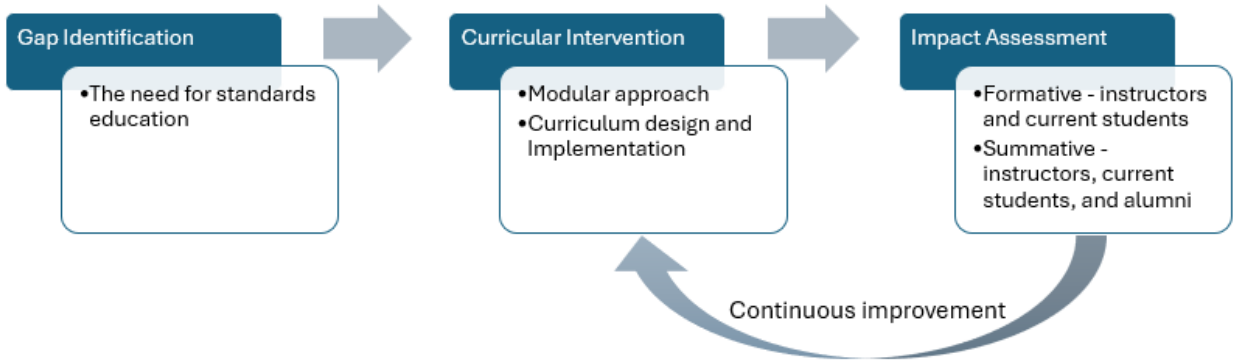

Figure 1. Module development framework

The curricular intervention involved developing and implementing modules that instructors could easily adapt for selected courses, based on a standards integration project in 2022 [18]. The effectiveness of the curricular interventions was assessed by gathering verbal and written feedback from instructors both at the curriculum design and module development phase and at the implementation phase. Student feedback through course feedback surveys was also considered. This served as a formative assessment. Summative assessments were gathered from students taking the courses by evaluating their performance on the module assessment pieces, such as group project assignments or exam questions.

Data triangulation is employed to enhance the validity and reliability of findings, cross-referencing insights from multiple data sources, including surveys, informal verbal and written feedback, and document analysis. Ethical considerations are carefully addressed, with adherence to ethical guidelines for research involving human participants, ensuring informed consent, confidentiality, and voluntary participation. Approval from the university's Institutional Review Board (IRB) was obtained before data collection. The findings of the formative and summative assessments gathered from the curriculum design and module implementation phases contribute to the continuous improvement data used to enhance the modules for faculty adaptation and improved student learning.

Modular approach

Our educational approach aims to integrate multiple standards in graduate and undergraduate curricula in a range of existing engineering and related courses through the design, testing, and evaluation of portable learning modules, organized in thematic elements that can be implemented in combinations appropriate to various course learning outcomes based on a proven education

structure consistent with Liu et al. [22, 23]. and Greenwood et al. [24, 25]. Compatible modules were developed to introduce students to standardization and application of standards while incorporating and integrating specific content used in U.S. industry and society.

While we introduce students to a core set of standards, the overall objective is to enable students to appreciate the value and benefits of standards, and to identify and apply the standards that are relevant and applicable, given the context of a particular project or initiative. Key standards related to infrastructure resilience in the identified areas included a selection of relevant frameworks and guidelines from the International Organization for Standardization, known as ISO, as well as U.S. standards from the American National Standards Institute (ANSI), the National Institute of Standards and Technology (NIST), The U.S. Green Building Council (USGBC), American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), ASCE, and the U.S. Environmental Protection Agency (USEPA).

The learning modules were designed to enable applicable elements to be easily incorporated into existing courses, allowing individual instructors to build out knowledge in diverse areas without requiring wholesale curricular changes. This enhances portability and engagement with multiple faculty and students across many disciplines to maximize the use of the intellectual products from this effort and create broader impacts within various engineering and applied computing majors. This structure is important because engineering and computing-related majors build or work in professional settings *for* or *on* a particular system, such as water, energy, etc., but the skills gained from these course modules can be applied across varied settings.

