Integrating Standards for Infrastructure Improvement and Resilience in University Curricula

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Abstract

In today's ever-changing world, we are increasingly vulnerable to shocks and stresses that disrupt industry and society. Persistent threats from natural and manmade hazards require our communities and infrastructure to be resilient despite possible disruption. Creating robust infrastructures is founded on operational and physical standards to withstand and respond to threats such as environmental exposures, climate change, and informational security breaches. The significant U.S. investment in infrastructure projects through the Infrastructure Investment and Jobs Act has amplified the need for professionals in engineering and related fields who – in addition to technical knowledge - possess the necessary knowledge and skill to identify and apply national and international standards relevant to their work. Our research focused on integrating standards for infrastructure improvement and resilience into graduate and undergraduate curricula at a large university in the Northeastern U.S. We developed, implemented, and evaluated a modular approach to introduce students in civil engineering, construction management, environmental sustainability, health and safety, computer science, and cybersecurity to standards for infrastructure improvement and resilience. Standards-based curriculum is essential for preparing tomorrow's professionals with the skills to lead and support improvement efforts as the U.S. seeks to make our communities safer and our infrastructure more resilient to threats.

Introduction

The United States National Standards Strategy (2020) developed by the American National Standards Institute (ANSI) stresses the importance of creating a standards-literate workforce by integrating standards into curricula, so that future professionals and the general public understand the standardization process and the importance of standards in everyday life (Jeffrey, 2007). With standards 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. The National Standards Strategy specifically named clean energy, biotechnologies, artificial intelligence, and communication technologies, among others, as critical technologies that are prioritized in standards development.

As we work to shore up and create new infrastructure, our next-generation engineers, designers, planners, and environmental, health, safety, and cyber security professionals must be prepared. Standards inform our design and operational expectations across our community infrastructures, actually framing our lives (The White House, 2021), forming best practices and technical specifications for increased reliability and common language (Ruth, 2023), and underscoring how we respond to shocks and stresses as a society. Standard conformity assessment for products, services, processes, and even personnel to which they apply provides assurance of systems that perform as expected (ANSI, 2024). 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 developed, implemented, and evaluated portable curricular modules to introduce and frame standards for graduate and undergraduate students in engineering and related disciplines. We implemented formative and summative assessments for this curriculum at a large private university in the Northeastern United States to evaluated the impact of standards literacy interventions across technical domains. At the 2011 joint meeting of the Asia-Pacific Economic Cooperation (APEC) Project Advisory Group on Education and American National Standards Institute (ANSI) Committee on Education, S. Joe Bhatia of ANSI maintained that "standards and conformance play a critical role in the economy, impacting more than 80% of global commodity trade" (p.2), making standards education both at the university level and in the professional environment essential. He further stated that "effective utilization of standards and conformance promotes technological interoperability and drives the global competitiveness of businesses," and "a new graduate or professional who is familiar with the standards relevant to their industry and how the standards system works is a strategic asset to their future employer" (2011 p. 2). Standards-based curricula in higher education can equip students with vital competencies that build their capacity to enhance organizational resilience and competitiveness in their future roles.

The paper is organized as follows. First, we review the literature on standards and standards education in higher education that informed our approach for module development and deployment. This is followed by our methods for the study, presentation and discussion of the results. Lastly, we provide our conclusion and recommendations.

Literature Review

Resilience from Concept to Implementation

Businesses and society are vulnerable to disruption in operations, supply chains, and our ways of life as we face increasing threats related to natural hazards (Kleindorfer & Saad, 2005), climate change and extreme weather events (Scott et al., 2020), aging infrastructure (Osei-Kyei et al., 2021), privacy and information security (Yao & Jong, 2010), terrorism (Coaffee, 2016), and global health threats (McInnes & Roemer-Mahler, 2017; OECD, 2003). It is critical that we embed resilience in the design of societal and organizational systems and infrastructure as a means to reduce vulnerabilities, and be able to respond and adapt when faced with disruption.

