Standards Education for Infrastructure Improvement and Resilience

Lisa Greenwood, Rochester Institute of Technology, llgcem@rit.edu

Introduction

Organizations and communities face escalating threats and increasing vulnerability to disruption associated with natural and man-made hazards, including aging infrastructure, changing climate, more frequent flooding and wildfires, and cybersecurity challenges. Infrastructure threats can disrupt essential services, increase costs, and hinder innovation, which can jeopardize economic competitiveness as well as national security. Addressing these threats requires a strategic approach to enhance resilience and protect the interconnected systems that underpin our economic stability. As our communities and systems become more complex and subject to risk, there is an increasing need for organizational and societal capacity to mitigate infrastructure risks, and to prepare for, respond to, and recover from disruption.

Standards have been described as a critical part of the "innovation infrastructure" that determines our nation's ability to be competitive (Jeffrey, 2007). Recent investment in infrastructure projects in the U.S. has created a need for engineering, science and management professionals with the skills to lead and support integration and implementation of standards in infrastructure projects. Recognizing, understanding, and being able to apply relevant standards to improve, secure, and enhance infrastructure is a useful, practical, and sought-after professional skill set as the U.S. seeks to enhance its competitiveness and its resilience to shocks and stresses.

Our project focused on developing and testing interactive learning modules to strengthen graduate and undergraduate education and learning about documentary standards in the context of sustainability and infrastructure improvement and resilience. Through implementation of these modules, we aimed to equip students with the knowledge and skills needed for engineers and other professionals to utilize national documentary standards in the domains of resilient power infrastructure, sustainable buildings and sites, and infrastructure resilience to climate change and other disruptions as they enter professional practice. With funding from the National Institute of Standards and Technology (NIST) Standards Services Curricula Development Cooperative Agreement Program, we applied a modular approach based on a proven educational structure, developed curricular materials, and supported instructional faculty to implement the standards-based content in a range of academic programs and course at a large private in the Northeastern United States. We also shared our content and resources with two other large private universities in the Northeast. The project was highly successful and we continue to utilize and expand upon the content developed beyond the scope and duration of initial work.

Importance of the Project

Increasing threats to infrastructure systems have heightened interest in systems-based and standards-based approaches to risk management and disaster preparedness. These strategies are essential for enhancing infrastructure resilience and shaping how society addresses vulnerability and disruption. As such, professionals entering the workforce must understand not only the role of standards but also how specific standards influence practice in their respective fields. To strengthen competitiveness, resilience, and sustainable development, we must cultivate professionals who comprehend the complex challenges

facing organizations and communities, and possess a strong understanding of standards and systems for managing risk and responding and recovering from disruption.

National and international documentary standards are playing an increasingly important role in areas such as risk management, crisis response and recovery, cybersecurity, and protection of critical infrastructure. Framework and operational standards within these areas enable the adoption of innovative systems that reduce infrastructure vulnerability, support effective crisis management, and promote long-term resilience. Proficiency in implementing such standards-based strategies is a practical, in-demand skill set.

Standards and conformity have a significant role in the global economy. Academic curricula that embed and apply key U.S. and international standards offer students a practical foundation as they enter the workforce—equipping them to deliver tangible value and perform effectively in their careers.

Project Goals and Approach

Our project involved integrating infrastructure resilience-related standards content into graduate and undergraduate courses and programs at the Rochester Institute of Technology (RIT) and sharing our content and resources with faculty at Penn State University and George Washington University. We developed curriculum that can be offered as stand-alone course(s) on power infrastructure, sustainable sites, and infrastructure resilience to disruptions.

The core project team was based in RIT's College of Engineering Technology (CET) in the Department of Civil Engineering Technology, Environmental Management and Safety; Golisano College for Computing and Information Sciences in the Department of Cybersecurity; and the RIT Collaboratory for Resiliency and Recovery. Faculty at partnering institutions were associated with departments in architectural engineering, and electrical and computer engineering, respectively.