Development of the learning content as course supplemental materials facilitates broader use or replication of the learning materials, as well as making it easier to incorporate and build upon the materials in existing academic curricula in online and in person formats. Modules include educational content, learning outcomes, and assessment tools at the appropriate level of understanding based on Bloom's taxonomy, and an instructor guide, as shown in Table 1, consistent with the educational model outlined by Liu et al. [22, 23].

Table 1: Module Design Template (adapted from Greenwood et al. [18])

Component	Description
Module Overview & Description	– Executive summary with introduction and overview of the module – Module learning outcomes, description, and rationale – Summary of key standards included in the module
Educational Content	– Slides and notes for lectures with guided activities and exercises – Supplementary resources, e.g., readings, links to materials and tools – Example discussion questions and exercises
Module Assessment	– Example assignments – Assessment tools and methods to measure module effectiveness

Curricular content is being integrated into master's level courses in construction leadership and management, sustainable building design, and risk management for information security and in undergraduate courses in environmental sustainability, health and safety, and civil engineering technology.

Module assessment is designed to occur at multiple levels, including internal and external content review as well as evaluation of student learning. Internal faculty evaluators are reviewing content for evidence that the materials reflected different cognitive learning levels, provided connection to real world contexts and situations, and connected back to the learning objectives. External content review was provided from faculty at two secondary partnering institutions as a means of content validation. Constructive feedback from these reviews was applied to refine and improve module content. Following completion of module implementation in courses, faculty evaluated student learning based on results achieved on assignments, exercises, projects, and exams.

Once the learning modules have been tested, they will be revised based on the feedback obtained during the pilot test, and when finalized, will be made available to other institutions.

Results and discussion

Module impact assessment

Our assessment of the effectiveness and impact of the curricular modules involved a review of the module materials themselves during development, evaluation of student learning within courses using the modules, and review of the module materials by external partners. Our assessment indicated that this work resulted in improved student learning and suggested translation to practice since many of our current graduate students work in these fields. The results in the classroom demonstrated that students gained a strong understanding of concepts related to the standards and could apply this knowledge. During the active project period, we engaged a total of 98 students with standards-based curricular content across the three modules (risk, continuity, and disruption) in two undergraduate courses and two graduate courses. Overall, 94 percent of students achieved a B or better on module-related assignments across the four courses, based on the number of students achieving at least 80 percent on each graded assignment, divided by the sum of the number of students completing each graded assignment. Effectiveness was also evaluated qualitatively through internal and external faculty feedback and was used to continually improve the module content. Table 2 indicates the modules implemented in each course and summative module assessment results.

Table 2: 2020 Module Effectiveness Assessment

Course	Modality	Module	No. of Students	Assessment Method	% B or Better
Principles of ESHS (undergraduate)	In-person	Risk Disruption	44	Formative: based on student application of module concepts and content in relation to a field trip	Assignment A: 100% Assignment B: 94%

Professional Communication (undergraduate)	In-person	Risk	21	Summative: based on class observation and student feedback on an in-class exercise, where students represented stakeholders in a case-based scenario.	80% successfully completed the exercise
EHS Management (graduate)	Online	Risk	21	Formative: based on application of module concepts and content within unit assignments. Summative: based on a comprehensive case-based term project.	Unit A: 95% Unit B: 86% Term project: 100%
EHS System Design (graduate)	Online	Continuity	12	Formative: based on class discussion and an extra credit assignment.	Qualitative assessment (not graded)

Programmatic impact assessment – instructor feedback

Instructors provided constructive feedback on the curricular content. In the EHS System Design graduate course, student observations indicated that they "grasp concepts well and were able to successfully apply them to the project and answer the related assignment questions." The instructor also noted that the team project approach allowed participant-participant collaboration to reinforce the concepts and advance students' learning. At the undergraduate level, instructors noted that students engaged well with the content and case-based assignments, and that this helped to "make content more relatable." This aligns with the observations of Brame [26] and Loepp [27] that a case study approach can promote active learning and help students to engage more deeply with the curricular content.