For our work, resilience is conceptualized as a characteristic of a system or an organization when considered as a whole. We arrive there by following an evolution of the understanding of resilience itself over the last several decades. Holling (1973) described resilience as “a measure of the ability of ecological systems to absorb changes of state variables, driving variables, and parameters, and still persist” (1973, p. 18). Persistence despite external disruption was added as a key component of resilience adaptation of individuals, human communities and larger societies (Linnenluecke & Griffiths, 2010; Nelson, Adger & Brown, 2007; Norris et al., 2008). Previously, a stable system was defined as strong, static and resistant to change (Manyena, 2006; McEntire et al., 2002). However, not all systems can resist change, thus remaining stable signals a state that is more or less the same within a range of conditions, is flexible, and able to adjust to stress (Holling, 2001; Thompson et al., 2009). Resilience then reflects the capacity to adjust, adapt, and recover despite vulnerability and disruptive forces that threaten the systems on which business and society depend (OECD, 2003). Implementation of practices that serve standards result in absorbing, managing, and then surviving vulnerabilities and risks. Therefore, our infrastructural resilience results from practices that evolve as our risks also evolve.

Consensus at the national and international level is reflected in structured frameworks with technical guidance and implemented through best practices as firms enhance organizational resilience (Tiernan et al., 2019). Tammineedi (2010) maintained that acceptable management standards must underpin business continuity management. Otherwise, the varied and inconsistent approaches result in unreliable and ineffective continuity plans. In contrast, organizational crisis performance improves through formalized business continuity management that incorporate standards (Alharthi and Khalifa, 2019). Operational standards implementation reduces organizational vulnerability, by providing for efficient crisis response and recovery and promoting resilience. As professions focus on functional risk management, environmental, health and safety (EHS), infrastructure, and cyber security programs represent the vanguard of risk-based standards education. Yet, even as examples, these educational programs also have knowledge gaps to address.

EHS

EHS professionals are specifically charged with ensuring risk mitigation and compliance with the various standards applicable to operations and activities (LaBar, 1995). The EHS domains reach across multiple fields that aim at risk mitigation and management, including environmental engineering, occupational health, occupational safety, industrial hygiene, environmental, social, and governance (ESG), and emergency preparedness and response - fundamentally, the protection of the environment, community and worker health and safety. Conformity with voluntary standards like ISO 14001 and ISO 45001 can also support regulatory compliance, customer demands, and improve risk management, among other benefits (Talapatra et al., 2019). These standards also allow corporations to reach beyond compliance to operational excellence for risk and impact management. (Goulden et al., 2019). Despite calls for broad standards education, even EHS educators have yet to evaluate the relationship of standards education to the efficacy of implementation, perhaps because voluntary systems have various endpoints beyond compliance. The EHS education experience can inform our best practices for creating professional competency and innovation needed as we rebuild our community infrastructures.

Cybersecurity

Our infrastructures are increasingly connected. 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 (Khan and Karim, 2016). The National Initiative for Cybersecurity Education (NICE) Cybersecurity Workforce Framework (NIST SP-800-181) highlights that "academic institutions are a critical part of preparing and educating the cybersecurity workforce" (Petersen et al., 2020). Despite literature calling for a standards-informed workforce (AlDaajeh, et al., 2022), there is negligible curricular material available for standards-based critical infrastructure protection education.

Civil Engineering and Infrastructure

Standards are relied upon across many disciplines to ensure quality, compatibility , and sustainability of products and processes. In some cases, following standards is so critical that ignoring them can be perceived as unethical and criminally negligent (Laporte and Munoz, 2021). Concerning infrastructure, standards are the actual and functional framing of our communities, particularly for critical infrastructures and critical systems that we rely upon. Regarding infrastructure resilience to disruption, the American Society of Civil Engineers (ASCE) (2022) recommended 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." The investment from the Infrastructure Investment and Jobs Act (IIJA) includes $50 billion to protect physical structures from climate and extreme weather events. The civil engineering body of knowledge describes civil engineers as individuals that "serve competently, collaboratively, and ethically as master planners, designers, constructors, and operators of society's economic and social engine, the built environment" (ASCE, 2008). They also emphasized the importance of critical thinking and engineering judgment in design while addressing "risk assessment, societal and environmental impact, standards, codes, regulations, safety, security, sustainability, constructability, and operability" and ensuring that these are integrated at various stages of the design process (ASCE, 2008). Standards are a critical component of the civil engineering discipline and successful project delivery is driven by adherence to standards. These standards ensure the safety, quality, durability, and efficiency of civil engineering projects considering the different lifecycle phases. Furthermore, standards are critical in advancing sustainability and resilience of buildings and infrastructure thereby protecting people and the environment.