To prepare students to meet increasing challenges for infrastructure resilience, our project applied a modular approach with the following goals:

1. Develop and embed a set of reusable, adaptable, and interchangeable course modules on the application of standards related to resilient and secure infrastructure design, construction, and operation, at levels appropriate for undergraduate and graduate students ***(Curricular Goal).***
2. Support cross-disciplinary faculty expertise development in infrastructure system standards application by sharing content both internally and externally ***(Faculty Goal)***.
3. Ensure the effectiveness of the course modules via a cohesive and proven educational structure ***(Educational Effectiveness Goal)***.
4. Disseminate results via published papers, conference presentations and a website ***(Dissemination Goal)***.

Project Outcomes

<u>Curricular Goal</u>

Our educational approach integrated multiple standards in graduate and undergraduate curricula through design, testing and evaluation of portable learning modules. We developed compatible modules to

introduce students to standardization and application of standards while incorporating and integrating specific content used in U.S. industry and society in three areas:

1. Resilient Power Infrastructure: Smart energy grid security and privacy.
2. Sustainable Buildings and Sites: Efficient, healthy buildings and remediation of legacy pollution to minimize harm to the environment and to communities.
3. Infrastructure Resilience: Enhancing infrastructure resilience to climate change and other disruptions.

Each module was organized in thematic sub-sections, or elements, to facilitate uptake and integration by faculty in applicable combinations according to the various course levels and learning outcomes. The 17 elements of the modules are shown below in Table 1.

Table 1: Module Elements

Module	Element
Power Infrastructure	a. Infrastructure Basics and Smart Energy Grid b. Smart Energy Grid Cybersecurity c. Privacy Threats to the Smart Energy Grid
Sustainable Buildings & Sites	a. Introduction to Sustainable Sites b. Legacy Pollution - Background c. Legacy Pollution – Remediation & Brownfields Redevelopment d. Environmental Justice e. Sustainable Buildings - Background f. Sustainable Buildings – Planning & Design g. Sustainable Buildings – Construction h. Sustainable Buildings – Operations and Maintenance i. Sustainable Buildings – End of Life
Infrastructure Resilience to Climate Change & Other Disruption	a. Introduction to Infrastructure Resilience & Disruption b. Resilience to Impacts of Climate change – Mitigation c. Resilience to Impacts of Climate change – Adaptation d. Resilience to Natural Disasters e. Resilience to Man-made Disruption

Our approach introduced and incorporated key documentary standards used in the U.S. that offer specifications and guidelines for organizations and utilities in one or more of these areas. Students were introduced to a core set of standards, with a broader goal to enable them to appreciate the value and benefits of standards, and to identify and apply the standards that are relevant and applicable, given the context and location of a particular project. Examples are shown in Table 2.

Table 2: Standards Introduced

Standards Domain	Standards Introduced – Select Examples
Energy/power infrastructure and cybersecurity	— NIST Risk Management Framework — SP 800-53 for security and privacy controls — NIST SP 800-30 for risk assessment and management — ISO/IEC 27001 for information security management
Sustainable buildings	— National Green Building Standard (NGBS) — US Green Building Council's LEED standards — ANSI/GBI Green Globes — Living Building Challenge — ASCE/SEI 7 for minimum design load and associated criteria for buildings — ASHRAE 189.1- Design of High-Performance Green Buildings
Sustainable sites/legacy pollution	— National Oil and Hazardous Substances Pollution Contingency Plan (NCP) — National Emission Standards for Hazardous Air Pollutants (NESHAP) — Superfund Climate Resilience Framework
Resilient infrastructure	— ISO 14090 – Adaptation to climate change — ISO 37101 — USGBC RELI — Stafford Act (Hazard Mitigation Planning & standards)

Modules were implemented in six courses at RIT, including three graduate courses, two introductory undergraduate courses, and one upper level undergraduate course across five degree programs, including the Environmental Sustainability, Health and Safety (ESHS) B.S., the Environmental, Health and Safety (EHS) M.S., the Civil Engineering Technology (CVET) B.S., the Construction Management (CONM) M.S., and the Computing Security B.S. Programs. Specific courses and instruction levels are shown in Table 3.