On the other hand, a new undergraduate adjunct instructor in the ESHS program who was not previously familiar with the standards content noted that a few students "were confused by exposure to frameworks from disciplines outside of the ESHS realm" and that it was challenging to present content that fell outside of his disciplinary expertise. This is consistent with results of the IEEE survey, regarding barriers to incorporation of standards [13]. Going forward, the instructor recommended more self-preparation and engagement with the provided module resources, as well as opportunities for instructional support to further adapt and integrate the content to target the specific focus of the course.

Programmatic impact assessment – survey results

Alumni working in EHS-related roles provided feedback through the survey that was administered in 2023. The survey focused on the importance of standards education in the EHS-related curriculum. Sample questions included how well their education prepared them to use

standards in the industry and how often they used standards in their jobs. The survey was administered through the Qualtrics survey development platform and included Likert-type and open-ended questions. Eighty-two alumni participated in the survey, and the majority (81.6%) reported using standards frequently or daily on their jobs (Figure 2).

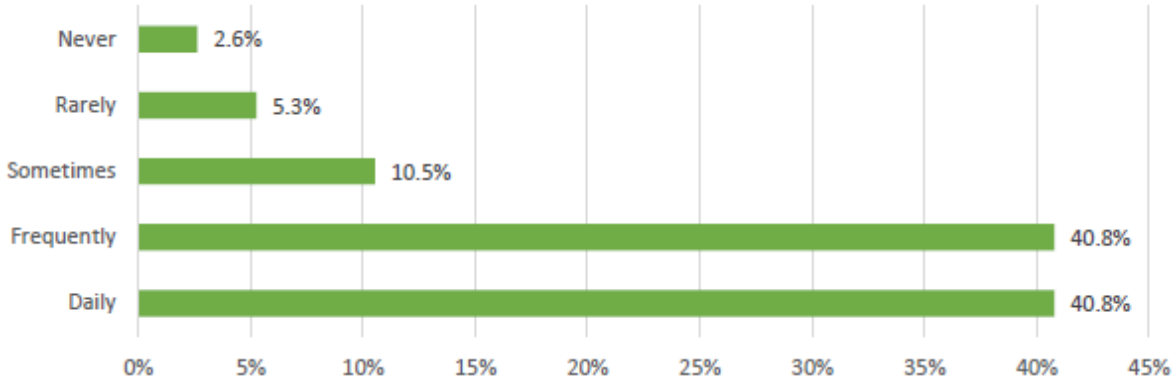

Figure 2: Frequency of the use of standards in alumni jobs

Most participants held ESHS/EHSM-related roles at the organizations where they worked. Of the 64 participants who provided their job titles, 53 directly identified a title in an EHS discipline, such as Director of Health and Safety, EHS Manager, Safety Engineer, or Lead Industrial Hygienist. While the remaining 11 did not specifically indicate an EHS discipline, most were somewhat vague, such as Compliance Officer, Assistant Director, Consultant, or Retired, and therefore could not be dismissed as outside of EHS disciplines.

40.8% of the alumni felt that the integration of standards in their degree program(s) prepared them very well for the industry, and 15.8% felt that they were extremely prepared (Figure 3). The industry continues to emphasize the need for students who are adequately prepared and well versed in understanding, interpreting, and applying standards in their job roles.