Infrastructure Resilience Standards in University Curriculum

In September 2022, our research team was awarded a grant from the National Institute of Standards and Technology (NIST) to support the integration of standards-based content into higher education curricula to strengthen student education, learning, and standards literacy. Faculty in engineering technology and computing security developed a set of multi-disciplinary learning modules to introduce students to standards and standards development integrating specific content from selected standards, and creating transportable introductory modules that can be integrated within various program courses. or knitted together into a standalone course (s) to create teaching and learning flexibility (Choi et al., 2006; Greenwood et al., 2023; McPherson et al., 2020). The modules encompass infrastructure resilience standards, including those related to power infrastructure, sustainable buildings and sites, and infrastructure resilience to climate change and other disruptions. These portable standards modules enable and empower instructors in a wide range of academic programs to incorporate content relevant to their courses.at graduate and undergraduate levels, allowing for relevant and accessible implementation across curriculum. We also evaluated course results and student and faculty feedback in our programs and then reflected that feedback in our module content and structure. The Method section outlines our approach to module development.

Method

Module Development Framework

A literature review identified research gaps related to standards education in higher education and this informed our approach for module development and deployment to comprehensively investigate the integration of standards education into university curricula. Our curricular interventions involved developing and implementing modules that instructors could easily adapt for selected courses, using a standards integration model developed by Greenwood et al. (2023). Formative curricular effectiveness was assessed by gathering verbal and written feedback from instructors across the study activity: at the curriculum design and module development phase and at the implementation phase. Student-based summative assessments were obtained from student performance on related module assignments or exam questions. Figure 1 shows our model for standards integration.

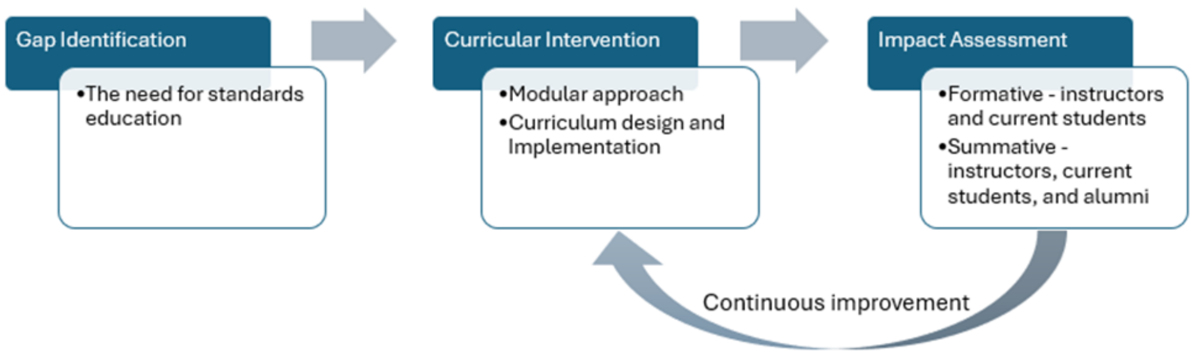

Figure 1. Module Development Framework

Validity and reliability of findings were developed by cross-referencing insights from multiple data sources, including informal verbal and written feedback as well as document analysis. The findings of the formative and summative assessments gathered from the curriculum design and module implementation phases contributed to the continuous improvement data used to enhance the modules for faculty adaptation and student learning.

Modular Approach

Integration of multiple standards in graduate and undergraduate curricula was interwoven through the design, testing and evaluation of portable learning modules with thematic elements that can be arranged in combinations appropriate to applicable course learning outcomes. Development of content incorporating and integrating specific standards used in U.S. industry and society focused on three domains, as shown below and in Figure 2:

(1) Resilient power infrastructure – smart grid security and privacy
(2) Sustainable buildings and sites - efficient, healthy buildings; remediation of legacy pollution
(3) Infrastructure resilience to climate change and disruption.