Table 3: Courses Using Project Educational Content

Course Number	Course Level	Course Title
ESHS 720	Graduate	EHS Management
ESHS 150	Undergraduate	Principles of Environmental Sustainability, Health & Safety
ESHS 755	Graduate	Corporate Social Responsibility
CONM 690	Graduate	Sustainable Building Design and Construction
CVET 180	Undergraduate	Introduction to Civil Engineering
CSEC 461	Undergraduate	Computer System Security

In addition, we developed and tested two standards implementation simulation exercises that can be incorporated in on-campus or online formats, as follows:

1. West Valley Development Project Simulation (Sustainable Sites Module): A scenario-based exercise was developed based on the West Valley Development Project (WVDP) in Western New

York State. The WVDP site was the first commercial nuclear fuel reprocessing plant in the U.S., in operation from 1966-1972. There was extensive contamination from radioactive waste at the site, which is now part of a long-term, complex 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 for instructors with suggestions on how to use the case study to enhance achievement of intended learning outcomes.

2. Securing Electrical Smart Grids Simulation (Resilient Power Infrastructure Module): A scenario-based simulation exercise was designed for and tested with engineering and computing students to enhance their understanding of the importance of NIST frameworks and standards in securing smart grids. Student participated in a real-time, four-hour simulation workshop using the NIST Risk Management Framework and Wazuh and Suricata open-source tools to protect critical infrastructure. The exercise was also designed to demonstrate the value of backups as a safeguard against ransomware attacks.

Faculty Goal

As noted in connection with our curricular goal, modules were organized in thematic elements to facilitate integration by faculty in combinations appropriate to their course levels and learning outcomes. We designed our instructional modules to be adaptable for multiple modes of instruction, including incorporation of online learning strategies to ensure that the content could be developed with resources or approaches needed for online delivery and customized accordingly for classroom delivery. Our final modules reflect faculty review and feedback internal and external to RIT. We have shared both our processes for development of the modules (curriculum development) as well as the overall goal of increasing new professional understanding and future application of these standards through several points of dissemination, including workshops and summits with academic faculty and other education professionals, conferences, and journal papers.

Educational Effectiveness Goal

Our final modules were developed using best pedagogical practices in order to achieve students' understanding of the standards, following a model developed by Liu et al. (2013, 2014) and implemented in previous curricular development projects led by investigators Greenwood and Schneider. Module development was transparent and shared among the faculty via a course shell in RIT's online learning platform, ensuring consistency across the modules and inclusion of components agreed upon and designed in advance. Each module followed a proven educational structure and included a module overview and description, module learning outcomes, educational content with sample questions, exercises, and supporting resources, and module assessment tools. The educational content was designed to reflect different learning levels and include key concepts, examples, relevant standards, and active learning activities. Table 4 provides an overview of the curriculum template.

Table 4: Overview of Curriculum Template (adapted from Liu et al. 2013, 2014)

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

The assessment of module effectiveness occurred at multiple levels. First, peer evaluation was conducted during the development phase through a systematic review of the module materials. Second, external partners conducted independent reviews of the module content to provide additional feedback and validation. Finally, effectiveness of the modules in promoting student learning was assessed during pilot implementation within academic courses. Assessment findings suggest that the modules contributed to enhanced student learning outcomes, the development of state-of-the-art instructional materials, and even successful translation of theoretical knowledge into professional practice, since many students in our graduate courses are also working professionals in related fields.

Quantitative evidence from classroom implementation indicated that students demonstrated a solid understanding of concepts aligned with relevant standards and were able to apply this knowledge effectively. Across six courses in which the three modules were implemented, a total of over 220 students engaged with the standards-based curricular content. Analysis of student performance across the course offerings indicated that 90% of students achieved a grade of B or higher on module-related assignments, 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. Table 5 presents a summary of the module implementation across courses, along with the corresponding formative and summative assessment results.