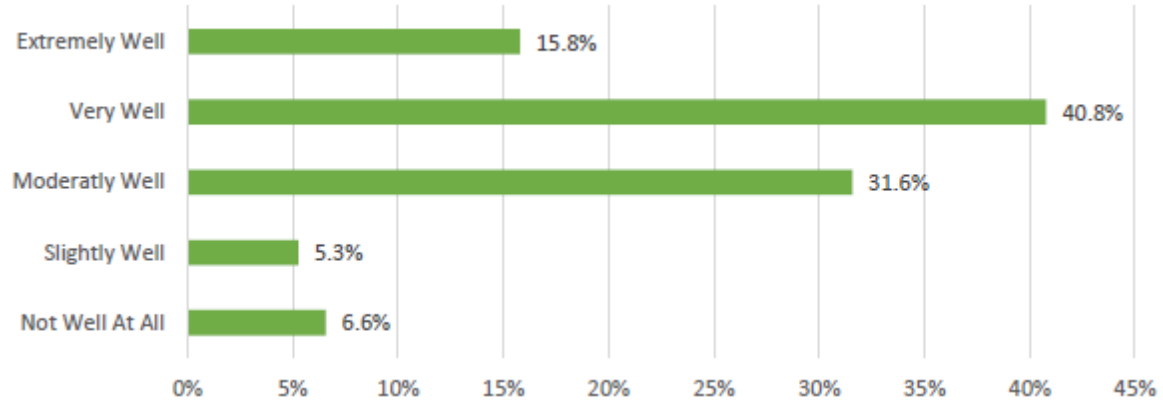

Figure 3: Extent that standards education prepared students for professional practice

Participants commented that incorporation of standards in the curriculum provided a "well-rounded knowledge base" that gave them an edge in their field:

> *"The curriculum prepared me better than other EHS professionals. I feel this is the key to my successful career working for one of the largest pharmaceutical companies in the world leading their EHS programs."*
>
> *The curriculum helped me to "learn to navigate and interpret regulations much faster than most of me [sic] peers."*

Others appreciated the skills they gained in relation to standards literacy, leadership, and critical thinking:

> *"My education … provided the leadership skills I needed to implement standards."*
>
> *"My education … gave me a good overview of the standards and how they should be used and applied. This is helpful in my career because you can't remember everything so you need to know where and how to find the information."*

Our results suggest that ESHS/EHSM professionals use standards extensively in the workplace. This includes a wide range of standards, including various regulatory and voluntary standards at national and international levels and across multiple disciplines, confirming the importance of enabling students to identify and implement a range of standards. Our research also supports the assertion that students gain considerable value from learning about standards and how to identify and implement them in their degree programs, as they prepare to enter the workforce.

Conclusion

This study emphasizes the importance of standards education across diverse industries and disciplines in ensuring safety, resilience, and sustainability. Standards provide a common framework for processes and products and for facilitating interoperability and compatibility. The need for standards literacy among future professionals is increasingly recognized by standards bodies and academic institutions alike, with efforts being taken to incorporate standards education into university curricula. As society grapples with evolving challenges such as aging infrastructure, cybersecurity threats, and climate change, standards-based curricula become critical for preparing graduates to navigate and address these complex issues effectively.

Our research contributes to this endeavor by proposing a modular approach to integrating standards education into university curricula, focusing on disciplines critical to infrastructure improvement, sustainability, and resilience. By equipping students with the knowledge and skills to identify and apply relevant standards, we aim to foster a standards-literate workforce capable of leading and supporting infrastructure enhancement efforts.

Potential limitations of the study include sample bias due to the focus on two academic programs at a single institution. Although modules have been used by instructors in other programs at other institutions, formal tracking has not yet been completed. In addition, industry professionals and practitioners who are not alumni were not included in the evaluation of the modules. Efforts were made to address these limitations through transparent reporting and triangulation of findings. Future work involves developing and implementing standards-based course modules focused on

resilient power infrastructure, sustainable buildings and sites, and infrastructure resilience to support civil engineering, computer science, and related fields.

Direction for future research includes incorporation of feedback from industry practitioners to ensure curricular relevance and alignment with industry needs. Understanding the different needs and levels of preparedness of undergraduate and graduate students is also an area that should be further investigated to determine when standards education should be introduced to students.

Acknowledgments

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