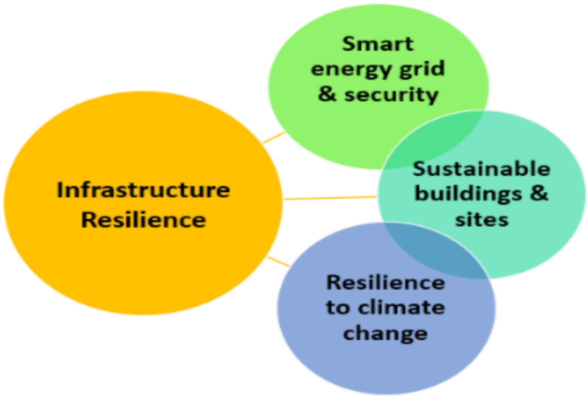

Figure 2: Module Domains

We began by building a curriculum to enable students to identify and apply the standards that are relevant and applicable for an organization's particular context, while also developing learning in specific areas. Module content focused first on domain-specific US national and international documentary standards, with specifications and guidelines for organizations. The chosen standards focused on assessment, planning, preventive action, and response to promote organizational and societal preparedness and resilience. Our approach was designed to enhance students' appreciation for the need for and key value of standards, and practice identifying and applying standards that are relevant within the context of a particular project or initiative. For our work, standards related to infrastructure resilience 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). Key standards related to infrastructure resilience in the identified areas are set out in Table 1 below.

Table 1. Infrastructure Improvement and Resilience Standards

Standards Domain	**Key Standards - Select Examples**
Energy/power infrastructure and cybersecurity	NIST SP 800-53 for security and privacy controls, NIST SP 800-30 for risk assessment and management, and ISO/IEC 27001 for information security management

Standards Domain	Key Standards - Select Examples
Sustainable buildings	National Green Building Standard (NGBS), US Green Building Council's LEED standard, ANSI/GBI Green Globes, Living Building Challenge, ASCE/SEI 7, ASHRAE 189.1- Design of High-Performance Green Buildings
Sustainable sites/legacy pollution	National Oil and Hazardous Substances Pollution Contingency Plan (NCP) - 40 CFR Parts 300-311, 355, and 373; National Emission Standards for Hazardous Air Pollutants (NESHAP) - 40 CFR Part 63; Superfund Climate Resilience Framework
Resilient infrastructure	ISO 14090, ISO 37101, USGBC RELI, Stafford Act (Hazard Mitigation Planning & standards)

Given the current and future challenges that face society, students must be knowledgeable and skilled in using management systems and strategies as well as applicable technical standards related to infrastructure improvement and resilience to their professional advantage. The project was structured to meet a series of goals that not only supported integration but also encouraged adoption by a broad set of faculty, students and programs. This included

(1) a curricular goal for developing and embedding a set of reusable and customizable course modules that integrate relevant documentary standards;
(2) a faculty goal for supporting cross-disciplinary faculty expertise development in infrastructure resilience and related standards; and
(3) an educational effectiveness goal for ensuring the effectiveness of the course modules via a cohesive and proven educational structure.

Module Design

Krechmer's (2007) research showed that standards-based curricular content should begin with a broad view of the standards and establish their value and relevance for engineers and technical experts. Purcell & Kelly's (2003) work echoes contextual relevance, practical connection, and how they impact other areas, such as business decision-making. A curriculum template was developed based on the literature review, following the approach of Greenwood et al. (2018a; 2018b; 2023), and consistent with Kretchmer (2007), Purcell and Kelly (2003), and Taylor and Kaza's (2011) philosophies on curricular design, forming a consistent approach among module developers in creating instructional materials. The resulting template was structured to ensure that module learning objectives served both the undergraduate and graduate levels, and connected course learning outcomes and topics.

As shown in Table 2, Modules include educational content and instructor guidance with an overview of the module and rationale, learning outcomes, and assessment tools at the appropriate level of understanding based on Bloom's taxonomy, consistent with the educational model outlined by Liu et al. [2013a; 2013b].

Table 2. Module Design Template (adapted from Greenwood et al.(2023)

Component	Description
Module Description & Overview	- 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

Loepp's (1999) research emphasized the incorporation of real-world problems in the design of standard-based curriculum, to show relevance of content. Consistent with this approach, our content framework was designed for flexibility to enable faculty to situate learning relevant to their courses, and to facilitate internalization of knowledge and deliver the material with real world meaning. The team created resources, case studies, sample questions, active-learning exercises and assignments, and assessment tools, to engage with students via three forms of interaction:

(1) Participant-instructor interaction through classroom presentation and in-class exercises;

(2) Participant-content interaction through lectures, homework assignments, and examination questions; and

(3) Participant-participant interaction through in-class group exercises, class discussion or online discussion boards, and group homework assignments or projects.

Our additional goal was to support instructor implementation. We enhanced 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. Therefore, we designed the modules to be customizable, within a framing that allowed for additions, enabling applicable elements to be easily incorporated into existing courses, without requiring wholesale curricular changes. 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.