Table 5: Module Effectiveness Assessment

Course	Module	No. of Students	Assessment Method	% B or Better
ESHS 720 - EHS Management (Graduate, Online)	Sustainable Sites Infrastructure Resilience	29	Formative: based on application of module concepts and content within two assignments. Summative: based on comprehensive case-based term project.	Unit 3: 90% Unit 4: 86% Term project:100%
ESHS 150 - Principles of ESHS (Undergraduate, On Campus)	Sustainable Sites Infrastructure Resilience	29	Formative: based on application of module concepts and content within two assignments. Summative: based on comprehensive case-based term project.	Unit A/Quiz 4: 83% Unit B/Quiz 7: 86% Term project: 93%

ESHS 755 – Corporate Social Responsibility (Graduate, Online)	Sustainable Sites	35	Formative: based on application of module concepts and content on Units 2 and 3 assignments. Summative: based on comprehensive case-based term project.	Unit 2 100% Unit 3 94% Term project:100%
CONM 690 – Sustainable Building Design and Construction (Graduate, Online)	Sustainable Sites Infrastructure Resilience	5	Formative: based on application of module concepts and content within a group assignment. Summative: comprehensive term project	Group assignment: 100% Term Project: 100%
CVET 180 – Introduction to Civil Engineering (Undergraduate, On Campus)	Sustainable Sites	63	Formative: based on application of module concepts and content within one assignment. Summative: comprehensive project	Assignment A:98% Project: 92%
CSEC-461 – Computer System Security (Undergraduate, On Campus)	Infrastructure Resilience	59	Formative: based on applying module concepts and content on Unit 3, 4, and 7 assignments. Summative: based on unit quizzes	Assignments Quizzes Unit 3: 81% Unit 3 81% Unit 4: 90% Unit 4 90% Unit 7: 91% Unit 7 90%

Overall, instructor feedback was both positive and constructive. Course instructors reported that students demonstrated a strong understanding of the core concepts in applicable standards and were able to effectively apply this in exercises, assignments, quizzes and projects. Students were able to leverage early participant-participant learning opportunities through discussion and class exercises to successfully complete related formative assignments, as well as later summative examinations and projects. The combination of formative and summative assignments, especially those based on comprehensive and scenario-based projects, facilitated deeper engagement with the material.

At the graduate level, one instructor observed that student performance on the final project improved noticeably due to the combination of the standards framework introduced in the curriculum and the case study approach. Another instructor noted that use of a group project as a summative assignment enabled collaborative learning through peer interaction, which reinforced and tethered conceptual understanding and gave students more confidence in the application of standards.

At the undergraduate level, one instructor for an introductory level course highlighted the value of the scenario-based project for enhancing the relatability and practical relevance of the material. Another instructor at the introductory level made similar observations, noting that the consideration and application of standards in the context of a historic case helped students to put the standards in context, and to operationalize them.

In addition to collecting instructor feedback, we conducted a survey of alumni in the ESHS and EHSM programs regarding the importance of standards education in environmental sustainability, health and safety curriculum, how well their education prepared them to use standards in the industry, and how often they used standards in their jobs. 82 alumni responded to the survey, indicating that standards education

is important, that they use standards frequently in their jobs, and that overall, the integration of standards in their coursework prepared them well for professional practice:

- 82% indicated frequent to daily use of standards in their jobs (41% daily, 41% frequently). Only 8% indicated that they use standards rarely.
- 57% indicated that standards education at RIT had prepared them very well to extremely well for professional practice, and an additional 32% indicated that standards education had prepared them moderately well.

Some participants commented that incorporation of standards in the curriculum provided a "well-rounded knowledge base" that gave them an advantage 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 commented on 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 indicate that students gain a high degree of value from integration of standards in their degree programs as they prepare to enter the workforce, and that ESHS/EHSM professionals use standards extensively in the workplace. This included 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 as applicable for their specific roles as professionals.