Devising learning content as course supplemental materials facilitated broader use or leveraging, as well as making it straightforward to integrate within existing academic curricula in online and in person formats. The standardization also advanced our instructional engagement, by following a 'project-based' recognizable format. Our research focused on 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

Assessment and evaluation occurred at multiple levels, including internal and external content review as well as evaluation of student learning, which is critical to modular design (Bharvad, 2010). Internal faculty evaluators reviewed content for evidence that the materials reflected different cognitive learning levels, provided a 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 higher education institutions as a means of both content validation, and also constructive feedback. Data and feedback from this review was applied to refine module content. Faculty evaluated student learning based on results achieved on assignments, exercises, projects, and examinations following completion of module implementation in courses,

Results

To date, we have engaged 153 students in six courses across five degree programs, including three undergraduate and two graduate programs in engineering and computing and information sciences colleges. Our assessment for module effectiveness in student learning was based on the number of students achieving a grade of B or better on related course artifacts, with a goal for at least 80 percent of students to achieve an 80 percent or higher. In all courses in which modules have been implemented with graded assignments, we have met our goal for student success. Overall, 91 percent of students achieved a B or better on module-related assignments across the six courses, based on the sum of the number of students achieving at least an 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 faculty feedback, which is addressed in the discussion section of the paper. Table 3 indicates the modules implemented in each course, with formative and summative module assessment results.

Table 3. Module Effectiveness Assessment Results

Course	**Modality**	**Module**	**No. of Students**	**Assessment Method**	**% B or Better**
ESHS 720 - EHS Management (Graduate)	Online	Sustainable Sites Infrastructure Resilience	16	Formative: based on application of module concepts and content within two unit assignments. Summative: based on a comprehensive case-based term project.	Unit 3: (15/16) 94% Unit 4: (14/16) 88% Term project: 100%
ESHS 150 - Principles of ESHS	In Person	Sustainable Sites Infrastructure	15	Formative: based on application of module concepts and content within	Unit A: (12/15) 80% Unit B:

Course	Modality	Module	No. of Students	Assessment Method	% B or Better
(Undergraduate)		Resilience		two unit assignments. Summative: based on a comprehensive case-based term project.	(12/15) 80% Term project: 100%
ESHS 755 – Corporate Social Responsibility (Graduate)	Online	Sustainable Sites	14	Formative: based on application of module concepts and content on Units 2 and 3 assignments. Summative: based on a comprehensive case-based term project.	Unit 2 100% Unit 3 (13/14) 93% Term Project 100%
CONM 690 – Sustainable Building Design and Construction (Graduate)	Online	Sustainable Sites, and Infrastructure Resilience	5	Formative: based on application of module concepts and content within a group assignment. Summative: to be completed at the end of the semester.	Group assignment: 100%
CVET 180 – Introduction to Civil Engineering (Undergraduate)	In Person	Sustainable Sites	44	Formative: based on application of module concepts and content within one assignment. Summative: to be completed at the end of the semester.	Assignment: (43/44) 98%
CSEC-461 – Computer System Security (Undergraduate)	In Person	Infrastructure Resilience	59	Formative: based on applying module concepts and content on Unit 3, 4, and 7 assignments. Summative: based on quizzes at the end of units.	Unit 3: 81% Unit 4: 90% Unit 7: 91%

Our curricular design also included the development of two scenario-based simulation exercises, to be utilized in classroom or online formats. The first was based on a case study of the West Valley Demonstration Project (WVDP), in Western NY. The WVDP site was the first commercial nuclear fuel reprocessing plant in the U.S., and operated from 1966 to 1972, when operations were discontinued when the cost of compliance with emerging regulations made it economically unfeasible. The contamination from radioactive waste at the site is part of a long-term, multi-faceted remediation project. Students in environmental, health and safety programs were presented with the details of the case, and were asked to apply their knowledge of ISO standards used in the class to identify stakeholders and stakeholder perspectives as well as environmental justice concerns and discuss how standards can be applied to manage the environmental and social risks. The case included a teaching note with suggestions on how to use the case study to enhance achievement of intended learning outcomes.

The second scenario focuses on protecting critical infrastructure. Smart grids and smart meters are being deployed worldwide to enable smart electricity distribution and management. Integrating computing technologies with traditional electricity systems, however, introduces cybersecurity risks and other vulnerabilities specific to energy infrastructure. Therefore, adopting NIST standards for smart grids is essential to ensure the security and resilience of these systems. In particular, NIST SP 800-53 outlines security and privacy controls, while the NIST Risk Management Framework (RMF) supports risk management for different levels of potential threats. This scenario is designed for engineering and computing students, helping them understand the importance of these NIST frameworks and standards in securing smart grids. Open-source tools like Wazuh and Suricata are included for easy integration into existing classes. Additionally, the scenario demonstrates the value of backups as a safeguard against ransomware attacks.

Discussion

Feedback from instructors has been positive overall, as well as constructive. At the graduate level, one instructor observed that students “ were able to successfully apply standards in their term project and appeared to find value in the skills they gained from implementing standards” and noted that the use of a group project allowed participant-participant collaboration to reinforce the concepts and advance students’ learning. Another instructor shared that students were able to gain exposure to the applications of national and international standards for sustainable built environments. At the undergraduate level, one instructor noted that students really engaged with the content while completing the term project assignment, and that the case-based approach helped to make the standards content relatable. Consistent with Loepp (1999) and Brame (2016), the case study approach promoted active learning and helped students to engage more deeply with the module content. An instructor for a first year course stated that incorporating project tours tied to an assignment also provided an immersive experience for students to better relate to standards in action. An undergraduate instructor observed that incorporating standards-related content into a course already focused on risk management and organizational security concepts was seamless.

Conversely, one adjunct instructor was not fully comfortable incorporating the standards-based content in their course, citing lack of confidence themselves with the standards and related material, and limited instructor time to review the curricular resources provided. This is similar to the findings described by Abu Karsh (2018) with individual faculty barriers and anxiety levels related to faculty adoption of new instructional technology and resources. Khan and Karim (2016) also examined why some educators do not incorporate standards into their curriculum, based on a 2003 survey conducted by the Institute of Electrical and Electronics Engineers (IEEE). Results showed that a lack of textbooks that include standards, cost of access to technical standards documents, and lack of faculty experience with the standards contribute to this problem, prompting the authors to recommend that standards education materials be developed specifically for implementation in existing courses. Phillips et al. (2023) investigated standards access and integration for engineering technology (ET) programs. 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 nevertheless, the authors found that only 58% of libraries at universities with ET programs subscribed to certain limited standards, while some larger universities had a higher percentage. Access to free or low-cost standards resources like the ANSI University Outreach Program was an oft mentioned option.

Conclusion

This research addressed methods, practices and results for integration of risk management, disruption, cyber security and continuity standards into curricula in higher education. A modular, active learning approach to standards-based curriculum development advances standards literacy across these critical domains of practice whether at the undergraduate or graduate level. Assessment of student learning outcomes shows students were able to develop capacity in standards that support infrastructure improvement and resilience through internalization, and to give meaning to, demonstrate, and then apply this knowledge. The modular sets were designed such that the content could be used in and adapted in a variety of course settings, and classroom activities and assessment methods could be customized to ensure relevance. Our faculty reviewers affirmed the critical nature and applicability of the modules to a wide range of professional programs; however, introductory materials required specific adaptation by the individual instructor to provide the targeted context for their student engagement. Involving instructors earlier in the development may drive better adoption of our educational content, especially among adjunct faculty.

The definition of professional capacity continues to evolve. Standards-based, systematic strategies for risk management and infrastructure resilience drive organizational and community resilience and competitiveness despite our *age of disruption*. The ability to identify and strategically implement standards shapes how we plan for and respond to vulnerability and disruptions, and will impact professional practice itself, and invariably, how the professional will create value for society. Standards-based teaching and learning provides the skills and competencies that prepare graduates for societal challenges that they will face.

Recommendations

While development of a faculty learning process was outside the scope of our initial project, our experience and feedback suggests that faculty with limited experience in implementation of standards may need support themselves in learning and teaching about standards, may lack capacity to internalize the standards content and the confidence for delivery of the technical framing. Additionally, while the work focused on higher education, this is not the only forum where professionals, young or seasoned may learn and be informed about standards within their discipline. All of us can benefit from structured and formalized instruction on standards and standardization. This would broaden the impact of this work beyond the classroom. Professional societies, credentialing organizations or other venues all have a role in the integration of standards and standards literacy. The IIJA highlighted the need for future engineering, computer security, management, etc. professionals who are conversant in and can apply standards to improve infrastructure and enhance its resilience to disruption. Making our infrastructure more resilient and secure through planning, design, development, and operation is founded upon the practical skills of standards integration.