Dissemination Goal

Our dissemination efforts have been very successful. We presented on both the modular curriculum process and the positive impacts of implementation of infrastructure improvement and resilience standards, generating feedback, interest and follow-up from academics and working professionals. In many ways, we were able to magnify our opportunity to showcase the power of standards as a teaching tool and as a professional tool, as well as an opportunity to enhance organizational and community resilience. Our dissemination venues and audiences were diverse, including workshops, meetings, conferences, summits and journal publications reaching business professionals, standards professionals, government representatives, and academe. We presented on our project at one NIST workshop, one education summit led by UL Standards & Engagement, and four conferences including the American Society for Engineering Education (ASEE) St. Lawrence Conference, the American Society for Quality's (ASQ) World Conference on Quality and Improvement, the U.S. Technical Advisory Group to ISO Technical Committee 207 (TAG 207) Fall 2024 session, and the International Conference on Social and Education Sciences (IConSES). Our conference paper for ASEE was published in the proceedings, and our conference paper for IConSES was accepted for publication in

the International Journal of Education Sciences (IJES). Our presentations and papers on our curricular integration and approach are shown in Table 6.

Table 6: Dissemination on Standards Integration for Infrastructure Improvement and Resilience

Date	Venues	Audience	Details
December 2022 Virtual	NIST Workshop on Standards Education	Academic faculty NIST personnel	**Presentation** Workshop for awardees
April 2024 Montreal, QC	ASEE St. Lawrence Annual Conference	Academic Faculty	**Presentation & Conference Paper** Conference Proceedings[1]
May 2024 San Diego, CA	World Conference on Quality and Improvement	Business professionals Academe	**Presentation & Panel Session**
August 2024 Washington, DC	TAG 207 Fall Conference	Business professionals Government Academe	**Presentation**
October 2024 Chicago, IL/Virtual	International Conference of Social and Education Sciences (IConSES)	Academic faculty Graduate students	**Presentation & Conference Paper** Journal publication[2]
November 2024	International Journal of Education Sciences	Academe	**Publication – Journal** publication in early 2025[2]
March 2025 Golden, CO	UL Standards Education Summit	Academic Faculty SDOs	**Presentation** Summit/Workshop for standards educators - Findings and Lessons Learned

[1] Greenwood, L. L., Hargrave, M., Abraham, Y. S., Mishra, S., & Schneider, J. L. (2024, August). Preparing the Engineers of Tomorrow: Standards Education for Infrastructure Improvement and Resilience. In *2024 ASEE St. Lawrence Section Annual Conference*.

[2] Greenwood, L. L., Schneider, J., Mishra, S., Abraham, Y. S., & Pandian, S. K. S. (2025). Integrating Standards for Infrastructure Improvement and Resilience in University Curricula. *International Journal of Education Science*, *2*(1), 75-90.

Lessons Learned

Overall the project was very successful, however we did have some challenges along the way with changes in faculty assignments, as well as in working with instructors outside of the core project team. Since these instructors were not directly part of the curriculum development and did not necessarily have experience or expertise with the standards incorporated in the modules, there were varying levels of comfort with utilizing the content, even with the teaching resources provided. Going forward, we recommend:

- incorporating an incentive, such as a stipend, for adjunct faculty and other faculty outside of the core project team who will implement standards-based curricula; and

- providing the option of faculty mentoring sessions or teaching circles to enhance instructor capacity to integrate standards-based content and teach students about standards as part of their pedagogy.

Suitability of the Project for Adoption in Other Educational Programs

Our modular approach to curricular development and standards integration is highly transferable and can be readily adapted for courses and programs across disciplines. Beyond higher education, the framework can also be applied in workforce development and K–12 educational settings. To date, the approach has been disseminated to diverse audiences through conference presentations, published proceedings, journal articles, and openly shared instructional materials.

The project's domain-specific content—focused on power infrastructure, sustainable sites, and infrastructure resilience—is designed for flexible adaptation across a wide range of academic and professional contexts. The modular structure allows instructors and trainers to select, customize, and integrate components that align with their program goals. For example, programs in sustainable construction or urban planning may draw from all three modules, while software and computing programs may focus primarily on the Power Infrastructure module, and environmental studies programs may emphasize selected elements of the Sustainable Sites and Infrastructure Resilience modules. This flexibility supports broad adoption while enabling context-specific implementation.

Acknowledgements

This final summary paper was prepared by RIT under award #70NANB22H202 from the National Institute of Standards and Technology, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Institute of Standards and Technology or the U.S. Department of Commerce.

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