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References

Abu Karsh, S. (2018). New technology adoption by business faculty in teaching: Analyzing faculty technology adoption patterns. *International Journal of Technology in Education and Science (IJTES)*, *2*(1), 17-30.

AlDaajeh, S., Saleous, H., Alrabaee, S., Barka, E., Breitinger, F., & Choo, K. K. R. (2022). The role of national cybersecurity strategies on the improvement of cybersecurity education. *Computers & Security*, 119, 102754.

Alharthi, M. N. A. N., & Khalifa, G. S. (2019). Business continuity management and crisis leadership: an approach to re-engineer crisis performance within Abu Dhabi governmental entities. *International Journal on Emerging Technologies*, *10*(2), 32-40.

ANSI. (2020). *United States standards strategy*. American National Standards Institute. Retrieved from https://share.ansi.org/Shared%20Documents/Standards%20Activities/NSSC/USSS 2020/USSS-2020-Edition.pdf

ANSI. (2024). *The importance of standards education & training*. American National Standards Institute, 2024. Retrieved from https://www.ansi.org/education/standards-education-training

ASCE. (2008, February). *Civil engineering body of knowledge for the 21st century: Preparing the civil engineer for the future.* American Society of Civil Engineers.

ASCE. (2022). *ASCE's 2021 infrastructure report card*. Retrieved from https://infrastructurereportcard.org/

Bharvad, A. J. (2010). Curriculum evaluation. *International Research Journal*, 1(12), 72-74.

Brame, C. (2016). Active learning. *Vanderbilt University Center for Teaching*. [Online]. Retrieved from https://cft.vanderbilt.edu/active-learning/.

Bhatia, S. Joe (2011, February 28). *It's Hard to Win if You Don't Know the Game: The Critical Importance of Education on Standardization in Universities*. Joint Meeting of the APEC SCSC Project Advisory

Group on Education and the ANSI Committee on Education, Washington, DC.

Choi, S. D., Kapp, E. A., & Cole, W. M. (2006). Educating Construction Safety Professionals: A collaborative model for the 21st century. *Professional Safety, 51*(7), 41-45.

Coaffee, J. (2016). *Terrorism, risk and the global city: Towards urban resilience*. Routledge.

Goulden, S., Negev, M., Reicher, S., & Berman, T. (2019). Implications of standards in setting environmental policy. *Environmental science & policy*, 98, 39-46.

Greenwood, L. L., Schneider, J., & Valentine, M. S. (2018a, April). Setting a course for student success: standards-based curriculum and capacity-building across risk prevention management system domains. In *2018 ASEE Mid-Atlantic Section Spring Conference*.

Greenwood, L., Schneider, J., & Valentine, M. (2018b). Environmental management systems and standards-based education: a modular approach. In *Charting the Future: Environment, Energy & Health, A&WMA 111th Annual Conference & Exhibition*.

Greenwood, L. L., Hess, D., Abraham, Y., & Schneider, J. (2023). Capacity Building for Organizational Resilience: Integrating Standards on Risk, Disruption and Continuity in the Curriculum. *International Journal on Social and Education Sciences*, *5*(2), 327-340.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 1-23.

Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems, 4*(5): 390–405.

Jeffrey, W. (2007). *Building the Innovation Infrastructure* [Speech transcript]. NIST. Retrieved from https://www.nist.gov/speech-testimony/building-innovation-infrastructure

Khan, A. S., & Karim, A. (2016). Importance of standards in engineering and technology education. *International Journal of Educational and Pedagogical Sciences*, 10(3), 1050-1054.

Kleindorfer, P. R., & Saad, G. H. (2005). Managing disruption risks in supply chains. *Production and Operations Management, 14(*1), 53-68.

Krechmer, K. (2007). Teaching standards to engineers. *International Journal of IT Standards and Standardization Research (IJITSR)*, *5*(2), 17-26.

LaBar, G. (1995). A Lifetime of Learning. *Occupational Hazards*, 57, 57-57.

Laporte, C. Y., & Munoz, M. (2021). Not teaching software engineering standards to future software engineers-malpractice?. *Computer,* 54(5), 81-88.

Linnenluecke, M. K., & Griffiths, A. (2010). Corporate sustainability and organizational culture. *Journal of World Business*, *45*(4), 357-366.

Liu, X., Raj, R., Reichlmayr, T., Liu, C., & Pantaleev, A. (2013a, October). Incorporating Service-Oriented Programming techniques into undergraduate CS and SE curricula. *In 2013 IEEE Frontiers in Education Conference (FIE)* (pp. 1369-1371). IEEE.

Liu, X., Raj, R. K., Reichlmayr, T. J., Liu, C., & Pantaleev, A. (2013b, October). Teaching Service-Oriented Programming to CS and SE undergraduate students. *In 2013 IEEE Frontiers in Education Conference (FIE)* (pp. 15-16). IEEE.

Loepp, F. L. (1999). Models of curriculum integration. *The Journal of Technology Studies*, 25(2), 21-25.

Manyena, S. B. (2006). The concept of resilience revisited. *Disasters, 30*(4): 434–450.

McEntire, D. A., Fuller, C., Johnston, C. W., & Weber, R. (2002). A comparison of disaster paradigms: The search for a holistic policy guide. *Public Administration Review*, *62*(3), 267-281.

McInnes, C., & Roemer-Mahler, A. (2017). From security to risk: reframing global health threats. *International Affairs, 93(*6), 1313-1337.

McPherson, P. B., Phillips, M., & Reiter, K. (2019). Integrating technical standards into ET curricula to meet ABET standards and industry needs.

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: contributions of a resilience framework. *Annual Review of Environment and Resources*, *32*(1), 395-419.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology*, *41*(1), 127-150.

Osei-Kyei, R., Tam, V., Ma, M., & Mashiri, F. (2021). Critical review of the threats affecting the building of critical infrastructure resilience. *International Journal of Disaster Risk Reduction*, *60*, 102316.

Organisation for Economic Co-operation and Development (OECD). (2003). *Emerging risks in the 21st century: An agenda for action.* Final Report to the OECD Futures Project. Retrieved from https://read.oecd-ilibrary.org/economics/emerging-risks-in-the-21st-century_9789264101227-en#page106

Petersen, R., Santos, D., Smith, M., & Witte, G. (2020). *Workforce framework for cybersecurity (NICE framework)* (No. NIST Special Publication (SP) 800-181 Rev. 1 (Withdrawn)). National Institute of Standards and Technology.

Phillips, M., McPherson, P. B., & LeClerc, D. (2023). Engineering technology programs and technical standards: Investigating library access and course integration. *Journal of Engineering Technology.*

Purcell, D. E., & Kelly, W. E. (2003). Adding value to a standards education: Lessons learned from a strategic standardization course. *ISO Bulletin*, *34*(7), 33-34.

Ruth, C. (2023, August 24). *What are standards? why are they important?* - IEEE SA. IEEE Standards Association. Retrieved from https://standards.ieee.org/beyond-standards/what-are-standards why-are-they-important/

Scott, M., Lennon, M., Tubridy, F., Marchman, P., Siders, A. R., Main, K. L., Hermann, V., Butler, D., Frank, K. Bosomworth, K., Blanchi, R. & Johnson, C. (2020). Climate disruption and planning: resistance or retreat?. *Planning Theory & Practice*, *21*(1), 125-154.

Talapatra, S., Santos, G., Uddin, K., & Carvalho, F. (2019). Maın benefıts of ıntegrated management systems through literature review. *International Journal for Quality Research*, 13(4), 1037-1054.

Tammineedi, R. L. (2010). Business continuity management: A standards-based approach. *Information Security Journal: A Global Perspective*, *19*(1), 36-50.

Taylor, B., & Kaza, S. (2011, June). Security injections: Modules to help students remember, understand, and apply secure coding techniques. In *Proceedings of the 16th Annual Joint Conference on Innovation and Technology in Computer Science Education* (pp 3-7).

Thompson, I., Mackey, B., McNulty, S., & Mosseler, A. (2009). Forest resilience, biodiversity, and climate change. In *Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 43*. 1-67. (Vol. 43, pp. 1-67).

Tiernan, A., Drennan, L., Nalau, J., Onyango, E., Morrissey, L., & Mackey, B. (2019). A review of themes in disaster resilience literature and international practice since 2012. *Policy Design and Practice*, 2(1), 53-74.

The White House (2021). *Fact Sheet: The Bipartisan Infrastructure Deal*. Press release, November 6. Retrieved from https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/06/fact-sheet-the-bipartisaninfrastructure-deal/

Yao, C. T., & Jong, C. Y. (2010). Perceived risk of information security and privacy in online shopping: A study of environmentally sustainable products. *African Journ*

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